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Environmental impacts along intensity gradients in Norwegian dairy production as evaluated by life cycle assessments

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ABSTRACT

The aim of the study was to explore whether and how intensification would contribute to more environmentally friendly dairy production in Norway. Three typical farms were envisaged, representing intensive production strategies with regard to milk yield both per cow and per hectare in the three most important regions for dairy production in Norway. The scores on six impact categories for produced milk and meat were compared with corresponding scores obtained with a medium production intensity at a base case farm. Further, six scenario farms were derived from the base case. They were either intensified or made more extensive with regard to management practices that were likely to be varied and implemented under northern temperate conditions. The practices covered the proportion and composition of concentrates in animal diets and the production and feeding of forages with different energy concentration. Processes from cradle to farm gate were incorporated in the assessments, including on-farm activities, capital goods, machinery and production inputs. Compared to milk produced in a base case with an annual yield of 7250 kg energy corrected milk (ECM) per cow, milk from farms with yields of 9000 kg ECM or higher, scored better in terms of global warming potential (GWP). The milk from intensive farms scored more favourably also for terrestrial acidification (TA), fossil depletion (FD) and freshwater eutrophication (FE). However, this was not in all cases directly related to animal yield, but rather to lower burden from forage production. Production of high yields of energy-rich forage contributed substantially to the better scores on farms with higher-yielding animals. The ranking of farms according to score on agricultural land occupation (ALO) depended upon assumptions set for land use in the production of concentrate ingredients. When the Ecoinvent procedure of weighting according to the length of the cropping period was applied, milk and meat produced on diets with a high proportion of concentrates, scored better than milk and meat based on a diet dominated by forages. With regards to terrestrial ecotoxicity (TE), the score was mainly a function of the amount of concentrates fed per functional unit produced, and not of animal yield per se. Overall, the results indicated that an intensification of dairy production by means of higher yields per animal would contribute to more environment-friendly production. For GWP this was also the case when higher yields per head also resulted in higher milk yields and higher N inputs per area of land.

1. Introduction

Food production represents a significant contribution to the global environmental burden, and impacts from ruminant husbandry are of special concern (e.g. Janzen, 2011; Lesschen et al., 2011). The relationship between the production intensity and the environmental impacts per unit of milk and beef produced has recently been widely analyzed and debated in the international scientific literature, mostly in terms of the global warming potential (GWP) of the production (e.g. Crosson et al., 2011; Hermansen and Kristensen, 2011; Weiss and Leip, 2012; Bellarby et al., 2013). When using the cowshed as the system boundary, high yields per animal and high feed efficiency lower the burden (per unit produce) from enteric methane production. However, expanding the boundaries to include also the feed production chains, may change the picture, since large emissions related to the production of energy- and protein-rich feed for the high yielding animals may undermine the benefits of high animal yields. Few recent studies of dairy production have included all processes and inputs to the forage production chain (Baldini et al., 2017).

In life cycle assessment (LCA) studies, emissions related to the

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production and acquisition of all major inputs in a production are normally accounted for, such as the feedstuffs used in dairy production. In LCA and other modelling work based on real farm data, the relation between GWP per unit milk and the production intensity, expressed as the average herd milk yield, appears, however, to be ambiguously negative. Gerber et al. (2011) and Vellinga et al. (2011) found no significant relationship above milk yields of 6000–7000 kg energy corrected milk (ECM) per year and head, and in the study of Bonesmo et al. (2013), the measures were not correlated at all. On the other hand, in a recent LCA of intensive dairy farms in Italy (Guerci et al., 2013), animal efficiency expressed as milk yield per cow and milk production per unit of dry matter (DM) intake, accounted for more than 80% of the variance in GWP in the population of farms. In their study, animal efficiency was clearly separated from farming intensity, expressing livestock units and amounts of milk produced per area farm land, nutrient balances, feed self-sufficiency and N-input from purchased feed. Farming intensity was, in contrast to animal efficiency, not significantly related to GWP. These findings were supported by a study of Dutch farms (Thomassen et al., 2009), in which the authors concluded that high annual milk production per cow and efficient use of feed per kg milk produced at moderate stocking density would be the best option for reducing GWP per kg milk.

The studies by Guerci et al. (l.c.) and Thomassen et al. (l.c.) also covered other impact categories as well as GWP. In brief, their findings showed that animal efficiency was significantly and negatively correlated to environmental acidification, eutrophication and both energy and land use per unit of milk, whereas farming intensity was positively correlated to the acidification and eutrophication burdens. None of these studies included the use of on-farm capital goods in the inventories, and they did not investigate or separate consequences of different forage production strategies as options for intensification.

