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# Nutrient balance at chain level: a valuable approach to benchmark nutrient losses of milk production systems

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ABSTRACT

A nutrient balance approach is often used to quantify losses of nutrients, such as nitrogen and phosphorus, that contribute to environmental problems such as eutrophication. A nutrient balance generally is computed at farm level, implying that nutrient losses related to pre-farm processes, such as production of purchased feed, are neglected. Using a nutrient balance at farm level to benchmark livestock systems or individual farms that differ in, for example, amount of purchased concentrates, however, may lead to biased conclusions. To determine whether a nutrient balance that accounts for losses during production of purchased feed (i.e. a chain balance from cradle-to-farm-gate) are more suited to benchmark nutrient losses of milk production systems or individual farms than a nutrient balance at farm level, we analysed 19 Irish grass-based dairy farms and 13 Dutch concentrate-based dairy farms. For each farm, we computed nitrogen and phosphorus losses at farm and chain level (i.e. from cradle-to-farm-gate, including losses from purchased feed production), and expressed these losses per ton fat-and-protein-corrected milk. An independent T-test and Wilcoxon–Mann–Whitney test were used to examine the difference in mean losses at farm and chain level between Irish and Dutch systems. Regression analysis was used to determine if the ranking of the farms changes using a nutrient balance at farm or chain level. Results show that on average, Irish farms had higher nitrogen losses per ton milk than Dutch farms, both at farm (Irish = 20; Dutch = 8 in kg N/ton milk) and chain level (Irish = 22; Dutch = 11 in kg N/ton milk). Phosphorus losses per ton milk, on the other hand, did not differ between Irish and Dutch farms at farm (Irish = 0.3; Dutch = 0.1 in kg P/ton milk) or chain level (Irish = 0.8; Dutch = 1.0 in kg P/ton milk). Regression analysis revealed that the nutrient balance at chain level could be accurately predicted from the nutrient balance at farm level ($R^2 = 0.992$ for N; $R^2 = 0.910$ for P); whereas in case of phosphorus, the slope tended to differ between Irish and Dutch farms ($p < 0.10$). Ranking 32 farms based on the nitrogen balance at farm or chain level, therefore, showed a similar pattern, whereas the ranking pattern based on the phosphorus farm balance differed from the pattern based on the chain balance. We concluded, therefore, that to benchmark nutrient losses of dairy systems, a nutrient balance at farm level can be used if differences in on-farm losses between systems are large, and pre-farm losses related to, e.g. production of purchased concentrates, are relatively unimportant. To benchmark individual farms, a nutrient balance at farm level can be used only if changes in pre-farm losses per unit change in on-farm losses are similar across farms. A chain level balance of a sample set, however, is required to verify these conditions.



## 1. Introduction

The world population is projected to increase from about 7 billion in 2013 to about 10 billion in 2050 (UN report, 2013). Population growth in combination with an improvement of living standards is expected to increase the demand for highly nutritious products, especially animal-source food, such as milk (FAO, 2006).

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The Food and Agriculture Organization of the United Nations (FAO) predicts global consumption of meat and dairy products to increase by 82% between 2000 and 2050, which implies an additional production of 466 million tonnes of milk (Boland et al., 2013).

Sustainable intensification of milk production may provide a possibility to meet this growing demand for animal-source food. Sustainable intensification implies increasing production levels from existing land while reducing the pressure on the environment (Garnett et al., 2013; Mont et al., 2014). Inefficient use of the nutrients nitrogen (N) and phosphorus (P) in agriculture is a main cause of environmental pressure, and might cause problems such as eutrophication, acidification and global warming (Volk et al., 2009; Djekic et al., 2014), but also soil degradation (Sutton et al., 2013).

One common method to quantify the environmental impact of nutrient use is the nutrient balance (NB) approach (Oenema et al., 2003). An NB computes the difference in nutrients entering and leaving a system, and allows computation of environmental indicators, such as nutrient use efficiency (NUE). NUE generally is defined as the amount of nutrients in valuable outputs of a system over the amount of nutrients in all inputs of that system (Nevens et al., 2006). Additionally, an NB yields indicators such as the nutrient surplus of a system expressed per hectare of on-farm agricultural area or per kilogram valuable outputs. An NB of a dairy farming system generally is computed at farm level. The balance of N and P are mostly studied because N and P are two major nutrients that can limit crop growth and losses of N and P can cause environmental problems (Thomassen and de Boer, 2005; Huhtanen et al., 2011; Toma et al., 2013; Dolman et al., 2014). An NB approach at farm level does not incorporate detailed information on material and nutrient flows within a farm, but only quantifies the inputs and outputs of the farm; therefore, it requires relative little data. An NB approach has been used as a valuable approach to provide farmers with farm-specific advice (i.e. identify best practices) (Oenema et al., 2001) and to benchmark environmental impacts of livestock systems (Halberg, 1999; Bengtsson et al., 2003; Powell et al., 2010; Gourley et al., 2012; Toma et al., 2013).

