# Eutrophication risk arising from intensive dairy cattle rearing systems and assessment of the potential effect of mitigation strategies



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# Eutrophication risk arising from dairy cattle intensive rearing systems and assessment of the potential effect of mitigation strategies

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## ABSTRACT

Nitrogen (N) and phosphorus (P) are fundamental nutrients in dairy cattle nutrition, but the majority of N and P fed to dairy cattle are excreted in urine and faeces, which may cause water eutrophication. The aim of the current study was to assess the eutrophication risk of dairy production in order to evaluate potential mitigation strategies. A group of 16 dairy farms, following an intensive rearing system and located in the northwest of Italy, was involved in the study. Data were collected for general farm characteristics, diet compositions, feed samples, livestock productive and reproductive performances as well as information on management to evaluate the diet N and P feed content, manure N and P content and apparent N and P utilization efficiency at herd level and for each category of reared animal (*i.e.*, lactating cows, dry cows, heifers, and calves). In order to properly assess the environmental risk, the N release losses into the atmosphere, prevalently as ammonia, were considered and the different forms of released N and P were converted into phosphate equivalent ($PO_4$). On the basis of the characteristics of each farm, some common dietary manipulation mitigation strategies, as adoption of precision feeding and reduction of proteins content of the diet, were proposed to evaluate their potential reduction in excreted nutrients. Feed analysis results showed interesting and notable differences from previously reported N and P contents in diets for dairy cows. The N balance conducted for these farms showed relatively good fitness of the diet for lactating cows, with only a slight deficit in crude protein supplementation (-2%), while diets for dry cows were slightly more unbalanced for N (+17%). The

P balance calculations revealed high excess of P in the diets of the farms in this study, especially for heifers (+106%). The highest and the lowest levels of N- and P-use efficiency were found for cows (20 and 28%, respectively) and for young heifers and calves (0-12 months; 7 and 11% N- and P-use efficiency respectively). It is possible to reduce N and P losses by levelling out this unbalance and in addition, in particular for N, by generally reducing the diet crude protein content by at least 1%. The estimated reduction in $PO_4$ by dietary manipulation was assumed to decrease the environmental eutrophication risk by 17%. On the basis of these results, and considering the number of the dairy cattle reared in the northern Italy, it is possible to estimate that the potential reduction in N and P excretion by dietary manipulation could be equivalent to 5693.5 metric T $y^{-1}$ or 1 metric T $(km^2)^{-1}$ of Utilized Agricultural Area per year of $PO_4$.

**Key words:** nitrogen; ammonia; phosphorus; nutrient excretion; phosphate equivalent

## 1. Introduction

Water eutrophication is a complex phenomenon that involves several physiochemical and biological factors, but which begins from anthropogenic nutrient over-enrichment, particularly of nitrate and phosphate (Shen *et al.*, 2013). Nutrient over-loading is not a risk in itself, *i.e.* nitrogen (N) and phosphorus (P) are not toxic for the environment, but it over-stimulates primary production of microbes and plant species in water, which changes the ecology of the system, and creates a cascade of events that present environmental risks to ecosystems and water quality. Soluble and particulate-associated P in runoff largely determines the degree eutrophication in lakes, streams and other freshwater systems (Marchetti, 1994; Withers and Hodgkinson, 2009). In estuaries and marine coastal ecosystems, N is most often the primary cause of eutrophication (Marchetti, 1994). In some cases, the main problems are associated with organic fertilizers that are produced in intensive livestock production systems (Eckolm *et al.*, 2005), a phenomenon which has been the subject of

European and North American legislation and control for several years (Ongley, 1996). The European Union, after the regulation on N environmental release (Directive 91/676 EEC), in the next years will rule on other pollutants, especially those, such as P, which have effects on the eutrophication of rivers and seas and which can also have consequences on the public health (Meschy and Ramirez-Perez, 2005). Nutrients recycling and efficiency (N and P) are regulated by other European environmental policies, such as the Water Framework Directive (2000/60 EC) and, indirectly, by other EU level strategic policy frameworks, such as the Raw Materials Initiative (EU Council, 2017).

In Italy, the problem of water quality is particularly acute in intensive livestock production areas, such as in the northern part of the country where the production of slurries and manure often exceeds the capacity of the land to assimilate these wastes. Among the reared species, dairy cattle represent one of the main livestock sectors, above all in some areas such as the North-West part of Italy (Piedmont region). Here, approximately 10% of the national livestock was raised, equivalent to about 1 million LUs (livestock units), and census data report the presence of approximately 580,000 LUs cattle, about 300,000 LUs pigs, about 100,000 LUs poultry and about 20,000 LUs of others species, especially sheep (ISTAT, 2010). Because of the high presence of livestock heads, and hence of the high number of animals per farm surface unit, and because of the kind of manure produced (slurry), these cattle herds could represent an environmental problem and an eutrophication risk, and could also affect agricultural water resources. Presently 54% of the Piedmont plain agricultural area is designated as vulnerable to nitrate and since 2011 the EU Commission (Decision 2011/721/EU) allows the farms to get derogations to go beyond 170 kg of nitrogen limit, under strict conditions. At that time, among Piedmonts livestock, the dairy cattle farms were the most problematic one in this area, with 266 farms exceeding the limit of 170 kg N $ha^{-1}$, including 88 exceeding the limit of 250 kg N $ha^{-1}$ admitted with the derogation (Anagrafe Agricola Regione Piemonte, 2011). Italy, with regard to Lombardia and Piemonte Region, have again request derogation to EU Commission, granted with Decision 2016/1040/EU.