In a previous LCA of combined dairy and beef production in Norway (Roer et al., 2013), we did include capital goods, and hypothesized that their inclusion would add to the environmental burden associated with the small-scale Norwegian production. The hypothesis was only correct for the toxicity indicators. Here, large (on a per unit produce base) investments in capital goods such as buildings, indoor mechanization and machinery accounted for more than 20% of the environmental burden of milk and meat production. By contrast, these investments accounted for less than 10% of the total impact for GWP, acidification and eutrophication. In terms of intensification, this study of Norwegian dairy farms appeared to support the findings for Italian and Dutch dairy farms, as moderate yields per animal and low forage yields (relative to N-fertilizer inputs) were identified as the two main bottlenecks for the environmental performance (i.e. they affected several impact categories negatively). However, the actual effects of increasing the level of intensity were not tested by Roer et al. (2013). The data gathered from this study did not allow for exploration of effects of intensity in forage production, although they revealed that forage production amounted to 50% or more of the environmental impact score for nine out of twelve investigated categories.

The intensity of Norwegian dairy production, expressed as yearly milk yield per cow has gradually increased over the last decade, to the present average of 7900 kg ECM (TINE Rådgiving, 2014). In some herds with Norwegian Red cattle, average yields up to 12,000 kg ECM per cow (l.c.) are found and single cows have been reported to produce 16,000 kg/year, indicating that there is a genetic potential to increase milk yields on a national basis. Hence, a thorough study is required of the environmental effects of the observed intensification in Norway, which is similar to that found in most comparable countries. It is also of interest to explore and compare the effects of different production strategies, since higher animal yields may be obtained by a range of means, including different combinations of feed, concentrates and several other factors.

In the present study, we explore whether and how the intensification of Norwegian dairy production, in terms of higher animal yields, may contribute to more environmentally friendly production, using recently improved LCA methodology (Goedkoop et al., 2012). We have envisaged farms representing intensive production strategies in three regions of the country, and included all capital goods and machinery investments regarded as necessary in a cost-effective and modern production with a long indoor housing season. Further, we have constructed and analyzed scenario farms, which are either intensified or extensified through management principles and options that we regard as likely to be implemented under northern temperate conditions, with similar farm size and structure as that found in Norway. In all these comparisons, we have used as base case a medium/normal intensity level dairy farm envisaged and analyzed in the previous study (Roer et al., 2013).

2. Materials and methods

2.1. Case description

Three farms representing intensive combined milk and meat production were selected from a defined population for further inventory and analysis. The basis and procedure for the definition and selection process have been outlined in Section 2.2. The farms were located in the counties Rogaland ('southwest intensive'; SWI), Oppland ('central southeast intensive'; CSEI) and Nord-Trøndelag ('central intensive'; CI). Figures for farm and herd characteristics, inputs and outputs have been listed in Table 1, and a brief description of farming practice and feeding strategies follows below. Further details are available in the Supplementary material section. The medium intensity farm serving as base case (BC) in the present study was one out of three modelled farms that have previously been described in detail by Roer et al. (2013). BC was located in central Norway, and was representative for the population of combined milk and meat production farms in this region with forage as the only plant production. This population constituted about 30% of the total number of dairy farm units. For farm and herd size, the grant data base of the Norwegian Agricultural Agency (2010) supplied the source statistics. Figures from the Norwegian dairy cooperative (TINE), representing more than 90% of the dairy farms in the region, were used to establish animal yields, diet composition of the dairy herd, culling ratio and fertility. Table 1 contributes figures for farm and herd characteristics and inputs and outputs at BC, and Section 2.4 outlines small modification of the assumption made in Roer et al. (2013)

Most of the forage at the intensive farms and at BC was harvested from leys dominated by perennial ryegrass and/or timothy and meadow fescue. Mown herbage was wilted before ensiling. At CI, all silage was preserved in round bales, whereas only 50% at CSEI and 33% at SWI. The rest was ensiled in tower silos. The average transport distances between fields and barns were 1, 2 and 3 km at SWI, CI and CSEI, respectively.

The manure produced by housed animals was spread on the farm fields, some of it on bare soil before reseeding, and the rest on established grass crops in spring and after succeeding cuts, except after the last cut.

The herds comprised freestall-housed dairy cows of the Norwegian Red breed and their offspring. Number of cows in the herds was expressed as cow-equivalents, i.e. the summarized number of cow days within/throughout a year, divided by 365. Each cow-equivalent produced 1.0 (CSEI) or 1.06 (CI, SWI) living calves (50% male) annually. At CI and SWI, all heifers were recruited to the dairy herd, whereas at CSEI 16% were slaughtered at an age of 20 months. All male offspring were housed on-farm for their entire lifetime.

Mixed concentrates were fed to all animal groups in addition to silage and pasture grazing. For simplification, we assumed that all diets were composed according to the 2013 recipes of Felleskjøpet Agri, Norway (Table 2). At BC, cows were fed FORMEL Favør 80® (F80), at CI and SWI they were fed FORMEL Energi Basis 90® (E90), and at CSEI they were fed FORMEL Energi Basis 80® (E80), whereas heifers and bulls received F80. Young calves were fed a total of 350 kg each of milk