

Nutritional and management strategies on nitrogen and phosphorus use efficiency of lactating dairy cattle on commercial farms: An environmental perspective

H. Arriaga,* M. Pinto,* S. Calsamiglia,† and P. Merino*¹

*Neiker-Tecnalia, Basque Institute for Agricultural Research and Development, 48160 Derio (Basque Country), Spain

†Universitat Autònoma de Barcelona, Faculty of Veterinary, 08193 Bellaterra (Barcelona), Spain

ABSTRACT

Dairy farm activities contribute to environmental pollution through the surplus N and P that they produce. Optimization of animal feeding and management has been described as a key strategy for decreasing N and P excretion in manure. Sixty-four commercial dairy farms were studied to assess the efficiency of N and P use in lactating herds and to identify dietary and management factors that may contribute to improving the efficiency of nutrient use for milk production, and decrease N and P excretion. The average ration was formulated to 50:50 forage:concentrate ratio with grass silage and corn silage as the main forage sources. Mean N and P intakes were 562 g/d [16.4% crude protein (CP)] and 84.8 g/d (0.40% P), respectively. Milk yield averaged 29.7 kg/d and contributed to 25.8% (standard deviation \pm 2.9) of N utilization efficiency (NUE) and 31.9% (standard deviation \pm 4.5) of P utilization efficiency (PUE). Dietary N manipulation through fitting the intake of CP to animal requirements showed a better response in terms of decreasing N excretion ($R^2 = 0.70$) than that estimated for P nutrition and excretion ($R^2 = 0.30$). Improvement in NUE helped increase PUE, despite the widespread use of feedstuffs with a high P content. Management strategies for lactating herds, such as the use of different feeding groups, periodical ration reformulation, and selection of feeding system did not show any consistent response in terms of improved NUE and PUE. The optimization of NUE and PUE contributed to decreasing the N and P excretion per unit of milk produced, and therefore, reductions in N and P excretion of between 17 and 35%, respectively, were estimated. Nevertheless, nutritional and herd management strategies were limited when N and P excretion were considered in relation to the whole lactating herd

and farmland availability. Dietary CP manipulation was estimated to decrease herd N excretion by 11% per hectare, whereas dietary P manipulation would be decreased by no more than 17%. We conclude that the correct match between the ingested and required N and P, together with an increase in milk productivity, may be feasible strategies for decreasing N and P excretion by lactating herds on commercial farms.

Key words: nitrogen, phosphorus, dairy farm

INTRODUCTION

One of the major objectives of the European Common Agricultural Policy is to develop a sustainable farming system with environmental-friendly production management (Van Passel et al., 2007). Efficient use of nutrients is one of the major assets of sustainable agricultural production systems, because inefficient nutrient use not only results in excessive and potentially harmful losses to the environment but also affects economic performance (Oenema and Pietrzak, 2002).

Dairy farm activities have been described as contributors to N and P environmental pollution (Spears et al., 2003a,b). Nitrogen pollution from dairy farms affects water, by nitrate leaching, which contributes to eutrophication, and also air, through the emissions of gaseous N compounds such as NH_3 and N_2O and NO . Accumulated P from dairy farms can leach into groundwater or cause eutrophication of surface waters due to run-off from agricultural land (Sims et al., 1998).

The application of extensive farming methods in dairy production, the reduction of external nutrient inputs, and the efficient use of nutrients at farm or regional levels have been described as advisable strategies for environmentally sustainable farming activity (Tamminga, 2003). Extensive farming and strategies to decrease nutrient inputs are difficult to develop in the Basque Country (northern Spain). Rural land prices have increased dramatically in this mountainous region in recent years because of the historical division of rural land for inheritance purposes and high industrial pressure. Moreover, the current trend is for intensified

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¹Corresponding author: pmerino@neiker.net

milk production on commercial farms in the Basque Country. Data from 1996 to 2003 showed that although the dairy cattle population was decreased by 31.6%, the milk quota in the territory remained constant (250,000 tons) due to the increased mean milk yield of the herds from 4,934 to 7,241 kg/(cow × yr). Intensified dairy farms (high input:output) are characterized by the widespread use of purchased concentrates and mineral fertilizers (CEAS/EFNCP, 2002), which make the minimization of external inputs in the dairy system difficult to achieve. Optimization of N and P use may therefore be the most realistic strategy for decreasing environmental N and P pollution in the Basque Country.

Optimization of animal feeding and management has been described as a key strategy for the reduction of N and P excretion in manure (CAST, 2002; Cerosaletti et al., 2004; Ipharraguerre and Clark, 2005). The correct match between the quantity and quality of protein required by the animal, together with an increase in animal productivity, helps improve the efficiency of N use for milk production and the reduction in N excretion (Rotz, 2004). Similarly, the reduction in P overfeeding, the use of feedstuffs with high amounts of available P, and the optimization of production may lead to decreased P excretion in manure (Maguire et al., 2005). Furthermore, herd management practices such as animal grouping (St Pierre and Thraen, 2001), the increased frequency of ration balancing, and the feeding system used (Jonker et al., 2002) may also contribute to decreasing nutrient excretion in manure.

Some options have been considered to mitigate the effect of dairy farming on environmental pollution (Merino et al., 2002, 2005; Menéndez et al., 2006). However, there is no evidence that improved nutritional strategies would be useful for minimizing the excretion of N and P at the farm level. The first objective of the present study was to determine the current N and P utilization efficiency and excretion levels in lactating dairy herds in the Basque region. The second objective was to identify dietary and management factors that may help to improve the efficiency of N and P use. The third objective was to relate nutrient use improvement to N and P excretion regarding the farm intensification level.

