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Eutrophication risk arising from intensive dairy cattle 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 is excreted in urine and faeces, which may cause water eutrophication. The aim of the current study has been to assess the eutrophication risk of dairy production in order to evaluate potential mitigation strategies. A group of 16 dairy farms, which follow an intensive rearing system and are located in the northwest of Italy, was involved in the study. Data pertaining to the general characteristics of the farms, to the diet compositions, feed samples and the livestock productive and reproductive performances as well as information on the management practices were collected to evaluate the N and P feed contents of the diets, the N and P contents of the manure and the apparent N and P utilization efficiency at a herd level and for each category of reared animal (*i.e.*, lactating cows, dry cows, heifers and calves). In order to accurately 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 their phosphate equivalent (PO_4). On the basis of the characteristics of each farm, some common dietary manipulation mitigation strategies, such as the adoption of precision feeding and the reduction of the protein content of the diet, were proposed to evaluate their potential reduction of the excreted nutrients. The results of the feed analysis showed interesting and notable differences from previously reported N and P contents in the diets of dairy cows. The N balance conducted on these farms showed relatively good fitness of the diet for lactating cows, with only a slight deficit in crude protein supplementation (-2%), while the diets for dry cows were slightly more unbalanced for N (+17%). The P balance calculations revealed a large excess of P in the diets of the farms in this study, especially for heifers (+106%). The highest levels of N- and P-use efficiency were found for cows (20 and 28%, respectively), while the lowest ones were found 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 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} of Utilized Agricultural Area per year of PO_4.

1. Introduction

Water eutrophication is a complex phenomenon that involves several physiochemical and biological factors, but which begins from an 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 the 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 a runoff largely determines the degree of 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 the organic fertilizers that are produced in intensive livestock production systems (Ekholm 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

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environmental releases (Directive 91/676 EEC), will rule on other pollutants over the next few years, especially those, such as P, that have effects on the eutrophication of rivers and seas and which can also have consequences on public health (Meschy and Ramirez-Perez, 2005). Nutrient 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 northwest part of Italy (*e.g.* the Piedmont region). Approximately 10% of the national livestock, which is equivalent to about 1 million LUs (livestock units), is raised here, and census data report the presence of approximately 580,000 LU cattle, about 300,000 LU pigs, about 100,000 LU poultry and about 20,000 LUs of others species, especially sheep (ISTAT, 2010). Because of the elevated 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 agricultural area in the Piedmont plain has been designated as vulnerable to nitrate and, since 2011, the EU Commission (Decision 2011/721/EU) has allowed farms derogations to exceed the 170 kg of nitrogen limit, albeit under strict conditions. At that time, dairy cattle farms were among the most problematic in Piedmont, with 266 farms exceeding the limit of 170 kg N ha^{-1}, and with 88 exceeding the limit of 250 kg N ha^{-1} admitted after the derogation (Anagrafe Agricola Regione Piemonte, 2011). In Italy, the Lombardy and Piedmont Regions, again requested further derogations from the EU Commission, which were granted with Decision 2016/1040/EU.

For these reasons, a study was carried out on dairy cattle farms over a homogeneous area (western part of the Po Plain: between 44°08¢33² and 46°08¢13² N, 6°70¢42² and 8°23¢02² E; surface: 13,722 km^2) to collect data from a representative sample of herds. The Holstein breed is prevalent in the considered area, and it is followed by the Brown Swiss breed. These regional farms generally adopt intensive rearing systems, with cows housed in free-standing cubicles without grazing. These systems usually have herd sizes of over 200 heads, with lactating cows (usually over 100), dry cows and replacing animals (AIA, 2016), and the diets are based on corn silage, leguminous and cereals meals and other concentrated feeds. The collected data pertained to the general characteristics of the farms, the productive and reproductive performances of the livestock and the managerial choices, so that the real N and P feed contents, the actual excretion level and apparent utilization efficiency of these nutrients could be evaluated for each different animal category and at a herd level. 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 as heifers and young females, which are often not considered in evaluations of this kind.

The objectives of this study were: a) to evaluate the nutrient surplus and to suggest the best practises among diet manipulation and management solutions that were the most suitable for the farm characteristics, and which 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 (northwest 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. The cows and heifers on all the farms were kept in permanent confinement without pasture grazing, while the replacement animals were reared in groups in pens and all the diets remained unchanged throughout the year.

The number of total cows (TC), lactating cows (LC), dry cows (DC), heifers (H; 12 months to first parity), young heifers (YH; 6–12 months) and calves (CA; 0–6 months) were recorded on each of the 16 farms. The diet composition of each animal group (*i.e.*, LC, DC, H, YH and CA), deriving from management choice, was recorded for each herd, as were 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 new-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}). The mean live weight was the weight used to prepare the diet on the basis of the animals' requirements. The weight gains, which affected the N and P balance by less than 1%, were calculated as LW gain per year (kg y^{-1}) and were obtained by dividing the difference between the real LW at the end of the productive period (the cows were weighed 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 calvings per year (n y^{-1}) and fertility rate (%). The productive and reproductive indices were used to evaluate the possible effects of dietary N and P consumption on cattle performance, and the statistical correlations between the N and P concentrations in the diet and the productive and reproductive parameters were studied.

All the feeds were individually sampled twice on each farm during the trial to determine their nutrient contents. In order to evaluate the true provision of nutrients with the TMR diet, samples were also collected from the feed bunk to determine the N and P contents that were then used as input in the mass balance. All the samples were analysed in a laboratory at 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 an analytical sample (method 950.02); dry matter (DM) content (method 934.01); total ash content (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) content; acid detergent lignin (ADL) content (method 973.18) and P content (method 965.17).

The 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 deficits) derivable from the correct knowledge of the feed characteristics.

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

In order to determine the N and P excretion in faeces and urine, the estimation referred not only to the single categories of animals, but also to a herd level, *i.e.* it was 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 of collecting representative samples of