Indicators derived from an NB approach at farm level, however, do not include nutrient losses related to the production of farm inputs, such as purchased concentrates. A farm-specific advice directed at reducing nutrient losses at the farm might affect the type and amount of purchased inputs, and, therefore, nutrient losses related to the production of these inputs. Similarly, comparing the environmental performance of contrasting farming systems based on a farm-based NB may lead to biased results because of differences in farm inputs. Concentrates-based dairy systems, for example, generally purchase large amounts of feed, whereas grass-based dairy systems use mainly on-farm produced feed. Comparing both systems using indicators derived from a farm-based NB may lead to biased conclusions in favour of concentrates-based dairy systems.

An NB that incorporates off-farm activities, such as production of purchased feed, therefore, might be needed to make a fair comparison (Gerber et al., 2014). Although life cycle assessment (LCA) can give a comprehensive evaluation of resource usage and emissions along the entire chain, it appears difficult and time consuming to collect all data required for LCA indicators (Thomassen and de Boer, 2005). The objective of this paper is to examine whether indicators derived from a chain-based (i.e. from cradle-to-farm-gate) NB can provide better insights than a farm-based NB when benchmarking different dairy systems and individual farms. We, therefore, compared indicators from an NB at farm and chain level for 19 grass-based dairy farms (Ireland) and 13 concentrates-based dairy farms (The Netherlands).

## 2. Material and methods

### 2.1. Data

To assess NB indicators of contrasting milk production systems, we used data of farms from Dairyman. Dairyman was a project in the INTERREGIVB program co-funded by the European Regional Development Fund, which aimed to improve regional prosperity through better resource utilization on 113 dairy farms in different European countries and stakeholder cooperation (Dairyman, 2010). The database contains detailed information on farm characteristics, such as production parameters (e.g. milk yield per cow, replacement rate) and type and amount of purchased production inputs, including the nutritional value of feed inputs.

We identified 32 specialised dairy farms from Dairyman and determined indicators for 2010, i.e. 19 farms are from Ireland (grass-based) and 13 farms are from the Netherlands (concentrates-based; see Table 1). We defined specialized farms as farms that have less than 5% non-dairy purpose animals, and less than 10% of their agricultural area in use for non-dairy purpose activities. As indicated in Table 1, Irish farms use more than 80% of their farm area and Dutch farms use more than 70% of their farm area to grow grass. This is in line with the former derogation regulation of the European nitrate directive in 2010 that prescribed that farms with at least 70% (NL) or 80% (IR) grassland can apply maximally 250 kg manure-N per ha per year instead of 170 kg manure-N per ha per year (EU, 2010; European Communities, 2010). In general, compared to the Irish situation, Dutch farms have a higher stocking rate, feed more concentrates per cow, purchase more roughages per cow, and have a higher milk production per cow and per ha of land.

### 2.2. System boundaries

We compared the impact of calculating an NB from cradle-to-farm-gate (chain) or at the farm level, as illustrated in Fig. 1. Inputs included in the NB at farm level were concentrates, roughage, organic fertilizer, mineral fertilizers and atmospheric deposition for N. Outputs included were milk, animals, and crops. The farm itself was considered as a black box. We calculated net inputs or net outputs of products that were both purchased and sold, such as animals. In case the animals output was larger than the animal input, the difference between input and output was considered a net output, whereas in case the animal output was smaller than the animal input, the difference between in-and output was considered as a net input (Godinot et al., 2014). For the case of manure, we subtract manure output from the organic fertilizer input, so when manure output exceeds organic fertilizer input, it was shown as a negative net input instead of a positive net output. Calculating a net in-or output for animals, crops and manure does not affect the NB at farm level. At chain level, however, estimating nutrient losses related to production of animals and manure entering the farm is avoided. Stock changes (defined as final stock of the year 2010 − initial stock of the year 2010) of the concentrates, roughages, animals and fertilizers were included in the computation of NB indicators.

At chain level, the system boundary included all relevant processes from cradle-to-farm-gate, i.e. all on-farm processes as well as the production of purchased feed. The chain level did not include processes after the farm gate (i.e. milk processing, retailing, consumer consumption and disposal stages), because these processes were assumed to be similar for Ireland and the Netherlands, and, furthermore, cannot be influenced by farmer's decisions. Nutrient losses from on-farm processes were adopted from the NB at farm level. For production of purchased feed, we considered nutrient