MATERIALS AND METHODS

Dairy Farm Survey

A confidential survey was conducted between September 2003 and April 2004. A total of 76 commercial dairy farms were selected by 4 Milk Producers Advisory Centers to represent different ranges of milk yield and

feeding systems. These farms represented 7.0% of all dairy farms in the Basque Country in 2004. Farmers were contacted by telephone and interviewed in person. The survey included information on adult dairy herd characteristics (breed, number and distribution by parity of milking animals, and number of dry cows in the herd). Farmers were also questioned about milk production level and quality, and all data were checked by the Advisory Centers. Ration data for milking herds were also requested (types and amounts of forage and concentrate, costs of daily rations) together with nutritional management strategies (feeding groups for lactating herds, frequency of ration balancing, feeding system, mineral supplementation, or grazing activity). Feeding systems were classified as TMR, purchased complete feed (**PCF**), or component feeding (**CF**). Information on concentrate composition was obtained from the corresponding commercial feed companies. Data regarding the land in relation to dairy activity (grassland or cropland), use of land (for homegrown forage production or slurry fertilization), and ownership (owned or rented) were also obtained from the survey.

Cornell Net Carbohydrate and Protein System

The Cornell Net Carbohydrate and Protein System (**CNCPS**) 5.0 model (Fox et al., 2004) was used to simulate an average lactating cow on each farm. Cow-related data were fitted to the average features of Basque commercial dairy farms: age (47 mo), BW (650 kg), pregnant days (40 d), days from calving (150 d), lactation number (2 lactations), breed (Holstein-Friesian), calving interval (13 mo), age at first calving (29 mo), and condition score (3.0). Environmental data (temperature, wind speed, and humidity) for the sampling day were obtained from Euskalmet (Basque Meteorological Service; <http://www.euskalmet.euskadi.net/>).

On-Site Sample Collection

On-site sample collection included feed, fecal, urinary, and milk samples from lactating herds. Feed samples were placed inside portable freezers and transported to the laboratory. The feed samples were then immediately dried in a forced-air oven (60°C, 72 h) for DM determination. The samples were ground to pass a 1.5-mm screen (0.2-mm screen for P determination). Each feed sample was analyzed for CP (Kjeldahl N method), NDF, ADF, acid detergent insoluble protein, acid detergent lignin (Van Soest et al., 1991), ash, ether extract (920.39/90 method in AOAC, 1990), and P (inductively coupled plasma spectrometry UV spectrophotometry, Cary 100, Varian Inc., Palo Alto, CA). Daily N and P intakes

were estimated on the basis of the concentrations of N and P in individual feeds (or imported blends), and information about the ration formulation was supplied by the farmers. Milking cows were divided in different feeding groups (high-low production), and when only an average herd milk production was known, the N and P intakes were averaged for the herd in proportion to the number of cows in each feeding group. Finally, the percentage of purchased N and P in the ration was calculated by taking into account the origin of the feedstuffs (home-grown forage or purchased feedstuff).

Freshly deposited feces were sampled from the barn floor just after being excreted by lactating cows. The fecal samples were collected from 5 to 15% of the lactating cows included in the herd, depending on lactating herd size. Each subsample was mixed to make a composite fecal sample (nearly 1 kg), which represented the mean sample for the herd. Samples were transported in portable freezers to the laboratory and analyzed for total N (N-Kjeldahl method), C:N ratio, and total P (inductively coupled plasma spectrometry UV spectrophotometry, Cary 100, Varian Inc.). Daily fecal volume excretion was estimated by the CNCPS 5.0 model, and this amount was multiplied by fecal N and P concentration to estimate the mean N and P excretion per day.

Urine samples were collected by a noninvasive method, by use of buckets, and collected samples represented between 5 and 15% of the total urine excreted by the herd. These samples were mixed to make a composite urine sample (nearly 1:l) with 10% H₂SO₄ solution to avoid losses of NH₃. Samples were divided into different subsamples in the laboratory before being frozen at -20°C. Urine was analyzed for total N (N-Kjeldahl method) and urinary urea-N (diacetyl monoxime method by Douglas and Bremner, 1970). Urinary P was not analyzed, because it is generally assumed that it is excreted in low quantities. Daily urinary volume was estimated by CNCPS 5.0, and daily urinary N excretion was estimated by multiplying the excretion volume by the analyzed N content. After determination of total N and P excreted, purchased N and P excretion was estimated by applying the same percentage of purchased N and P intake to the total N and P excretion, according to Powell et al. (2002).

Milk samples were collected from the bulk tank (100 mL) and analyzed for fat, CP, lactose, and MUN by the Milk Institute of Lekunberri (Instituto Lactológico de Lekunberri, Navarra, Spain). Milk fat and CP were analyzed according to AOAC (1990) procedures, and MUN concentrations were determined by the diacetyl monoxime method (Douglas and Bremner, 1970). A milk P concentration of 0.09% was assumed (NRC, 2001). Daily milk N and P outputs were estimated considering the mean milk yield and the analyzed N

content and estimated P concentration, respectively. The N utilization efficiency (**NUE**) and P utilization efficiency (**PUE**) values were obtained considering the N and P content of the milk compared with the amount of N and P ingested.

Statistical Analysis

Statistical analyses were carried out with Statview software (SAS Inst. Inc., Cary, NC), and each farm was considered as an experimental unit. When farmers did not answer all the questions or some answers were considered misleading, the corresponding herds were excluded from the statistical analysis. Thus, 64 out of 76 sampled commercial farms were finally considered for statistical analysis. Descriptive statistics were analyzed for the complete data set. Treatment means were tested by regression analysis, for continuous variables, or ANOVA, for discrete variables. A multivariate regression was developed with N-P excretion by the lactating herd per day and per hectare as the dependant variable and herd size, land area, N-P intake, ration CP and P concentration, N-P fecal or urinary excretion, and milk yield of the herd as independent variables. Normality test and equality of variances F-test were performed before ANOVA. The Tukey-Kramer test was used for post-hoc analysis, at a significance level of $P < 0.05$. For application of the analysis to annual basis data (e.g., annual herd N-P excretion per hectare), only those farms in which the farmers agreed not to change the ration were selected.