For these reasons, a study was carried out on dairy cattle farms in a homogeneous area (western part of the Po Plain: between 44°08¢33$^2$ and 46°08¢13$^2$ N, 6°70¢42$^2$ 8°23¢02$^2$ E; surface: 13,722 km$^2$) to collect data from a representative sample of herds. Holstein breed is prevalent in the considered area followed by Brown Swiss. Typically the regional farms adopt intensive rearing systems, with cows housed in free-standing cubicle without grazing. The herd size is usually over 200 heads, including both lactating cows (usually over 100), dry cows and replacing animals (AIA, 2016) and diets are based on corn silage, leguminous and cereals meals and other concentrated feed. The collected data pertain to the general characteristics of the farms, the livestock productive and reproductive performances and the managerial choices so that the real N and P feed content, the actual excretion level and apparent utilization efficiency of these nutrients could be evaluated at a herd level and for different animal categories. In fact, the aim of this work has been to evaluate the nutrient excretion and utilization efficiency not only of cows but also of the other most important cattle categories reared on dairy farms, such heifers and young females, which are often not considered in evaluations of this kind.

The objectives of this study were: a) to evaluate the nutrients surplus and to suggest the best practise among diet manipulation and management solutions that best fit the farms characteristics, that could be adopted in the future to reduce N and P release into the environment; b) to estimate the potential effect that these strategies could have, at a regional level, on the reduction of the eutrophication risk.

## 2. Materials and methods

The survey involved 16 commercial dairy farms, visited twice during spring (March-June), that rear Italian Holstein Friesian or Brown Swiss cattle (3,484 animals and 1,722.5 metric T of live weight) spread over a homogeneous area (North-West plain of Italy, the Cuneo and Torino provinces, as previously detailed), which were selected on the basis of their representativeness, for breed, rearing system, number of lactating cows and mean milk production per cow of the prevalent herds in the area. In all farms, cows and heifers were kept in permanent confinement without pasture, the replacement animals were reared in group in pen and all the diets unchanged throughout the year. The number of total cows (TC), lactating cows (LC), dry cows (DC), heifers (H; 12 month-age to first parity), young heifers (YH; 6-12 months) and calves (CA; 0-6 months) were recorded for each of the 16 farms. The diet composition of each animal group (*i.e.*, LC, DC, H, YH and CA) for each herd, deriving from management choice, were also recorded, as well as the productive and reproductive indices. The considered productive indices were: feed consumption (kg $d^{-1}$), mean live weight (LW; kg) and production of the animals: weight gains (kg $y^{-1}$), number (n $y^{-1}$) and weight (kg) of born calves, milk production (kg $d^{-1}$ and kg $y^{-1}$) and its qualitative parameters (fat, %; protein, %; casein, %; urea, mg $L^{-1}$; somatic cells, n $mL^{-1}$; bacterial count, CFU $mL^{-1}$). Specifically, mean live weight was the weight used to prepare the diet on the basis of animals' requirements. The weight gains, that affect the N and P balance less than 1%, were calculated as LW gain per year (kg $y^{-1}$) obtained by dividing the difference between the real LW at the end of the productive period (the cows were weighted when sold at the end of their career) and the estimated LW at the beginning of the first lactation by the productive period. The collected reproductive indices were: calving interval (d), calving-conception period (d), number of services per conception (n), age at first calving (months), number of calving per year (n $y^{-1}$) and fertility rate (%). The productive and reproductive indices were useful to evaluate the possible effects of dietary N and P consumption on cattle performance and statistical correlations were studied between the N and P concentrations in the diet and the productive and reproductive parameters.

In each farm, all feeds were individually sampled two times during the trial to determine their nutrient contents. To evaluate the true nutrients provision with the TMR diet, samples were also collected from the feed bunk to determine N and P content used as input in the mass balance. All samples were analysed in the laboratory of the Department of Agriculture, Forestry and Food Science of the University of Torino to determine the proximate composition of the diets according to AOAC International (2006): preparation of analytical sample (method 950.02); dry matter (DM) content (method 934.01); total ash (method 942.05); crude protein (CP) content (method 984.13); ether extract (EE) content (method 2003.05); neutral detergent fibre (NDF) content (method 2002.04); acid detergent fibre (ADF); acid detergent lignin (ADL) content (method 973.18) and P content (method 965.17).

Mean total N and P feed contents of the feed samples bulked across farms were compared with literature data collected from several bibliographic references (INRA, NRC and other authors) by Cevolani (2005) to establish the possible advantage (avoiding excesses or deficit) derivable from the correct knowledge of the feed characteristics.

The measured total N and P contents in the diets of each farm were compared to those of the animal requirements determined according to the National Research Council (2001) recommendations, based on animal empty body weight, daily body gain, equivalent shrunk body weight, dry matter consumption, milk production, protein milk content and weight of the conceptus, in order to evaluate their potential deficit or surplus in the diets.

In order to determine N and P excretion in faeces and urine in addition to the single categories of animals, the estimation also referred to a herd level, *i.e.* calculated on the basis of replacement units (RU), which considers how many calves and heifers per cow are reared on average on each farm.

Considering the difficulty to collect representative samples of faeces and urine in commercial farms to analyse for total N and P content, nutrient excretion was calculated by means of the balance method, following the procedure adopted by the EU Commission to estimate N excretion (ERM/AB-DLO, 2002) that is: nutrient intake minus nutrient retention in animal products (milk, meat, calves). The method does not require to calculate the digestibility of each single nutrient (*i.e.*, N and P). Moreover, the mass balance method for N has been chosen because it is used by public authorities at local scale to verify the N excretions and surpluses at farm level and because it is not affected by digestibility of N source.

The actual total N and P intakes were calculated on the basis of the feed analysis, whereas the retention, excretion and utilization efficiency were calculated on the basis of productive and reproductive indices. In other words, according to the ERM/AB-DLO (2002) recommendations, the retention per animal weight gain and calf production were estimated to calculate N excretion considering an N content of 25.0 and 29.5 g $kg^{-1}$ of LW respectively. Instead, the N retention in milk production was determined on the basis of the actual CP content of the milk divided by 6.38. The P retention in weight gain, calf and milk was estimated considering a P content of 7.5, 6.0 and 0.95 g $kg^{-1}$, respectively, of LW or milk production according to the Food Standard Agency (FSA, 2002) recommendations.

