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Impact of subclinical mastitis on greenhouse gas emissions intensity and profitability of dairy cows in Norway

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ABSTRACT

Impaired animal health causes both productivity and profitability losses on dairy farms, resulting in inefficient use of inputs and increase in greenhouse gas (GHG) emissions produced per unit of product (i.e. emissions intensity). Here, we used subclinical mastitis as an exemplar to benchmark alternative scenarios against an economic optimum and adjusted herd structure to estimate the GHG emissions intensity associated with varying levels of disease. Five levels of somatic cell count (SCC) classes were considered namely 50,000 (i.e. SCC50), 200,000, 400,000, 600,000 and 800,000 cells/mL (milliliter) of milk. The effects of varying levels of SCC on milk yield reduction and consequential milk price penalties were used in a dynamic programming (DP) model that maximizes the profit per cow, represented as expected net present value, by choosing optimal animal replacement rates. The GHG emissions intensities associated with different levels of SCC were then computed using a farm-scale model (HolosNor). The total culling rates of both primiparous (PP) and multiparous (MP) cows for the five levels of SCC scenarios estimated by the model varied from a minimum of 30.9% to a maximum of 43.7%. The expected profit was the highest for cows with SCC200 due to declining margin over feed, which influenced the DP model to cull and replace more animals and generate higher profit under this scenario compared to SCC50. The GHG emission intensities for the PP and MP cows with SCC50 were 1.01 kg (kilogram) and 0.95 kg carbon dioxide equivalents (CO_2e) per kg fat and protein corrected milk (FPCM), respectively, with the lowest emissions being achieved in SCC50. Our results show that there is a potential to reduce the farm GHG emissions intensity by 3.7% if the milk production was improved through reducing the level of SCC to 50,000 cells/mL in relation to SCC level 800,000 cells/mL. It was concluded that preventing and/or controlling subclinical mastitis consequently reduces the GHG emissions per unit of product on farm that results in improved profits for the farmers through reductions in milk losses, optimum culling rate and reduced feed and other variable costs. We suggest that further studies exploring the impact of a combination of diseases on emissions intensity are warranted.

1. Introduction

The dairy sector contributes approximately 40% of agricultural greenhouse gas (GHG) emissions in Norway, producing around 1.9 million tonnes (t) of carbon dioxide equivalent (CO_2e) emissions every year (Sandmo, 2014; Statistics Norway, 2016). The projected human population growth and the increased demand for food production by at least 20% by the year 2030 in Norway are likely to result in increased GHG emissions from the agricultural sector. Therefore, the Norwegian Ministry of Agriculture and Food requires reducing the agricultural emissions by 20% from GHG emissions levels measured in the year 1990 by the year 2020 (Climate and Pollution Agency, 2013). In order to meet the expected extra food production and yet reduce the GHG emissions from dairy cows, minimum use of inputs is required for a

Abbreviations: ARmilk, allocation ratio milk; BMR, beef milk ratio; C, carbon; CH_4, methane; CM, clinical mastitis; CO_2, carbon dioxide; CW, carcass weight; DM, dry matter; DMI, dry matter intake; DP, dynamic programming; ENPV, expected net present value; FPCM, fat and protein corrected milk; GHG, greenhouse gas emissions; IPCC, Intergovernmental Panel on Climate Change; kg CO_2e, kilogram carbon dioxide equivalents; mL, milliliter; MJ, megajoules; MP, multiparous; NE, net energy; NEA, net energy for activity; NEL, net energy for lactation; NEM, net energy for maintenance; NEP, net energy for pregnancy; N_2O, nitrous oxide; NOK, Norwegian krone; PP, primiparous; SCC, somatic cell count; SCM, subclinical mastitis

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given level of milk output i.e. improved production efficiency (Place and Mitloehner, 2010). Poor animal health and welfare conditions that often lead to clinical and subclinical diseases may result in reduced production efficiency through increased mortality (Ersboll et al., 2003), reduced milk yield (Bareille et al., 2003), reduced reproductive performance (Bennett et al., 1999), and increased animal replacement rates (Weiske et al., 2006), all of which have the potential to increase the GHG emissions produced per unit of product (i.e. emissions intensity) (Place and Mitloehner, 2010). Therefore, it has been argued that if animal health and welfare are improved, there is potential to reduce the intensity of GHG emissions and increase productivity, increase farm income, reduce losses and therefore improve farm profitability (Stott et al., 2010; Williams et al., 2013).

Bovine mastitis is an endemic disease of mammary glands and may be responsible for a substantial proportion of the total production losses in dairy herds (Barkema et al., 2009). It has also been recognized as one of the most intractable health conditions in cows (Skuce et al., 2016), therefore an impediment to perform an efficient and sustainable livestock production. The losses associated with bovine mastitis include reduction in milk yield, discharge of contaminated milk due to treatment with antibiotics, treatment losses and increases in mortality and replacement rates (Geary et al., 2012). If the disease occurs in the form of subclinical mastitis (SCM), no visible signs may be found in the udder or milk (International Dairy Federation, 2011). Milk from cows with SCM is characterized by increased lipolysis, proteolysis, rancidity and bitterness (Ma et al., 2000) and reduction in milk yield (Halasa et al., 2009). The reduction in milk yield and quality related to udder health are commonly calculated by somatic cell count (SCC) (Bartlett et al., 1990). The International Dairy Federation (2013) reports that the level of SCC in cows suffering from SCM is greater than 200,000 cells/mL (milliliter). Although some studies reported that SCM causes increased SCC, impairs milk composition (Gonçalves et al., 2016; Bobbo et al., 2017) and milk yield (Botaro et al., 2015), their impacts on the environment have not been questioned widely. Integrated modelling approaches combining different models provide a thorough assessment of the livestock production systems studied and facilitate the decision-making process (Özkan Gülzari et al., 2017). In this study, we aimed to assess the changes in GHG emissions intensity and economic performances associated with raised SCC in relation to changes in milk yield, feed intake and replacement rates. For this purpose, an optimization model along with a GHG calculating model (HolosNor) were used. A dynamic programming (DP) model that maximizes the long-run profit of a dairy herd by optimizing future culling and replacement decisions was used to inform the GHG calculating model about the optimum composition of the herd in terms of the age and production levels of the cows in herd under different SCC challenges.