RESULTS AND DISCUSSION

Description of Farms

The selected farms represented 5.9% of total commercial dairy farms in the Basque Country for the period 2003 to 2004. These farms included 5,618 adult Holstein-Friesian cows representing on average 16.4% of the whole dairy cow population in the territory and 19.2% of total quota allocated to the Basque Country. Large ranges of herd size and milk production were observed in the survey (Table 1). Cow herds ranged from 19 to 596 cows, and annual milk yield ranged from 5,713 to 12,165 kg/(cow × yr). Mean milk yield [9,057 kg/(cow × yr) or 29.7 kg/d] and mean herd size (87 cows) were greater than mean values described for the region in 2003 and 2004, which reached 7,401 kg/(cow × yr) and 32 cows, respectively (EUSTAT, 2004; FEPLAC, 2004). The selected farms were biased to more intensive farms, representing the current trend of dairy farming in the Basque Country. The level of intensification was much greater than that reported for commercial dairy

Table 1. Herd size, milk production, and land use in 64 dairy commercial farms in the Basque Country

Item	Mean	SD	10th percentile	90th percentile
Cows				
Total	87	76	33	156
Milking	76	68	29	136
Dry	11	9	3	23
Production				
Annual yield, kg/cow	9,057	1,395	7,213	10,522
Milk yield, kg/(cow × d)	29.1	4.83	22.6	34.6
Farmland availability				
Grassland, ha	42.9	30.2	14.9	80.0
Cropland, ha	5.0	11.7	0.0	16.7
Slurry spreading area, ha	50.5	36.8	16.9	91.0
Farmland property, %	48.5	32.3	3.2	100.0
Stocking rate, cows/ha of farmland	2.1	0.15	1.0	3.6
Milk yield per area, kg/ha	16,767	9,522	8,248	27,186

farms in other countries in the European Union (Table 1; Bos, 2004). According to the ranking defined by Berentsen and Tiessink (2003; low <12,000 kg/ha; 12,000 kg/ha < medium <15,000 kg/ha; high >15,000 kg/ha), 46.9% of surveyed farms were classified as highly intensive farms, 15.6% were classified as having a medium level of intensification, and 37.5% as having a low level of intensification. The average cow stocking rate was 2.1 cows/ha, just above the suggested stocking rate for the European Union (Tamminga, 2003). Univariate and multivariate regression analysis of the present data confirmed land availability as the main factor that affected the observed overall high stocking rates ($R^2 = 0.17$, $P < 0.05$; negative slope).

The average farmland area for sampled dairy farms was 47.9 ha and was used for grass or corn, or both, production and for slurry spreading (Table 1). On average, 89.1% of surveyed farms included farmland rented from neighboring areas, and therefore, only 48.5% (23.2 ha) of farmland belonged to dairy producers. Grassland production was the main use of farmland area and represented on average 89.6% of the total area (Table 1). Grassland is usually managed as permanent or rotational grassland, with ryegrass (*Lolium perenne*, *Lolium multiflorum*) or *Festuca* (*Festuca arundinacea*, *Festuca rubra*) as the main grass species (I. Albizu, Neiker-Tecnalia, Derio, Spain; personal communication). Most grass forage was used to produce silage (90.6%), and only 26.6% of the herds grazed on pasture in the spring-summer period (when the current study was carried out, all of the herds were confined to stalls).

Description of Lactating Herd Ration

The ration parameters, the mean use of the forage and concentrate ingredients, management strategies, and milk production data for all 3 different feeding systems are shown in Table 2. The choice of each feeding system basically depended on farmland availability and

herd size ($P < 0.05$). Farms with large herds and low land availability imported PCF blends daily, because home-grown forage production was limited ($P < 0.05$). On the other hand, large farms chose TMR or CF rations, allowing farmers to use more home-grown forage ($P < 0.05$). Grass silage was the main forage used in TMR or CF rations rather than corn silage, mainly used in PCF ($P < 0.05$). Imported alfalfa hay and concentrate use was similar among feeding systems. The average forage:concentrate ratio was around 50:50 for each feeding system. Soybean meal and corn grain were used in all concentrates and together with gluten feed were the main ingredients in the concentrates.

On selected farms, mean DMI of milking cows was 21.3 kg/(cow × d) and was similar among different feeding systems. Dietary CP concentrations ranged from 12.7 to 18.4% with a mean content of 16.4% and differed between feeding groups ($P < 0.05$). The concentration of CP was greater for PCF (17.3%) than TMR (16.5%) and CF (16.0%). Recent research has shown that a CP concentration of between 16.5 and 17% may be sufficient to produce milk yields >30 kg/d (Broderick, 2003; Ipharraguerre and Clark, 2005; Colmenero and Broderick, 2006). On average, only one-third of surveyed rations were formulated with >17% CP concentration, and the greatest milk yield (39.9 kg/d) was achieved with a grass and corn silage-based TMR ration (40:60 forage concentrate ratio) with a mean CP content of 16.9%. The wide range of CP content observed in the diets was due to the variability in concentration of CP in grass silage (7.5 to 17.7%) and commercial concentrates (17.5 to 24.2%). Mean RDP was estimated from CNCPS 5.0 as 62.9% of total CP, and the use of grass silage was related to a greater proportion of RDP ($P < 0.05$). On the contrary, the greater use of concentrates helped increase the proportion of RUP in the ration ($P < 0.05$), and the greater RUP content was related to greater mean milk yields ($R^2 = 0.10$, $P < 0.05$; positive slope).

Table 2. Ration description, forage and concentrate ingredients use, and management and production data for 3 different feeding groups

Item	TMR	PCF ¹	CF ¹	Total
Ration data				
DMI, kg/d	21.9 ^a	21.5 ^a	20.5 ^a	21.3
Ration cost, €/(cow × d)	3.9 ^a	4.2 ^a	3.5 ^b	3.8
Forage:concentrate	49:51 ^a	49:51 ^a	54:46 ^a	50:50
CP, %	16.5 ^{ab}	17.3 ^a	16.0 ^b	16.4
P, g/kg of DM	4.00 ^a	4.16 ^a	3.87 ^a	3.98
Home-grown forage, % of ration DM	27.8 ^a	7.7 ^b	34.9 ^a	27.2
Ingredients, % of the diet				
Grass silage, %	21.0 ^a	6.7 ^b	24.5 ^a	19.9
Corn silage, %	15.0 ^b	25.2 ^a	6.1 ^c	13.2
Alfalfa hay, %	9.2 ^a	14.4 ^a	10.4 ^a	10.6
Grass hay, %	1.2 ^b	1.9 ^{ab}	8.5 ^a	4.3
Soybean meal, %	18.6 ^a	7.5 ^b	16.0 ^a	15.6
Corn grain, %	16.5 ^a	10.9 ^b	12.4 ^b	13.9
Gluten feed, %	8.3 ^a	11.0 ^a	10.8 ^a	9.8
Cottonseed, %	6.1 ^a	4.3 ^a	5.9 ^a	5.7
Beet pulp, %	2.6 ^{ab}	0.4 ^b	4.7 ^a	3.1
Barley grain, %	4.8 ^{ab}	3.1 ^b	6.3 ^a	5.1
Wet brewers grains, %	0.8 ^b	28.6 ^a	0.0 ^b	5.3
Management and milk parameters				
Herd size, no. of cows	114 ^a	93 ^a	58 ^b	—
Farmland area, ha	64.4 ^a	32.2 ^b	39.2 ^b	—
Stocking rate, cows/ha of farmland	2.0 ^b	3.1 ^a	1.8 ^b	—
Milk yield, kg/(cow × d)	30.6 ^a	31.1 ^a	26.6 ^b	—