Nutrient utilization efficiency was calculated as the ratio between N and P retention and intake. In order to evaluate annual *per capita* nutrient use efficiency, the LC and DC group data were processed to obtain the annual mean values of TC. Further clarifications are necessary to establish the nutrient utilization, since N and P absorption efficiency indicates the retention as a fraction of the sum of N and P entering the digestive tract (N or P absorption / [N or P intake + N or P secretion]) where N and P absorption and secretion are calculated from the quota of exogenous and endogenous faecal N and P (Pfeffer *et al.*, 2005). These quotas can be extremely variable for P, as reported by Kleiber *et al.* (1951) who found a wide range of endogenous faecal P (43-70%). Considering that, in this study, the faeces were not collected or analysed for their N and P contents, but the absorbed N and P were calculated on the basis of the cattle productions (increase in LW, milk and calf production for TC, increase in LW and calf production for H and increase in LW for YH and CA) and of their mean N and P concentration, calculating the nutrient efficiency as (N or P retention on N or P intake), it was decided to name this ratio “apparent efficiency”.

The excreted nutrients will be spread on fields , and, in order to evaluate their supplies, N and P contents in the manure were converted to nitrate ($NO_3$) and phosphorus pentoxide ($P_2O_5$), respectively, on the basis of their stoichiometric coefficient of conversion (4.427 and 2.2915) to the respective molecular weight.

In order to properly assess the environmental risk related to the level of N and P with potential to contaminate soil and water, the N losses due to volatilization into the atmosphere during the waste

removal, storage and spreading phases, prevalently as ammonia ($NH_3$), were considered as proposed by ERM/AB-DLO (2002), and adopted for the specific Italian waste management systems as equal to 28% of excreted N , as stated by the Committee of the Interregional project on N excretion from livestock for the waste management systems in Italy (Xiccato *et al.*, 2005). It was decided not to consider the oxidation of $NH_3$ to $N_2O$ or $NO_x$, the latter having a different eutrophication potential (*e.g.* $NO_x$ has an eutrophication potential of 37% of that of $NH_3$), because they are difficult to quantify exactly and are negligible in quantity (*e.g.* $N_2O$ is about 0.01% of the $NH_3$ produced, as deduced from IPPC reports; IPPC, 2014). The estimated N, $NH_3$ and P losses were converted to phosphate equivalent ($PO_4$; whose eutrophication potential is 1) using the equivalence factors suggested in the CML method (proposed by the Centre of Environmental Sciences, University of Leiden in 1992, and updated in 2000), which is generally used in Life Cycle Assessments (LCA). The reduction in the $PO_4$ potential eutrophication obtainable with more correct livestock management strategies was assumed as a potential reduction of the environmental eutrophication risk. Where necessary, literature data were taken into account to evaluate the potential reduction in N and P excretions obtainable by the methods that will be discussed later.
The collected data were analysed to establish the descriptive parameters (mean and standard deviation) and their statistical correlations (IBM SPSS, 2016).

## 3. Results

The farms selected for this study represent 4.6 and 2.5% of the Holstein Friesian plus Brown Swiss cows and dairy cattle herds of the selected area, respectively. The average number of reared animals per farm and their mean LW, as well as the average productive and reproductive indices of the animal categories are shown in Tables 1 and 2, respectively. Only five of the sample farms had split the LC into two groups: cows at the beginning of lactation (first 2-3 months of lactation) and other lactating cows, with the 2 groups being fed different diets. The number of cows per group is not reported in Table 1, but the subdivision was taken into account in the calculation of the nutrient intake and requirements.

The feed sample composition referring to the DM content is shown in Table 3. The most common feed were corn silage and permanent meadow hay (75% of the farms), corn meal (50% of the farms), alfalfa hay (44% of the farms) and Italian ryegrass hay, soybean meal, wheat bran, cotton seeds (31% of the farms). The other feed were collected in less than 20% of the farms. In all farms the mineral supplementation was given within the feedstuffs and then was impossible to sampling the supplement, but the phosphorous supplementation used was mineral dicalcium phosphate.

Table 4 shows the actual N and P feed contents and a comparison with literature data and puts in evidence the amount of differences (as %) between such values. The nutritional values of the beet molasses shows a wide variability compared to the literature data, which depends on the industrial extraction process and subsequent concentration of sugar refining by-products; the literature data should therefore only be considered indicative.

Tables 5 and 6 report the apparent balance and apparent efficiency for N and P and the environmental release of $NO_3$ and $P_2O_5$ for the dairy cattle categories considered in this analysis. In order to allow a comparison of the animal diets to be made, the study was referred only to four categories (LC, DC, H and YH plus CA) combining the data of the different groups of LC in a unique category. For the nutrients balance, the categories were reduced to three, combining LC with DC data, because the balance referred to the whole year. All the data were elaborated to obtain the values referring to the RU. The mean DM intake and standard deviation were 21.21±1.26, 10.47±0.90, 8.54±0.46, 6.37±0.47 (kg $d^{-1}$) for LC, DC, H and YH plus CA, respectively.

The statistical correlations between the N and P concentrations in the diets and the productive and reproductive indices were verified and no correlations were found for the studied herds, except between the N concentration of the LC diet and milk production ($R^2$=0.813; $P<0.01$) and the number of somatic cells in milk ($R^2$=0.558; $P<0.05$).

