Impact of grass silage quality on greenhouse gas emissions from dairy and beef production

Running title: Silage quality and GHG emissions

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Abstract

High quality grass silages may represent a mitigation option by reducing enteric methane production and by increasing productivity, thus reducing greenhouse gas emissions per kg of product (emission intensity). Two previous studies found considerable effects of three different silage qualities cut at different maturity stages (very early (H1), early (H2) and normal (H3)) offered ad libitum with various levels of concentrate supplementation, on animal performances of growing/finishing bulls and dairy cows in early lactation, indicating that emission intensities may also vary. Based on results from these previous studies, the aim of this study was to estimate emission intensities for milk and beef carcasses for the included combinations of silage qualities and concentrate levels, by using the farm-scale model HolosNor. The emissions intensities were lowest for the H1 silage, and highest for the H3 silage, independent of concentrate levels for both milk and beef. Thus, increasing concentrate levels did not compensate for lower grass silage quality. Improvements in silage quality from H3 silage to H2 is realistic and has the potential to reduce emission intensities with approximately 10% while keeping the milk yield per cow constant and reducing the use of concentrates considerably. For beef production the potential is even larger, with a reduction in emission intensity of approximately 17%. We conclude that improving grass silage quality may be a mitigation option that will also reduce the dependence on concentrates.

Keywords: greenhouse gas emissions, grass silage quality, dairy production, beef production, farm scale models; emission intensity

1 INTRODUCTION

Grasslands are an important land use in Europe, and permanent grasslands cover about 8% of the land area and 35% of the agricultural area, with large geographical variations (Smit et al., 2008). Grasslands are especially important (i.e., proportion of permanent and temporary grasslands of total agricultural land >50%) in parts of Western Europe (the Netherlands, Luxembourg, Ireland, Scotland and Wales), the mountainous areas of Central Europe (Austria, Montenegro, Slovenia and Switzerland), the Mediterranean area (Greece, Macedonia, Bosnia and Montenegro), the Caucasus (Georgia and Azerbaijan) and Northern Europe (Iceland and Norway) (Smit et al., 2008). In the latter, climate and topography restrict areas suitable for agriculture, crop production especially (FAO, 2012). In the Nordic countries, agricultural land area is only 9% of the total land area, of which 38% is used for grain production (country-specific values ranging from 0% on Iceland to 56% in Denmark). Meadows and pastures covers 48% of the agricultural area, ranging from 30% in Finland to 98% in Iceland. Even so, the use of these grass resources has decreased during the last decades, and the use of concentrates for ruminants is substantial and increasing (Åby et al., 2014). However, expected human population growth, climate change that may lead to more challenging production conditions resulting in reduced yields for important food and feed crops in tropical and temperate regions, and increased competition with other land use, such as biofuels and urban expansion, may pose risks to global food security and limit the availability of grains for animal feeds (IPCC, 2014; FAO, 2006; Nordic Statistics, 2016). Thus, production systems for ruminants which is mainly based on grass and less dependent on concentrates may be of importance for maintaining a high degree of self-sufficiency in many regions.

Grass silage is the main winter feed for both dairy and beef production in Norway (Randby et al., 2010). There is a potential to improve grass silage quality, here defined as grass silage nutritive value, which is mainly obtained by cutting the grass at an earlier maturity stage (Harrison et al., 1994). This may increase net energy intake from grass, thus obtaining increased productivity, for example higher milk yield per cow and growth rates of fattening bulls, while decreasing the use of concentrates.

The effects of varying grass silage qualities and levels of concentrate supplementation on feed intake and performance of growing/finishing dairy bulls and dairy cows in early lactation was investigated by Randby et al. (2010, 2012). These authors used three grass silage qualities (denoted H1, H2 and H3, where the maturity stage at harvest corresponded to very early, early and normal maturity stage, respectively) offered *ad libitum* with different levels of concentrate supplementation. Maturity stage at harvest was found to correlate with grass silage quality, and a variation from 6.75 MJ net energy/kg DM for the very early maturity stage to 5.52 for the normal maturity stage was found. Animal performances varied considerably between treatments, demonstrating the effects of improved grass silage quality. For example, dairy bulls were finished before 15 months of age on H1 silage. Average daily milk yield during lactation week 1-16 was highest using H1 silage with 8 kg concentrates (32.8 kg energy corrected milk (ECM)), however relatively high yield was obtained solely on this silage (H1; 23.4 kg ECM). H3 silage led to a maximum of 30.1 kg ECM, when supplemented with the optimal level of concentrate, 12 kg. Corresponding grass silage DM intake for the treatments were 16.7, 16.9 and 11.9 kg, respectively.