^{a-c}Different superscripts within the same row indicate significant differences ($P < 0.05$).

¹PCF = purchased complete feed; CF = component feeding.

The range of dietary P content was just above NRC (2001) recommendations (0.32 to 0.38%) and ranged from 0.28 to 0.54% (mean 0.40%), and there were no differences between feeding systems. The variability in the surveyed data in this trial was lower than that reported by Dou et al. (2003; range from 0.36 to 0.70%; mean 0.44%) and Powell et al. (2002; range from 0.23 to 0.85%; mean 0.40%). According to previous studies, which reported grass silage as a large contributor to dietary P intake (Valk et al., 2000; Kebreab et al., 2005), the present survey confirmed grass silage as the main source of forage P. The average P content of grass silage was 0.33% and ranged from 0.12 to 0.93%; this variability suggested an opportunity to decrease the mean P content of silage through correct grassland P fertilization (Valk et al., 2000). Nevertheless, the use of forage with a high P content has been related to difficulties in minimizing the P content of rations (Cerosaletti et al., 2004). As expected, concentrates contained more P than grass silage (range between 0.38 and 0.69%; mean 0.53%). The substitution of grass silage by corn silage and the greater use of low P content by-products (beet pulps or citrus pulp) rather than other by-products such as wheat middlings or soybean meal may contribute to decreasing the P content of the ration (Dou et al., 2003; Cerosaletti et al., 2004). Nevertheless, the heterogeneity of the ingredients used in the surveyed rations did not allow identification of specific ingredients that could be

used to decrease the ration P content. Some authors also consider that minimizing mineral P supplementation may be a key strategy to minimize ration P content (Dou et al., 2003). In this sense, P mineral supplementation was detected in 67% of surveyed herds, although the mineral P in concentrates represented only 0.2% of concentrate feedstuffs.

Lactating Cow Nutrient Balance

Lactating Cow N Balance. The mean, standard deviation, and percentile distribution of N intake, utilization, and excretion for lactating cows across all herds are given in Table 3. Mean N intake was 562 g/d, and the estimated MP supply was 7.4% greater than estimated requirements. The greatest milk yield (39.9 kg/d) corresponded to a grass and corn silage-based TMR ration (40:60 forage concentrate ratio) with a mean daily N intake of 608 g/cow. According to recommendations on protein intake made by Ipharraguerre and Clark (2005), the intake of N by high-producing dairy cows could be decreased to about 600 to 650 g/d. Mean N intake from home-grown forage was 21.0% (SD = 1.8) but depended on the level of farm intensification ($P < 0.05$).

Mean NUE (%) was 25.8% (SD = 2.9) and ranged from 19.2 to 32.3% (Table 3). Average NUE was lower than reported by other authors for grass silage-based

Table 3. Mean, standard deviation, and percentile distribution of N intake, fecal N, urinary N, milk N, and N utilization efficiency for lactating herds on 64 dairy commercial farms in the Basque Country

Item	Mean	SD	10th percentile	90th percentile
N intake, g/(cow × d)	562.6	87.4	465.5	675.0
N output, g/(cow × d)				
Feces	214.7	43.1	162.3	273.5
Urine	215.5	63.3	140.1	295.9
Milk	144.9	24.5	110.8	173.6
N output, % N intake				
Feces	38.3	5.8	31.3	45.9
Urine	38.1	8.4	27.4	47.5
Milk	25.8	2.9	22.0	29.5
MUN, mg/dl	10.4	2.7	7.2	13.8

rations, which reached about 28% (Castillo et al., 2001; Yan et al., 2006). Maximum NUE value corresponded to the above-mentioned grass and corn silage-based TMR ration (40:60). Milk CP content was not correlated to N intake or milk yield, and therefore, NUE milk variability depended on ration N intake (Figure 1). This indicated that protein nutrition could be still improved on dairy farms in the Basque Country. The MUN has also been proposed as an indicator of the protein nutrition and efficiency of N utilization in dairy cows. The mean MUN value was 10.4 mg/dL (SD = 2.7; Table 3) and ranged from 3.8 to 15.5 mg/dL. Although a univariate regression model confirmed that MUN was not an accurate estimator of NUE in this study ($P > 0.05$), mean MUN value was lower than that reported by Nousiainen et al. (2004) of 16.0% CP and 507 g/d of N intake rations (MUN = 13.3 mg/dL). This may suggest that despite the observed high supply of MP, protein nutrition may accurately match cattle requirements on the farms under study.