The eutrophication potential and the reduction in the correlated risk obtainable with mitigation strategies are shown in Table 7. On the basis of the farm characteristics shown in the current investigation, the strategies that could be adopted to decrease N and P excretion are: i) routine sampling of the feedstuffs, especially forages and by-products, to establish their nutrient content; ii) splitting the cows into at least 3 groups (cows at the beginning of lactation, other lactating cows and non-lactating ones); iii) adopting precision feeding for cows, but especially for replacement heifers. In order to decrease N excretion, it is also possible to: i) reduce the CP content in the diet (a reduction of 1 percentage point in the diet CP generally reduces the N excretion by 10%; CRPA, 2014a); ii) supplement the diet with essential amino acids; iii) synchronize the N, carbon chain and energy availability over the entire digestive tract (rumen and intestine) on the basis of the protein degradability. In order to decrease P excretion, it is possible to: i) accurately determine the requirements of each group of animals on the basis of the most recent suggestions (Meschy, 2010), which are lower than in the past, to avoid the recorded excess.

Considering this evidence, it was decided, as a minimum goal, to envisage the adoption of the measures that could be applied immediately without difficulty by the farmers, but at the same time those that give the best results. Therefore, it is possible to act, for N and P, by improving the balance between nutrient intake and utilisation reducing the excesses adopting precision feeding strategies, as routinely sampling and analysing the feed or considering the nutrient availability, and in addition, but only for N, by generally reducing the CP content of the diet by at least 1%, eventually supplementing the diet with amino acids if necessary (Tables 5 and 6). The latter action has proved easily achieved, as can be seen from the results of the Life+ European project AQUA (CRPA, 2014b). It is also important to consider the recent studies on P requirements that have been revised downwards or given as available P (INRA, 2007; Meschy, 2010). The possibility to use form of P mineral supplementation more easily available was not taken into account as common strategy because the farms involved in the study already used a mineral form with a good availability (dicalcium phosphate). The effects of these simple reduction strategies are shown in

Table 7 where the actual N and P release showed in the Tables 5 and 6 were reduced following the suggested strategies and transformed in $PO_4$ equivalent to estimate the eutrophication potential. Specific other strategies could be adopted in single farms but do not represent a common strategy adoptable in all.

On the basis of these results, in particular for the reduction in the eutrophication potential per RU, and considering that the number of RU in the western part of the Po Plain (Cuneo and Torino provinces) was 40,402 (AIA, 2015), it is possible to estimate that the reduction in the potential nutrient excretion would be equal to 5,693.5 metric T $y^{-1}$ or 1 metric T $(km^2)^{-1}$ of Utilised Agricultural Area per year of $PO_4$.

## 4. Discussion

The productive and reproductive indices of the 16 dairy farms investigated in this study are similar to the mean values computed by the Italian Breeders Association (AIA, 2016). In fact, milk production is an index of the productive and genetic level of the considered farms and the AIA bulletin reports an average milk production of 31.07 kg $d^{-1}$per cow for the considered breeds and for the farms in the same area, that is, practically the same yield as the farms in this study (considering the real milk yield, without correction for the fat content). The others indices reported in the bulletin are also in agreement with this assertion; in fact, the milk fat (3.76%) and protein contents (3.38%), calving-conception period (181 d), services per conception (2.83) and age at the first calving (26.4 month) are very near or even coincident with the indices calculated for the farms in this study. On the basis of this evidence, the selected herds can be considered as representatives of the farms in North-Western Italian plain.

The feed sample composition shows a higher DM variability for the silages than the other feeds, and an apparent lower variability for the other determined parameters. The feed N and P contents instead show interesting and large differences, compared to the literature data. Excluding the beet molasses values, which, as previously mentioned, depend on the industrial extraction process and on the subsequent concentration of the sugar-refining by-products, the N feed content differs by between -41 and +23% from the literature data. Instead, the P differences, which varied from -23 to +20%, according to the feed, were more limited, although always large. These results confirm the importance of an accurate knowledge of the characteristics of the feed used in diets because the use of balanced diets decreases the level of excretion of nutrients and in turn of their environmental release.

The diet analysis has shown that the adopted DM intake satisfies the physiological requirements of the different cattle categories, even though it could be slightly increased for H.

The observed differences in the N balance highlight a good balance in the diets for LC. Only a slight deficit in CP supplementation can be observed, together with slightly more unbalanced diets for DC. Such a result can be attributed to the approximation level in the diet evaluation. This evaluation has determined the N supplementation in terms of CP, whereas diets, particularly those of LC, are normally prepared on the basis of more precise parameters, *e.g*. digestible protein, rumen degradable protein or protein solubility. However, the collected data confirm the good balance in the diet of dairy cows, although the N balance shows that the level of utilization efficiency for these animals (about 20%), considering the annual N balance (lactation plus dry period), is not excellent. This efficiency is a little higher than the average N efficiency calculated in ERM AB-DLO (2002) for large breeds (18%). In the intensive dairy farms of North Italy, Crovetto and Colombini (2010) found that the N efficiency of cows, calculated as the ratio of N retained in milk and the N intake, hence without considering the non-productive period (dry period), was between 27.9 and 28.7%, according to the amount of milk produced, or 26.3 and 30.2% according to the starch/CP ratio in the diet. This efficiency would surely be lower if the dry period were also considered. In fact, Wilkerson *et al*. (1997) found an N efficiency of 31.1 and 27.3% in lactating cows producing 29 and 14 kg $d^{-1}$ of milk, respectively, but only 6.7% in non-lactating cows. In two experimental trials, Crovetto and Colombini (2010) and Colombini *et al*. (2012) found an N efficiency (N in milk/N intake) of between 22 and 32% and 25 and 26%, respectively. Other authors have calculated an N efficiency (as the percentage of N in a feed that is recovered as N in the milk), which, according to the diet and the number of parities, is between 29 and 31% (Nadeau *et al.*, 2007). The N efficiency of dairy cows calculated by ADAS (2007), using the same balance model utilized in the present trial, is 23.5% and therefore closer to those calculated for the investigated farms in this study.