2. Materials and methods

In this study, we combined two models, one DP model for replacement decisions, and one GHG model (HolosNor) to calculate the emissions associated with varying levels of SCC. Fig. 1 shows the relationship between the two models, their input-output interactions, and the inputs that were estimated. Circle shapes refer to the model outputs while rectangular shapes describe the inputs. Optimum culling strategies, one of the outputs of DP, were used as an input in HolosNor. Most of the equations in both models were adapted from previously published papers (Stott et al., 2002; Stott et al., 2005 for the DP model; and Bonesmo et al., 2013 for HolosNor model) and the parts where both models shared the same input to be representative for the Norwegian conditions; or used each other's input/output were deemed novel to the current study.

The DP model uses revenues from milk yield and sold calves as well as fixed costs of feed production and variable costs for cows in each parity and SCC category to estimate the profit. It then optimizes the keep or replacement decisions and determines the culling rates and therefore the proportion of animals in each parity and SCC categories that generate the maximum profit in the long term. The estimated proportion of animals in each parity and SCC categories are then used in the HolosNor model to calculate GHG emissions intensity. Following sections describe data, assumptions and details of the processes adapted in the DP and HolosNor models.

2.1. Herd characteristics and some key management data of the modelled farm

The modelled farm that comprises of individual dairy cows, except for milk production, concentrate intake and replacement rates, reflects an average Norwegian dairy farm based on the data originally reported by Bonesmo et al. (2013) from an inventory of 30 farms located all around Norway and those reported by TINE Advisory Services (2012, 2014) (Table 1). Input values for fuel and electricity consumption were as described by Bonesmo et al. (2013).

2.2. Inclusion of SCC levels in models

Five scenarios of SCC levels in milk were defined. Cows with a SCC level of 50,000 cells/mL milk and below were considered uninfected (Laevens et al., 1997). Since International Dairy Federation defines the level of SCC in milk of cows with SCM as above 200,000 cells/mL milk (International Dairy Federation, 2013), we assumed that there was no reduction in milk production in cows with SCC levels less than 200,000 cells/mL milk (named as “SCC50”) (see also Svendsen and Heringstad, 2006). Reductions in milk yield were calculated for the following scenarios of SCC levels in milk: SCC levels at 200,000 cells/mL (named as “SCC200”); SCC levels at 400,000 cells/mL (named as “SCC400”); SCC levels at 600,000 cells/mL (named as “SCC600”); and SCC levels at 800,000 cells/mL milk (named as “SCC800”). It was assumed that the average milk yields in Table 1 reflect a SCC level of less than 200,000 cells/mL (at the assumed fat and protein contents of milk of 4.12% and 3.40%, respectively). All levels of SCC were set at individual cow level, which was used to scale it up to herd level of 25 cows per farm. It is acknowledged that an individual cow's cell count varies from one milk recording to the next, and even from week to week as some cows recover and others become infected. Because we did not intend to cover the dynamics of the disease at an individual animal level, but instead meant to determine the overall possible financial and environmental impacts of the disease at herd level, it was deemed sufficient to set the SCC level at individual cow level.

Milk yield losses associated with different levels of SCC were calculated at single point level for each scenario e.g. milk losses associated with SCC200 scenario were calculated for SCC level of 200,000 cells/mL. Elevated SCC level of 200,000 cells/mL and above was assumed to be due to SCM. Possible cases of clinical mastitis (CM) were not included in this analysis. Milk losses due to increased SCC were calculated by deducting the milk production of cows with elevated SCC levels from the milk production of cows with SCC50 during a 305-day lactation period. The amount of milk delivered on farm was assumed to be 93.3% of that produced (TINE Advisory Services, 2014) as the rest is assumed to be discharged due to use of antibiotics or used for feeding calves.

Milk yield of cows with SCC50 were provided by TINE Advisory Services and it reflects years between 2009 and 2013 (TINE Advisory Services, 2014). For lactation numbers from 10 to 12, there were no data available after the year 2000. Therefore, we used an average milk yield of data available for 1999 and 2000 for lactation 10 and above. The milk loss associated with different levels of SCC was calculated using the mathematical formula used by TINE Advisory Services based on Hortet et al. (1999) below (Eq. (1)). Losses were calculated as a percentage. Note that the milk loss associated with different SCC levels for lactation six and onwards was calculated based on the assumption that the reduction remained constant after lactation five. The formula reflects first lactation and equations for the 2nd, 3rd, 4th and 5th