The present estimates indicated that 76.4% of ingested N was excreted as fecal or urinary N (Table 3). Recently, Yan et al. (2006) reported that 72% of the ingested N was excreted by Holstein lactating cows, and the authors concluded that the amount of N ingested could be a good predictor of excreted N. In this sense, the present data also indicated N ingestion as the best estimator of N excretion ($P < 0.05$; $R^2 = 0.7$; positive slope). Therefore, the amount of N ingested can be described as a more accurate predictor of N excretion than the CP content of the ration, which is usually considered by dairy farmers. Previous studies have demonstrated a similar contribution by fecal and urinary N outputs to the total N excretion (Kebreab et al., 2001; Yan et al., 2006). Nevertheless, Kebreab et al. (2001) also suggested a mean N intake of 400 g/d as a threshold value for an increasing urinary output. The present estimates of N excretion by the fecal and urinary pathways were similar to those reported in the above-mentioned studies. In fact, we estimated

that 38% of N was excreted in feces and 38% in urine. Univariate regression revealed the relationship between the total N ingested and the estimation of excreted N in urine and feces (Table 4: equation 1). Estimations were significant ($P < 0.05$) for fecal N ($R^2 = 0.44$) and urinary N ($R^2 = 0.41$) (Table 4: equations 2 and 3; Figure 2). Nevertheless, data from the present survey may overestimate the fecal N output regarding urinary N output. In fact, the estimated mean fecal DM excretion (7.5 kg/d) in the present study was similar to that reported by Nennich et al. (2005) for high-producing Holstein cows (7.3 kg/d) even though not all herds comprised high-producing cows in the present study (26.6% of the herds averaged fewer than 8,000 kg of milk/yr). Furthermore, the present data would overestimate fecal N excretion by 22.3% when the mean N intake (569 g/d) was used to predict fecal N output with the regression model developed and established by Kebreab et al. (2001). This overestimation may explain why the urinary N threshold was established at around 550 g/d in the current study, suggesting that the threshold of 400 g/d proposed by Kebreab et al. (2001) may be advisable even for dairy farmers in the Basque Country.

From an environmental point of view, it is advisable to decrease N excretion per milk unit produced. In this sense, improved milk production decreases the partial contribution of maintenance N requirements (Rotz, 2004), which directly helps to improve the NUE and decrease N excretion per liter of milk. The present data showed that NUE improvement contributed to decreasing N excretion per liter of milk produced ($P < 0.05$; $R^2 = 0.68$). Thus, considering 2 of the quota levels on surveyed farms (low 268 tons/yr and high 1,150 tons/yr), a reduction of 3.2 g of N/L between 2 farms with 268 tons/yr milk quota would minimize the excreted N to 865 kg/yr. Meanwhile, N excretion would be decreased by 7,337 kg/yr considering the reduction of 6.4 g of N/L observed between 2 farms with high milk quotas (1,150 tons/yr). The overall reduction in N excretion in

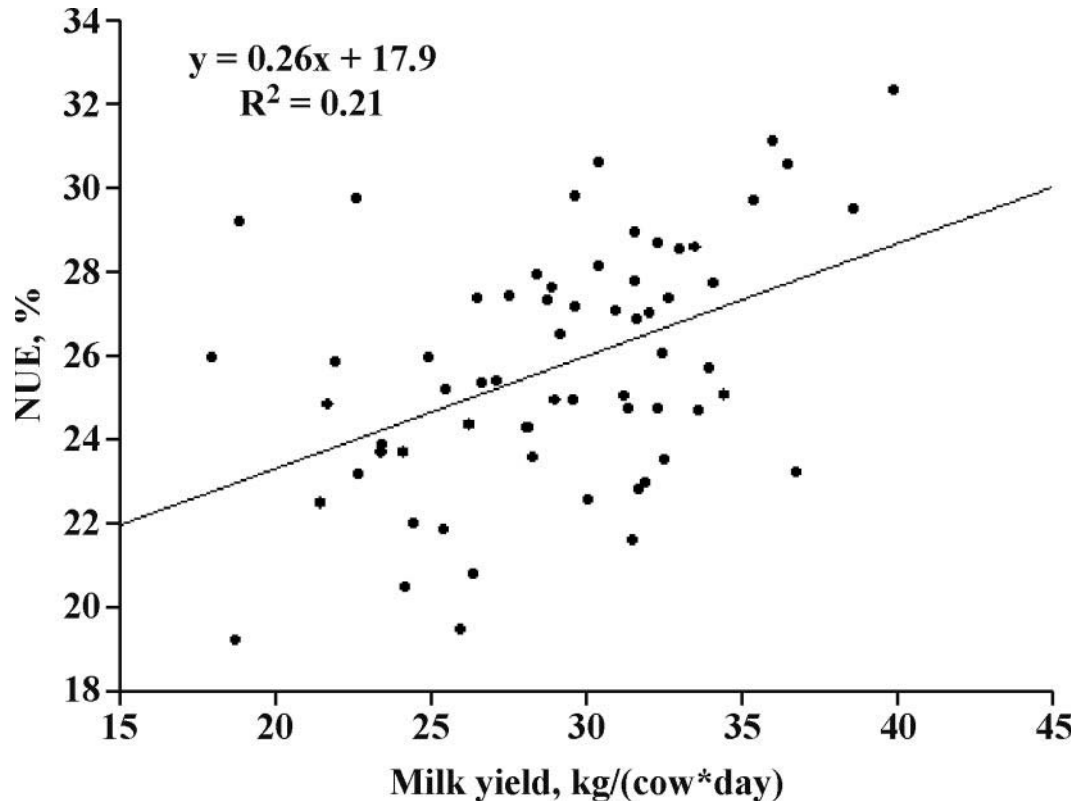


Figure 1. Herd mean milk yield versus nitrogen use efficiency (NUE) value obtained through onsite sample collection and analyses.

lactating herds obtained by minimizing N excretion per milk liter would allow N excretion to be decreased in the herd from 17.2 to 35.5%.

Lactating Cow P Balance. Mean P intake was 84.8 g/d (SD = 14.1), similar to that reported by Powell et al. (2002) for commercial farms in Wisconsin. On average, daily P intake exceeded the P requirements estimated by CNCPS 5.0 by 63%. Previous studies have demonstrated P overfeeding as common practice on several commercial dairy farms (Dou et al., 2003; Chapuis-Lardy et al., 2004; Hristov et al., 2006), although P overfeeding on sampled farms was greater than reported by other authors (Valk et al., 2000; Powell et al., 2002; Dou et al., 2003). Reduction of P overfeeding was the main strategy for improving PUE ($P < 0.05$; $R^2 = 0.78$; negative slope), and the second was to increase milk

yield ($P < 0.05$; $R^2 = 0.35$; positive slope). Optimization of both parameters should be considered as the main strategies for decreasing fecal P excretion. Milk P content is fairly constant (NRC, 2001), but urinary P was not consistent in previous studies. Urinary P variability ranges from negligible amounts (Valk et al., 2002) to 500 mg/L (Wu et al., 2000).