As far as replacement animals are concerned, since calves and heifers need to grow for about 2 years before they can produce milk, the H and YH plus CA show a low N utilization efficiency. In fact, H and YH plus CA use most of the N intake for growth and do not retain as much of the additional N absorbed as LC, which results in more N being excreted when additional N is absorbed (Nadeau *et al.*, 2006). This suggests that H and YH have a lower demand than LC because they do not have to restore the body protein that is mobilised in lactation, and an N excess in the feeds could therefore lead to a greater excretion. On the other hand, the younger females (H and YH plus CA) have a higher CP percentage of LW than LC (from 17% to 19% of LW for H and YH plus CA and 16% for LC; National Research Council, 2003), but the N retention for growth has less efficiency than the N utilised for milk production. These considerations justify the differences in N efficiency found for the three cattle categories, and especially those between LC and the other categories. It is also possible to suppose an increase in N efficiency in the investigated farms for the replacement females. As regards the N efficiency rate that has been published in other papers, Stoumann Jensen and Schjoerring (2011), in the European Nitrogen assessment, converting the data reported by CBS (2009) to animals housed for 365 days per year, reported N efficiencies for Dutch livestock categories, which, for dairy cattle fed high fodder maize diets, were 15.5, 6.6 and 26.3% for replacement females under or over 1 year of age and lactating cows, respectively. Hill *et al*. (2007), in late-gestation dairy Holstein heifers fed diets with varying forage contents, reported an N efficiency ranging between 10 and 19%. Wilkerson *et al*. (1997) found an N efficiency of 15.7% for growing and replacement cattle.

Consistently with literature, the proportion of N excreted decreased as the milk yield increased (Crovetto *et al.*, 2010). In the studied herds, the absence of statistical correlations between the N (and P) concentrations in the diet and the considered productive and reproductive indices suggests that there may be room to reduce the contents of N (and P) in the diet without affecting the performances of the animals.

Therefore, it is possible to consider increasing the N utilization efficiency with suitable feeding strategies, such as a CP reduction and a contemporary supplementation of synthetic amino-acids in the diet or with inorganic N (*e.g*. protected ureic nitrogen) with a gradual release to obtain the contemporaneous availability of the carbon chain and of nitrogen in the protein synthesis.

The use of these strategies may raise the utilization efficiency of nitrogen to almost 35% in lactating cows, but a dairy cow fed a well-balanced diet will on average convert about 30% of the N consumed into protein (Chase, 2004).

The P balance showed a large excess in diet supply, especially for H. The apparent efficiency of RU appeared to be low, even though the efficiency of the cows amounted to about 28%. This efficiency confirms the mean efficiency found by other authors. Tamminga (1992) found a P intake/excretion ratio of 75% (apparent P efficiency 25%) in Dutch dairy cows producing 6250 kg of milk per year, but this efficiency was affected by milk production, which was lower than on the farms of the present study. In fact, it is well known that P efficiency also depends on the productivity level and consequently on the P diet concentration, as pointed out by Wu (2005), who, in cows fed diets containing different amounts of P and sources of fibre, found an efficiency ratio of 24-44%.

Puggard *et al*. (2011) found a P apparent digestion (P feed – P faecal) of 26-36% in Holstein cows, where the faecal P normally represented 98-99% of the total P excreted (faecal plus urinary).

Efficiency is normally lower for replacement cattle than for lactating cows, as affirmed by Nennich *et al*. (2005), who found that heifers in late-gestation excrete 60 to 70% as much P as lactating cows. These results were confirmed by Hill *et al*. (2007), who found a negative P balance with depletion of body reserves in late-gestation dairy Holstein heifers. The differences in P efficiency could also be imputable to the incomplete development of the digestive tract of the young animals and to microbial equilibrium (e.g. a lower absorption or lower microbial phytase production), and to the phosphorus metabolism of the cows, which is correlated to calcium bone storage and mobilization.

It is also possible to consider increasing P utilization efficiency by adopting several strategies, and the easiest ones to adopt for the farms considered in this research have already been described. In order to estimate the reduction in excreted P, the easiest adoptable strategy was chosen that is, of avoiding an unbalance and of paying attention to the most available mineral supplementation. In fact, the P in animal diets is obtained from the P that is present in the basic feed ingredients and from mineral supplementation. The feed ingredients, particularly forages, should be analysed systematically to establish the exact P content, while it is very important to choose the forms of P that are more easily available (monocalcium or dicalcium phosphate, monosodium phosphate, *etc*.) for the mineral supplementation of the diet, and to reject the mineral supplementation with medium (sodium triphosphate, defluorinated phosphate, *etc*.) or low (soft rock phosphate) availability (Bleukx, 2005).

About the relationship between agroecosystems and natural environment, it is very difficult to evaluate how the strategies proposed for the dairy farms could influence the natural environment because in the considered area, part of the Piedmont region, the intensive dairy farms are located in plain, area with a high level of anthropization, *i.e.* with a total conversion of open spaces, landscapes and natural environments by human action. In Piedmont the natural environments are mainly located in the hilly and mountainous area, therefore at a higher altitude than the farms involved in the study, so there is no repercussion of eutrophication in the watersheds that are located upstream of the considered area. Anyway some consideration could be done on the protection of ground and surface water quality by preventing nitrates from livestock sources. In fact on the basis of the proposed strategies it is possible estimate a reduction of N excretion of 15.10 N kg year$^{-1}$ per RU. Considering that in Piedmont about 40% of the nitrates of livestock origin derives by dairy farms (Anagrafe Agricola Regione Piemonte, 2011) the estimated value corresponds to a reduction about 8% of the N of livestock origin in the Piedmont river basins. More difficult was estimate this reduction for the P because no data were found about the phosphates release quantified per sources. However in Piedmont this pollutant is important as well as the nitrates considering that the phosphates, also if substantially firm in the period 2006-2013 (+1%), represent about 78% of the agricultural P, while the nitrates of livestock origin, increased by 17% in the same period, represents about 50% of the N of agricultural origin (Nappi *et al.*, 2016). So, a reduction of the nitrates and phosphates could affect the water quality of the northern Adriatic Sea where the Piedmont rivers flow together the Po, the main Italian river, and where, starting from the 70s of the last century, a series of acute eutrophication phenomena occurred. In this closed sea basin the influence of the anthropogenic nutrient input showed a dominant effect than the natural (climatic) causes (Degobbis *et al.*, 2000), so a control of the input of livestock origin, one of the most important nutrient sources, could have an important effect on preserving the marine ecosystem.