Greenhouse gas (GHG) emissions from ruminants are important to consider due to its effects on climate change (FAO, 2006), and mitigation strategies to reduce the environmental impact are of high interest. Several nutritional strategies have been suggested to reduce methane emissions (Beauchemin et al., 2008). Hristov et al. (2013a) proposed improving forage quality as one of the most efficient ways of decreasing CH_4 emissions, through increased production efficiency thereby diluting the maintenance energy requirement and reducing the number of animals needed to produce the same amount of product (Boadi et al., 2004; Hristov et al., 2013b). Improving forage quality may reduce enteric methane production due to lower fibre and/or higher soluble carbohydrates content. Improved forage quality may also increase voluntary intake, reducing the retention time in the rumen and reducing the proportion of dietary energy converted to methane (Eckard et al., 2010). On the other hand, cutting grass at an early maturity stage reduces the dry matter (DM) yield, which may increase the need for grassland areas (e.g., Kuoppala et al., 2008) and thereby increase the use of fertilizers, leading to higher N_2O emissions, and increased use of fossil fuels. Thus, when looking into mitigation options, it is crucial to use a whole farm approach, to ensure that emissions do not increase elsewhere in the production chain as pointed out by Eckard et al. (2010).

The considerable effects of improved grass silage quality on animal performances found by Randby et al. (2010) and Randby et al. (2012), gives reason to believe that emission intensities (GHG emissions per product; milk and finished young bull carcass) may also vary. Thus, the objective of this study was to investigate if improved grass silage quality reduces emission intensities by using the results from these studies for the included combinations of grass silage qualities and concentrate levels as inputs in the farm scale model HolosNor (Bonesmo et al., 2013) to calculate emission intensities for both milk and beef carcass.

2 MATERIALS AND METHODS

Emission intensities for milk and young bull carcass were calculated based on the results from the feeding experiments of Randby et al. (2012) and Randby et al. (2012), and a short summary of the studies are given below (section 2.1 and 2.2). In addition, several assumptions were made in order to do the calculations in the HolosNor-model, described in section 2.3.

2.1 Grass silages used

The two studies were performed simultaneously in the same barn with the same feeds. Five leys used for silage preparation were sown with the same seed mixture, consisting of 50% timothy, 35% meadow fescue and 15% red clover. All swards were fertilised 26.-27. April with 69 kg N, 13 kg P and 33 kg K/ha. Each ley was divided into three parts, consisting of approximately 50%, 30% and 20% of the area, for harvesting at the three different maturity stages/harvesting dates, respectively: 30 May to 1 June (H1), 6-8 June (H2) and 14-16 June (H3), corresponding to 6.75, 6.26 and 5.52 MJ net energy lactation/kg grass silage DM, respectively. Compared to Norwegian practice, H1, H2 and H3 corresponds to harvesting at very early, early and normal maturity stages for timothy, respectively. The silage DM yield per ha were 3,350, 5,210 and 6,250 kg for H1, H2 and H3, respectively.

2.2 Animal performances

The three grass silage qualities were fed to Norwegian Red dairy cows during early lactation, 2-3 weeks before expected calving date to week 16 in lactation (Randby et al., 2012) and to growing finishing Norwegian Red bulls from age 7 months until slaughter (Randby et al., 2010).