The mean PUE was 31.9% (SD = 4.5) and ranged from 19.3 to 44.7% (Table 5). The greatest PUE values were reached with rations containing 0.39% P, which allowed production of more than 30 kg/d of milk. No correlation was observed between dietary P content and milk yield ($P > 0.05$). The high P overfeeding levels demonstrated that rations did not match P requirements, because diets for lactating cows are nearly always formulated to match energy and CP require-

Table 4. Linear prediction equations for manure, fecal, and urinary N output with N intake as primary predictor¹

Equation	R ²	SE	Equation no.
Manure N output = $0.8_{(0.067)} \text{ NI} - 19.8_{(38.0)}$	0.698	46.3	1
Fecal N output = $0.329_{(0.047)} \text{ NI} + 29.8_{(26.6)}$	0.444	32.4	2
Urinary N output = $0.164_{(0.178)} \text{ NI}^{1.13}_{(0.172)}$	0.410	0.23	3

¹Values in subscript parentheses are standard errors. NI = N intake.

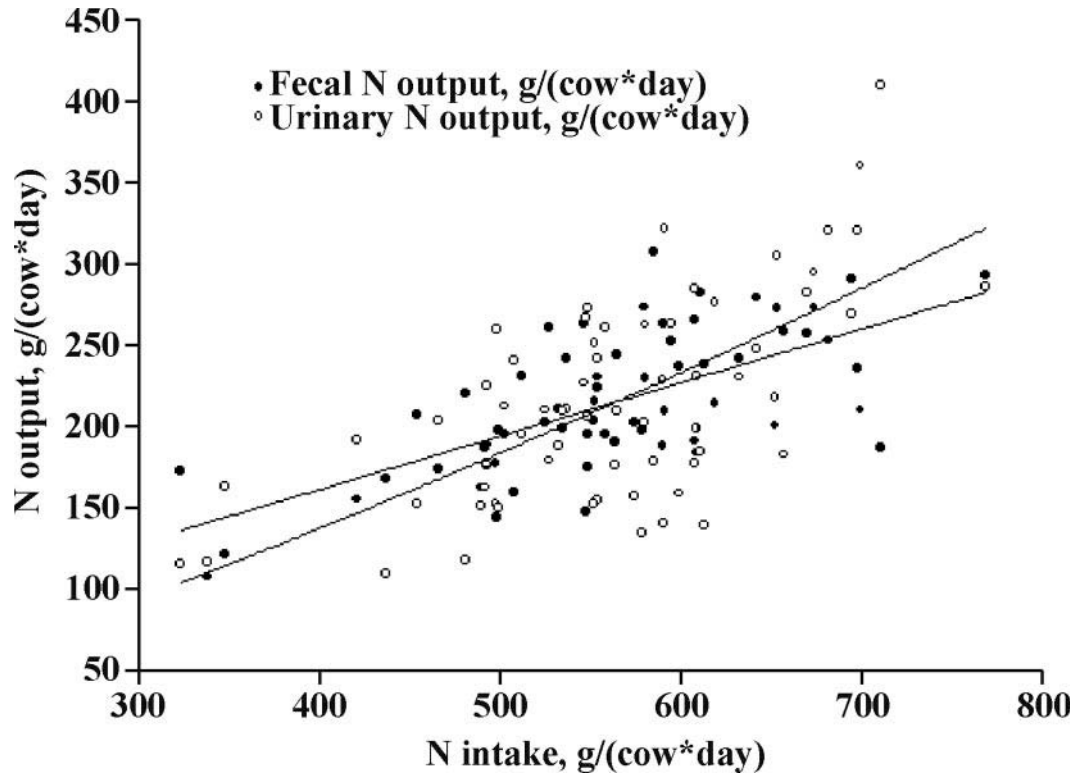


Figure 2. Relationship between total N intake and fecal, urinary, and milk N outputs.

ments. This meant that although farmers tried to improve NUE, the PUE was not usually considered. However, and according to previous data (Jonker et al., 2002; Nennich et al., 2005), NUE improvement might contribute to optimizing PUE ($P < 0.05$; Figure 3). The above-mentioned P-decreasing strategies should be implemented on farms to improve PUE and make NUE a better predictor of PUE.

Data from the present study indicate that 69.9% (SD = 12.3) of ingested P was excreted as fecal P (Table 5). Daily fecal P excretion (equation 4 in Table 6) and fecal P concentration were dependent on the amount of daily P intake (Valk et al., 2002) or ration P concentration (Powell et al., 2002), respectively. The endogenous fecal P excretion (the sum of P in microbial residues,

sloughed cells, and digestive secretions as salivary P; Valk et al., 2002) and the above-mentioned fecal output overestimation from the CNCPS 5.0 model may contribute to the weak relationship observed between the ingested and excreted P ($R^2 = 0.30$). In fact, previous studies showed greater coefficients of determination than observed in the present study (Dou et al., 2003; Chapuis-Lardy et al., 2004). Nevertheless, the linear equation obtained was consistent with the equations obtained by the same authors (Dou et al., 2003; Chapuis-Lardy et al., 2004).

Taking into account the 4 quota levels on the surveyed farms, 2 low milk quotas (268 tons/yr) with a reduction of 0.91 g of P/L between farms could decrease P excretion by 244 kg/yr. Similarly, a reduction of 0.82

Table 5. Mean, standard deviation, and percentile distribution in P intake, fecal P, urinary P, milk P, and P utilization efficiency for lactating herds on 64 dairy commercial farms in the Basque Country

Item	Mean	SD	10th percentile	90th percentile
P intake, g/(cow × d)	84.8	14.1	65.2	103.1
P output, g/(cow × d)				
Feces	59.3	11.6	45.1	73.9
Milk	26.7	4.4	20.7	31.8
P output, % N intake				
Feces	69.9	12.3	54.5	80.3
Milk	31.9	4.5	27.0	37.1

Table 6. Linear prediction equations for fecal P daily output and fecal P content with P intake and dietary P content as primary predictors¹

Equation	R ²	SE	Equation no.
Fecal P output, g/(cow × d) = 0.46 _(0.09) PI + 19.9 _(7.8)	0.303	9.7	4
Fecal P content, g/kg of DM = 0.75 _(0.37) Pcont + 5.21 _(1.5)	0.06	1.3	5

¹Values in subscript in parentheses are standard errors. PI = P intake, g/(cow-d); Pcont = ration P content, g/kg of P.

g of P/L for the 2 greater milk quotas (1,150 tons/yr) may enable reduction to about 989 kg/yr. Therefore, the likelihood of decreasing P excretion at herd level by minimizing P excretion per liter of milk could range from 18.0 to 30.8%.