The reduction in the potential nutrient excretion, and therefore in the eutrophication risk, that can be obtained with the proposed N and P reduction strategies should be considered the minimum target that has to be reached by the farmers in the considered area. This reduction is not negligible, considering that it is about 17% of the actual potential eutrophication risk derived from the local dairy cattle sector, as the RU potential eutrophication reduction showed in Table 6.

## 5. Conclusions

This study has shown that it is possible to reduce pollution from dairy farms and in particular the risk of water eutrophication. N supplementation has been found to be balanced for productive animals, but in excess for replacement cattle, while the P surplus has been found in all the studied farms. Therefore, it is necessary to pay more attention to each animal category reared on dairy farms, and in particular to the diets of replacing animals, which should be formulated as closely as possible to their requirements. The strategies suggested to decrease livestock pollution are simple: reducing the N and P contents or supplementations in the diets to avoid overfeeding, and increasing nutrient utilisation efficiency of the animals and at a herd level, without affecting the minimum requirement and hence the productive and reproductive performance.

In short, the N and P balance method and the evaluation of nutrients efficiency could be useful tools for livestock farms to estimate the risk of eutrophication from dairy farms, to control and reduce the flow of these nutrients and to highlight the critical points of the production systems.


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**Table 1.** Average number of reared animals per category and per farm and their mean live weight (mean value ± standard deviation).

| | Number of animals (n) | Live weight (kg) |
|---|---|---|
| Total animals | 217.8±98.3 | n.r. |
| Total cows | 116.4±54.0 | 656.3±22.5 |
| Lactating cows | 100.3±45.6 | n.r. |
| Dry cows | 16.1±9.0 | n.r. |
| Heifer | 49.4±22.0 | 426.7±25.3 |
| Young heifers plus calves | 48.5±23.6 | 254.7±35.9 |

n.r. = not recorded.

**Table 2.** Productive and reproductive indices (per year, mean value ± standard deviation).

| Productive indexes | | Reproductive indexes | |
|---|---|---|---|
| Milk yield (kg cow$^{-1}$ d$^{-1}$) | 31.19±3.91 | Calving interval (d) | 428.6±19.6 |
| FCM[1] yield (kg d$^{-1}$) | 30.29±3.38 | Calving-conception period (d) | 151.5±18.5 |
| Milk fat (%) | 3.82±0.19 | Services per conception (n) | 2.53±0.43 |
| Milk crude protein (%) | 3.38±0.19 | Age at first calving (months) | 25.44±1.32 |
| Milk casein (%) | 2.67±0.10 | Calves per cow (n) | 0.85±0.04 |
| Milk urea (mg L$^{-1}$) | 26.07±3.60 | Fertility rate (%) | 40.59±6.56 |
| Milk somatic cells (n mL$^{-1}$) | 219,130±56,028 | Heifers per cow (n) | 0.43±0.10 |
| Milk bacterial count (CFU mL$^{-1}$) | 13,560±9,913 | Young heifers and calves per cow (n) | 0.42±0.05 |

[1]FCM = Fat Corrected Milk, corrected to 4% of fat.