2.2.1 Dairy cows

Cows were held in a 3 x 3 factorial arrangement with the three grass silage qualities supplemented with three levels of concentrates (4, 8, 12 kg/day, denoted C4, C8 and C12). In addition, H1 was offered as a sole feed and H3 with 16 kg of concentrates/day, giving in total 11 diets studied. The dietary treatments are denoted H1C0, H1C4, H1C12,……H3C16. From the observed average daily milk yield in week 1-16 by Randby et al. (2012), 305-days yields (Table 1) was approximated by comparing the average daily milk yield in week 1-16 from the standard lactation curve as used by the Norwegian dairy cooperative TINE SA:

$$Kg\ FPCM_{DIM} = 0.993 + (0.00312 * 305yield - (0.0984 * DIM) + \big(LN(DIM * 3.726)\big))$$

Where FPCM is fat- and protein-corrected daily milk yield, DIM is days in milk (1,2….305), 305yield is 305-day milk yield in kg, LN is the natural logarithm

The milk composition (fat and protein %) for the included grass silage qualities and concentrate levels was as found by Randby et al. (2012) (Table 1).

2.2.2 Growing/finishing bulls

All bull calves were given hay and grass silage *ad libitum*, 4-8 l acidified milk during the first 3 months, and up to 1.5 kg of concentrates per day. Average daily growth rate pre experiment was 1,036 g. From age 7 months, bulls were divided into six groups and given the three grass silage qualities *ad libitum* as a sole feed, or with a daily supplementation of 2 kg concentrates, increasing to 3 kg at 385 kg live weight (LW) and 4 kg at 500 kg LW. The bulls were slaughtered at approximately 575 kg LW. Age at slaughter, LW and total concentrate consumption for the included combinations of silage qualities and concentrate levels are given in Table 2.

2.3 Calculation of greenhouse gas emissions using HolosNor

Emissions intensities, kg CO_2-equivalents per kg FPCM or finished young bull carcass, for the three grass silage qualities and concentrate levels were calculated using the farm scale model HolosNor (Bonesmo et al., 2013). This model estimates GHG emissions from dual-purpose milk and beef production systems and considers the direct and indirect emissions of CH_4, N_2O and CO_2 from direct and indirect sources. The direct emissions result from on farm livestock production activities such as enteric fermentation and production of roughage, while the indirect emissions are from inputs used on farm such as fuel and fertilisers, and nitrate leaching and volatilization. In addition, soil C changes are estimated (Bonesmo et al., 2013). Enteric methane emissions in kg are calculated on the basis of an IPCC Tier 2 approach. Gross energy (GE, MJ) is multiplied by the methane conversion factor (Ym, proportion of methane of total GE intake) divided by the energy content of methane (55.64 MJ/kg) (Bonesmo et al., 2013). Gross energy intake is calculated from the net energy requirements (IPCC, 2006; NRC, 2000; NRC, 2001) for all animal groups and taking into account the energy density of the diet. HolosNor adjusts Ym to account for the digestibility of the dietary dry matter (DM) where $Ym = 0.1150 - 0.0008 \times DE\%$ (Bonesmo et al., 2013). For example, Ym values of 5.8, 6.1 and 6.6%, were calculated for the H1, H2 and H3 silage, all supplemented with 4 kg concentrates, respectively. Farm characteristics used as inputs in HolosNor were from various sources, described below. Animal performances were based on Randby et al. (2010) and Randby et al. (2012) as described above. Weather and soil data used were from Ringsaker municipality