Management Practices to Improve NUE and PUE

St-Pierre and Thraen (2001) determined a positive effect of animal grouping on nutrient utilization efficiency and nutrient excretion in research dairy herds. Nevertheless, recent data obtained on commercial farms (Jonker et al., 2002; Powell et al., 2006) did not demonstrate any improvement in NUE or PUE values through group feeding. Data from our survey in which cows were divided into different feeding groups by DIM did not

improve NUE ($P > 0.05$), although PUE was improved by herd grouping ($P < 0.05$; Table 7). Improvement in P use may occur due to the greater milk yield of those herds fed in separate groups ($P < 0.05$) rather than to well-matched P feeding. This strategy was not observed in NUE because of the greater N intake recorded in farms with several feeding groups ($P < 0.05$).

Increased frequency of ration balancing has also been associated with greater milk yields on commercial dairy farms (Jonker et al., 2002), although it was not related to the improvement of NUE. In the present study, 51% of farmers recognized that they reformulated the diets in accordance with forage availability (grazing activity or grass and corn silage availability) and feedstuff prices. The present data showed that although N excess was decreased through diet reformulation ($P < 0.05$),

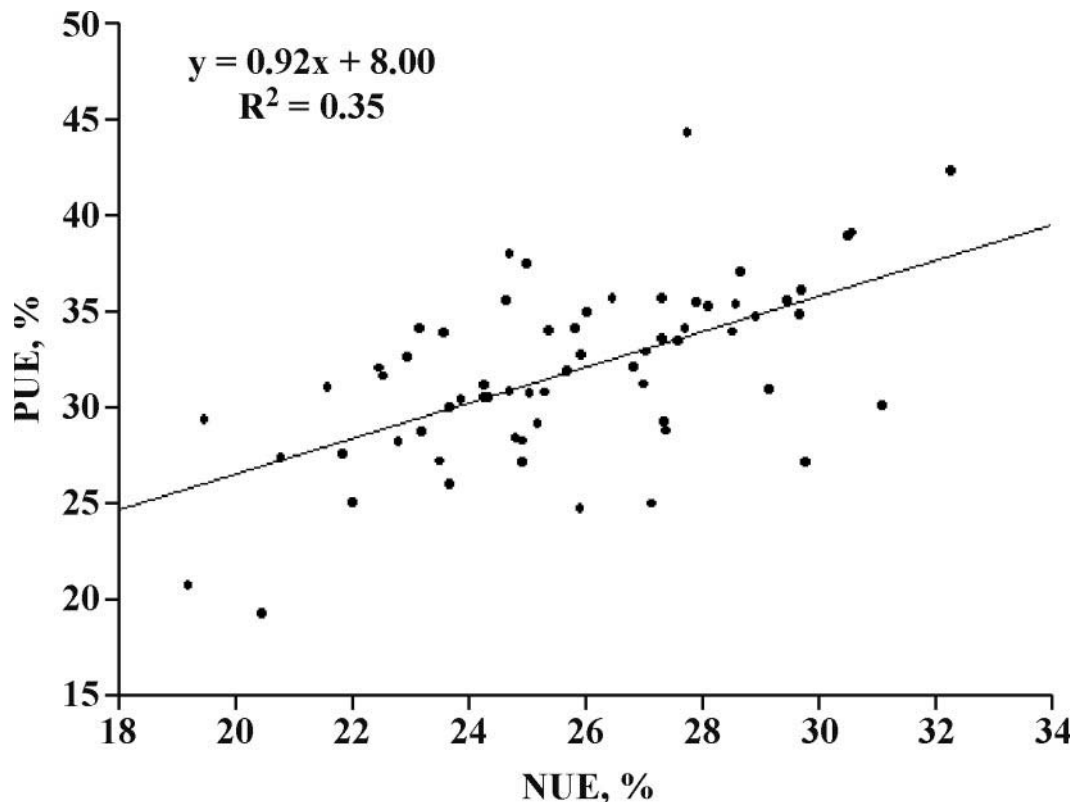


Figure 3. Relationship between nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE) from 64 surveyed dairy farms in the Basque Country

Table 7. Effect on N and P utilization, of feeding groups, feeding systems, reformulation, and degree of intensification

Management	Option ¹	NUE, ² %	PUE, ² %
Feeding system	TMR	26.6 ^a	32.6 ^a
	CF	24.9 ^a	31.0 ^a
	PCF	25.6 ^a	32.1 ^a
Group feeding	Yes	26.6 ^a	34.7 ^a
	No	25.6 ^a	31.3 ^b
Reformulation	Yes	25.9 ^a	31.8 ^a
	No	25.6 ^a	31.9 ^a

^{a,b}Different superscripts within the same row indicate significant differences ($P < 0.05$).

¹CF = component feeding; PCF = purchased complete feed.

²NUE = N utilization efficiency; PUE = P utilization efficiency.

there was no improvement in NUE or milk yields ($P > 0.05$; Table 7). Phosphorus overfeeding was not decreased by diet reformulation ($P > 0.05$), and PUE did not vary depending on this strategy.

Choice of different feeding systems may also help to improve nutrient use in milk, because TMR rations may improve milk yield or NUE compared with PCF (Jonker et al., 2002). Our data showed that the feeding system did not contribute to increasing NUE and PUE (Table 7), although TMR and PCF provided greater milk yields [30.0 – 31.0 kg/(cow × d)] than the CF system [26.5 kg/(cow × d)] ($P < 0.05$).