**Table 3.** Feed compositions as a percentage of Dry Matter (% DM; mean value ±standard deviation).

| Feed | Samples (n) | DM[1] (%) | Ash (% DM) | CP[2] (% DM) | EE[3] (% DM) | NDF[4] (% DM) | ADF[5] (% DM) | ADL[6] (% DM) |
|---|---|---|---|---|---|---|---|---|
| Italian ryegrass hay | 10 | 89.26±1.04 | 8.65±0.17 | 9.83±1.98 | 1.69±0.27 | 59.37±4.09 | 37.22±1.60 | 3.40±0.28 |
| Fescue hay | 6 | 88.60±1.01 | 11.90±0.42 | 12.70±0.39 | 3.50±0.08 | 66.50±4.28 | 36.50±1.58 | 3.20±0.21 |
| Alfalfa hay | 14 | 87.69±1.41 | 9.60±2.62 | 16.83±4.51 | 2.00±0.55 | 49.85±9.32 | 37.36±7.85 | 7.82±1.50 |
| Permanent meadow hay | 24 | 87.67±2.38 | 8.70±3.01 | 11.39±2.65 | 2.10±0.79 | 55.99±7.23 | 39.42±7.08 | 5.44±2.15 |
| Corn silage | 24 | 32.70±3.56 | 4.24±0.22 | 7.90±0.56 | 3.10±0.15 | 42.61±1.79 | 24.74±1.87 | 2.83±0.66 |
| Italian ryegrass silage | 6 | 31.93±3.97 | 9.15±1.91 | 10.57±0.93 | 2.33±0.58 | 57.97±2.70 | 36.70±0.26 | 5.55±0.64 |
| Triticale silage | 6 | 28.10±3.54 | 11.70±2.05 | 11.30±1.00 | 2.70±0.50 | 69.50±2.80 | 45.90±0.45 | 5.90±0.61 |
| Corn meal | 16 | 87.06±1.29 | 1.59±0.28 | 9.86±0.95 | 3.27±0.59 | 14.73±1.78 | 3.94±0.77 | 0.73±0.39 |
| Wheat meal | 6 | 89.5±0.14 | 2.85±0.07 | 14.75±0.07 | 1.48±0.04 | 18.05±0.07 | 3.50±0.98 | 0.60±0.11 |
| Soybean meal | 10 | 87.86±0.59 | 7.64±0.56 | 50.41±1.61 | 2.03±0.67 | 17.90±0.90 | 8.80±1.20 | 0.57±0.15 |
| Wheat bran | 10 | 87.66±1.01 | 4.60±0.37 | 17.68±0.82 | 2.30±0.01 | 40.00±2.95 | 10.70±1.08 | 3.10±0.31 |
| Cotton seeds | 10 | 91.24±1.31 | 4.88±0.22 | 24.79±2.95 | 23.47±2.96 | 38.23±3.67 | 26.48±3.51 | 8.40±1.19 |
| Cereal straw | 6 | 89.45±1.20 | 8.05±0.35 | 3.90±0.01 | 1.10±0.14 | 81.70±2.97 | 57.35±0.92 | 9.00±4.53 |
| Beet pulp | 6 | 88.52±0.46 | 6.48±2.02 | 10.40±0.99 | 0.90±0.11 | 60.01±2.36 | 29.80±2.75 | 4.40±0.51 |
| Beet molasses | 6 | 56.67±0.31 | 22.10±0.10 | 7.23±0.25 | 8.90±0.36 | n.d. | n.d. | n.d. |
| Brewers grain | 6 | 22.93±0.15 | 4.70±0.10 | 25.43±0.06 | 7.00±0.01 | 44.29±17.29 | 28.58±14.40 | 4.33±3.02 |
| TMR Lactating Cows | 32 | 53.07±4.28 | 5.38±0.34 | 15.83±0.75 | 4.42±0.54 | 35.29±1.12 | 20.07±0.73 | 3.23±1.14 |
| TMR Dry Cows | 32 | 64.24±3.80 | 5.98±0.37 | 10.82±1.55 | 2.35±0.48 | 51.93±3.67 | 29.29±5.60 | 3.37±0.97 |
| TMR Heifers | 32 | 64.23±4.63 | 5.78±0.38 | 12.21±0.58 | 2.49±0.48 | 50.91±2.70 | 30.86±1.82 | 3.51±1.06 |
| TMR Young Heifers | 18 | 64.59±3.84 | 5.86±0.34 | 13.64±0.84 | 2.40±0.54 | 48.37±3.43 | 28.92±2.20 | 3.25±0.94 |

[1]DM = Dry Matter.

[2]CP = Crude Protein.

[3]EE = Ether Extract.

[4]NDF = Neutral Detergent Fibre.

[5]ADF = Acid Detergent Fibre.

[6]ADL = Acid Detergent Lignin.

n.d. = not determined.

**Table 4.** N and P of the feeds as a percentage of the actual Dry Matter (% DM) content compared with literature values (Cevolani, 2005; mean value ± standard deviation).

| Feed | Actual N content (% DM) | Literature N content (% DM) | Difference (%) | Actual P content (% DM) | Literature P content (% DM) | Difference (%) |
|---|---|---|---|---|---|---|
| Italian ryegrass hay | 1.57±0.32 | 1.73 | -10.2 | 0.28±0.04 | 0.28 | 0.0 |
| Fescue hay | 2.03±0.30 | 1.56 | +23.2 | 0.23±0.04 | 0.23 | 0.0 |
| Alfalfa hay | 2.36±1.16 | 3.32 | -40.7 | 0.26±0.09 | 0.30 | -15.4 |
| Permanent meadow hay | 1.82±0.42 | 1.79 | +1.7 | 0.28±0.05 | 0.32 | -14.3 |
| Corn silage | 1.26±0.09 | 1.34 | -6.4 | 0.22±0.03 | 0.27 | -22.7 |
| Italian ryegrass silage | 1.69±1.49 | 1.87 | -10.7 | 0.28±0.04 | 0.36 | -28.6 |
| Triticale silage | 1.81±0.10 | n.a. | - | 0.42±0.05 | n.a. | - |
| Corn meal | 1.58±0.15 | 1.50 | +5.1 | 0.30±0.04 | 0.23 | +23.3 |
| Wheat meal | 2.37±0.01 | 1.94 | +18.1 | 0.46±0.01 | 0.37 | +19.6 |
| Soybean meal | 8.06±0.26 | 8.26 | -2.5 | 0.72±0.03 | 0.71 | +1.4 |
| Wheat bran | 2.83±0.13 | 2.72 | +8.7 | 0.95±0.02 | 1.13 | -18.9 |
| Cotton seeds | 3.97±0.47 | 3.74 | +5.8 | 0.67±0.06 | 0.70 | -4.5 |
| Cereal straw | 0.62±0.05 | 0.54 | +12.9 | 0.10±0.01 | 0.12 | -20 |
| Beet pulp | 1.66±0.16 | 1.78 | -7.2 | 0.10±0.01 | 0.10 | 0.0 |
| Beet molasses | 1.16±0.04 | 2.32 | -100.0 | 0.24±0.02 | 0.03 | +87.5 |
| Brewers grain | 4.07±0.17 | 4.13 | -1.5 | 0.58±0.01 | 0.60 | -3.4 |

n.a. = not available.