Effect of Intensification on N and P Excretion

A multivariate regression model was used to determine the nutritional influence on whole-herd N and P excretion by considering intensification parameters. When N excreted by lactating herd per farmland hectare was considered as a dependent variable, N intake was able to explain 11.2% of the variance ($P < 0.05$), and 60.4% of the variation was accounted for by farm intensification parameters (herd size and land availability; $P < 0.05$). When P excreted by lactating herd per farmland

hectare was considered, fecal P excretion accounted for 16% of the variance, and those parameters related to farm intensification explained 57% of the variation. Phosphorus intake was not included in the regression model ($P > 0.05$), and the weaker relationship observed between P intake and P excretion may explain the above observation. Therefore, the data indicated that nutritional management may not be able to decrease overall herd N and P excretion per hectare to above 20% in commercial dairy farms in the Basque Country. Although highly intensified dairy farms were more efficient in terms of N use (26.5%; $P < 0.05$), N excretion of the herd per hectare of land was greater in highly intensified farms. The same trend was observed for P excretion ($P < 0.05$) taking into account that PUE was not improved on highly intensified farms ($P > 0.05$). The mean daily and annual N and P excretion by the herd in relation to farmland area is shown in Table 8. On average, N excreted by the herd was 781 g/(d × ha) (SD = 424) and 317 kg/(yr × ha), whereas P excreted by the herd was 110 g/(d × ha) (SD = 64.9) and 45.4 kg/(yr × ha) (SD = 29.2). These data confirmed that estimated annual N and P excretion per hectare were greater than reference values for N and P slurry application on grassland (150 and 40 kg/ha, respectively). Even considering N gas losses of about 50% from housing and storage (Rotz, 2004), the sampled farms would exceed the maximum annual threshold for N excretion. Highly intensified herds had the greatest annual pollutant capacity for N and P with 402 and 58.5 kg/(yr × ha), respectively ($P < 0.05$; Table 8). Lactating herds from farms with a medium level of intensification had mean N and P excretion of 220 and 31.4 kg/(yr × ha), and herds from farms with low levels of intensification showed N and P excretion of 187 and 24.7 kg/(yr × ha). Furthermore, the origin of excreted N and P may vary depending on the farm intensification level. Highly intensified farms showed the lowest use of home-grown N with 10.7% compared with 17.4 and 26.4% for me-

Table 8. Daily and annual N and P excretion by the herd in relation to farmland area

Item	Mean	Low ¹	Medium ¹	High ¹
N excreted, g/(ha × d)	781.1 (424.7)	479.2 ^b	635.4 ^b	1,071.3 ^a
P excreted, g/(ha × d)	110.0 (64.9)	66.0 ^b	98.3 ^b	149.2 ^a
N excreted, ² kg/(ha × yr)	317.8 (164.9)	187.2 ^b	220.3 ^b	402.0 ^a
P excreted, ² kg/(ha × yr)	45.4 (29.2)	24.7 ^b	31.4 ^{ab}	58.4 ^a
Purchased N excretion, ³ g/(ha × d)	647.8 (435.5)	337.9 ^b	484.7 ^b	950.1 ^a
Purchased P excretion, ³ g/(ha × d)	89.4 (60.4)	46.8 ^b	71.9 ^b	129.3 ^a
Purchased N excretion, ^{2,3} kg/(ha × yr)	273.3 (165)	137.7 ^b	181.9 ^b	359.1 ^a
Purchased P excretion, ^{2,3} kg/(ha × yr)	38.0 (26.5)	17.5 ^b	25.2 ^b	50.9 ^a

^{a,b}Different superscripts within the same row indicate significant differences ($P < 0.05$).

¹Low <12,000 milk kg/ha; 12,000 milk kg/ha < medium <15,000 milk kg/ha; high >15,000 milk kg/ha.

²Annual excretion was estimated for farms that did not change the diet during the year (n = 31).

³Purchased N and P excretion was estimated by considering the purchased N and P intake relative to total N and P intake.

dium and low levels of intensification, respectively ($P < 0.05$). Similarly, intake of home-grown P was also lower for highly intensified farms (12.8%) than for medium (19.7%) and low levels of intensification (29.1%; $P < 0.05$). Therefore, considering the proportion of home-grown N and P in rations and applying the same ratio to N and P excretion, we estimated the N and P excreted imputed to imported feedstuffs. The differences between high and low levels of intensification increased for daily and annual imported N and P excretion by the herd and farmland hectare (Table 8). Annual imported N excretion was estimated as 359 kg/(yr × ha) for highly intensified farms and 181 and 137 kg/(yr × ha) for medium and low levels of intensification ($P < 0.05$). Phosphorus-imported excretion was also greater for highly intensified farms [50.9 kg/(yr × ha)] than for medium [25.2 kg/(yr × ha)] and low levels of intensification [17.5 kg/(yr × ha)] ($P < 0.05$).

CONCLUSIONS

Feeding N closer to recommendations together with an increase in milk yield may contribute to enhancing NUE and decreasing N excretion. Nutritional P management may be improved by no mineral supplementation of concentrates, low-P grass silage production through decreasing P fertilization in grasslands, and the use of feedstuffs containing low amounts of P. Improvement of NUE contributed to improving PUE, despite the use of grass silage and commercial concentrates with high P content. Increasing NUE and PUE in milk can lead to reductions in N and P excretion per liter of milk, and the observed differences in these on different farms allowed estimation of the reduction in N and P excretion at herd levels of 17 and 35%, respectively. Management strategies such as the use of different feeding groups, ration reformulation, and selection of feeding system did not result in a reliable improvement in NUE and PUE on commercial dairy farms. When nutrient excretion was considered for whole lactating herd and farmland availability, the level of intensification was the main factor found to affect farm N and P excretion. Dietary N manipulation may explain only 11% of total variance, and dietary P manipulation could explain no more than 17% of the variance in herd nutrient excretion per hectare. We conclude that the correct match between CP and P quantity fed and that required by the animal, together with an increase in animal productivity, are feasible strategies for decreasing N and P excretion by lactating herds on commercial farms. Nevertheless, the level of farm intensification may limit the effect of nutritional strategies on N and P excretion at farm level.

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