**Table 5.** N apparent balance and $NO_3$ environmental release (mean value ± standard deviation).

| | LC[1] | DC[2] | H[3] | YH[4] and CA[5] | RU[6] |
|---|---|---|---|---|---|
| CP in diet (% DM) | 16.17±1.26 | 11.01±1.73 | 13.58±1.40 | 13.70±1.95 | 14.12±1.51 |
| CP requirements (g $d^{-1}$) | 3533.9±302.0 | 1094.0±13.9 | 1153.3±53.7 | 744.0±17.1 | 3624.1±327.8 |
| CP in feed (g $d^{-1}$) | 3494.1±300.0 | 1166.7±230.6 | 1162.2±145.6 | 872.4±126.7 | 3781.5±326.5 |
| CP balance (%) | -1.75±6.00 | 6.56±20.66 | 0.65±12.90 | 17.23±17.26 | 4.6±6.0 |
| N intake (kg $y^{-1}$) | 186.15±21.78 | | 21.72±2.24 | 21.93±2.90 | 233.9±23.0 |
| N retention (kg $y^{-1}$) | 37.65±5.14 | | 4.74±0.74 | 3.41±0.97 | 41.3±5.5 |
| N excretion (kg $y^{-1}$) | 148.50±19.18 | | 62.14±8.53 | 47.54±7.61 | 192.6±21.0 |
| N apparent efficiency (%) | 20.32±2.51 | | 8.58±1.67 | 6.95±2.67 | 17.7±2.0 |
| N losses (kg $y^{-1}$) | 41.58±5.37 | | 17.40±2.39 | 13.31±2.13 | 53.27±5.44 |
| $NO_3$ release (kg $y^{-1}$) | 657.43±84.93 | | 275.71±37.76 | 210.47±33.71 | 842.31±85.99 |
| $NO_3$ excess (kg $y^{-1}$) | -13.10±64.47 | | 1.69±37.27 | 33.03±33.18 | 0.45±68.86 |

[1]LC = Lactating Cows.

[2]DC = Dry Cows.

[3]H = Heifers.

[4]YH = Young Heifers.

[5]CA = Calves.

[6]RU = Replacement Unit.

**Table 6.** P apparent balance and $P_2O_5$ environmental release (mean value ± standard deviation).

| | LC[1] | DC[2] | H[3] | YH[4] and CA[5] | RU[6] |
|---|---|---|---|---|---|
| P in diet (% DM) | 0.38±0.03 | 0.35±0.03 | 0.19±0.01 | 0.25±0.01 | 0.29±0.03 |
| P requirements (g $d^{-1}$) | 80.14±8.22 | 36.06±0.94 | 15.23±1.04 | 15.93±1.18 | 65.58±5.95 |
| P in feed (g $d^{-1}$) | 93.09±9.70 | 43.26±10.26 | 31.61±8.28 | 23.59±4.51 | 91.20±12.96 |
| P balance (%) | 17.16±16.19 | 19.99±28.21 | 106.98±51.28 | 49.14±31.86 | 39.11±15.55 |
| P intake (kg $y^{-1}$) | 30.68±3.33 | | 11.54±3.02 | 8.61±1.65 | 36.43±4.02 |
| P retention (kg $y^{-1}$) | 8.56±1.82 | | 1.97±1.21 | 0.87±1.12 | 7.23±1.94 |
| P excretion (kg $y^{-1}$) | 22.13±2.90 | | 9.57±2.88 | 7.74±2.17 | 29.21±4.04 |
| P apparent efficiency (%) | 27.90±5.73 | | 17.22±11.52 | 10.82±14.46 | 19.94±5.71 |
| $P_2O_5$ release (kg $y^{-1}$) | 50.70±6.63 | | 21.93±6.60 | 17.74±4.97 | 66.93±9.25 |
| $P_2O_5$ excess (kg $y^{-1}$) | 7.44±5.93 | | 13.70±6.65 | 6.41±4.01 | 16.44±8.87 |

[1]LC = Lactating Cows.

[2]DC = Dry Cows.

[3]H = Heifers.

[4]YH = Young Heifers.

[5]CA = Calves.

[6]RU = Replacement Unit.

**Table 7.** Eutrophication potential and reduction in the correlated risk obtainable by adopting mitigation strategies as precision feeding and reduction of CP content of the diet by at least 1% (mean value ± standard deviation).

| | LC[1] and DC[2] | H[3] | YH[4] and CA[5] | RU[6] |
|---|---|---|---|---|
| Actual N net release (kg $y^{-1}$) | 106.92±13.81 | 44.74±6.14 | 34.23±5.48 | 138.68±15.10 |
| Actual $NH_3$ release (kg $y^{-1}$) | 50.56±6.53 | 21.16±2.90 | 16.19±2.59 | 65.57±7.14 |
| Actual P release (kg $y^{-1}$) | 22.13±2.90 | 9.57±2.88 | 7.74±2.17 | 29.21±4.04 |
| Eutrophication potential ($PO_4$ kg $y^{-1}$) | 129.89±14.28 | 54.80±9.79 | 37.82±16.64 | 168.93±14.81 |
| Obtainable N net release (kg $y^{-1}$) | 98.56±13.40 | 41.15±6.01 | 31.55±5.40 | 127.81±14.64 |
| Obtainable $NH_3$ release (kg $y^{-1}$) | 46.61±6.34 | 19.46±2.84 | 14.92±2.55 | 60.43±6.92 |
| Obtainable P release (kg $y^{-1}$) | 16.26±2.91 | 3.90±1.01 | 4.33±1.84 | 22.21±3.32 |
| Eutrophication potential ($PO_4$ kg $y^{-1}$) | 106.86±13.20 | 35.10±2.44 | 33.29±3.56 | 140.92±12.79 |
| Potential Eutrophication reduction (%) | 17.73 | 35.95 | 11.97 | 16.59 |

[1]LC = Lactating Cows.

[2]DC = Dry Cows.

[3]H = Heifers.

[4]YH = Young Heifers.

[5]CA = Calves.

[6]RU = Replacement Unit.