(Skjelvåg et al., 2012), an important dairy region in the Eastern parts of Norway. In order to compare the different treatments at the same level of milk production, a target milk production on farm was determined based on the current average herd size in Norway (26 cows), and an average milk yield of 7,100 kg ECM per cow and year (Statistics Norway, 2016). The number of dairy cows needed to fulfil this target for all treatments were calculated based on the 305-days yields in Table 1. HolosNor requires input on the time spent on pasture for dairy cows and heifers, however as the data from the experiments did not include grazing, time spent on pasture was set to zero. The ley areas needed for all treatments (Table 3) was estimated based on the total grass yield per ha, and the total grass silage requirement for all animal groups. Total grass yields were calculated assuming two cuts for the H3 quality, and three for H1 and H2 (Bakken et al., 2009). Based on the results from a large field study (Bakken et al., 2009) it was assumed that yields for the second and third cut for H1 was 90 and 74% of the first cut, while it was 56 and 48% for H2. For H3, yield of the second cut was assumed to be 78% of the first cut. Thus, the total silage yield for H1, H2 and H3 was 8,860, 10,620 and 11,120 kg DM/ha, respectively. Grass silage requirements was calculated by HolosNor on the basis of net energy requirements (IPCC, 2006; NRC, 2000; NRC 2001), as functions of herd specific data such as animal performances and the number of animals in all groups, after subtracting the energy intake from concentrates (Table 3). Concentrate use was calculated separately and was an input into the model. Total concentrate consumption for dairy cows was calculated as the total feed requirements as a function of milk yield (Volden, 2013) corrected for the observed grass silage intake by Randby et al. (2012). For growing fattening bulls, concentrate consumption from age 7 months to slaughter was given by Randby et al. (2010). In addition, it was assumed a concentrate consumption of 228 kg DM per bull before 7 months of age, based on the feed recommendations of Berg & Matre (2007). Concentrate net energy value was 6.56 MJ per kg DM. The emission intensity for purchased concentrate was calculated from the amount of grains (barley produced off-farm) and imported soybean meal needed to supply the energy and crude protein used. Emission intensities for barley and soy bean meal was, 0.62 and 0.93 kg CO_2-eq/kg DM, respectively. Land use change was not included in these figures (Bonesmo et al., 2013). Estimates of soil C change were based on the Introductory Carbon Balance Model (ICBM) (Andrén et al., 2004). The ICBM model estimates the change in young and old soil C from total C inputs (sum of C in plant residues and manure), a humification coefficient, two decay constants and the relative effect of soil moisture and temperature. Fertiliser use for all silage qualities and cuts was 69 kg N per ha (Randby et al., 2010). A dairy cow replacement rate of 30% (TINE, 2013) was used and the number of finished young bulls was 0.57 per cow and year (calculated as a function of average values for slaughter age of cow, age at first calving, calving interval and calf losses) (TINE, 2013). Average live weight of dairy cows was 539 kg and barn electricity consumption per cow was 1,720 KWh (Bonesmo et al., 2013). To allocate emissions between meat and milk, a physical allocation method which reflect the underlying use of feed by the animals to produce milk and meat, was used (Bonesmo et al., 2013).

To calculate the effect of varying grass silage quality on total greenhouse gas emissions from the cattle population (dairy and suckler), the current Norwegian production levels of 1,500 million liters of milk and 80,000 tons of beef (Åby et al., 2014) and the emissions intensities from HolosNor was used. In order to limit the number of combinations of various grass silage qualities and concentrate levels for milk and beef, two contrasting ones were chosen: H1C8 (highest yield) vs. H3C4 (low yield constrained by high dietary fiber concentration), combined with the two levels of concentrate use in beef production. In addition H1C0 was included, to investigate the effects of a completely grass silage-based system. Beef originating from the dairy population was calculated from the number of dairy cows needed to meet the production level of milk as a function of the 305-day yield (Table 1) and an annual beef production of 250 kg carcass per cow (Åby et al., 2016). Annual beef production per cow was calculated based on average lifetime of cows, age at first calving, calving interval, calf loss and carcass weights for young bulls, heifers and cows from slaughter statistics. A calve sex ratio of 1:1 was used. One heifer calve was assumed kept as replacement. The discrepancy between the total production level for beef and the beef production from the dairy population was assumed to be from suckler cows. The emission intensity of suckler beef was assumed to be 25.5 kg CO_2-equivalents per kg beef carcass, and annual beef production per cow was 277 kg (Åby et al., 2016).

3 RESULTS

3.1 Emission intensities for milk

The lowest emission intensity was found for H1C8, but with very minor differences with H1C4 (+0.001 kg CO_2-equivalents per kg FPCM), while the difference with H3C4, the treatment with the highest emission intensity, was 0.252 kg CO_2-equivalents (Figure 1). Moderate amounts of concentrate supplements, up to 8 kg per day with H1 and H2 and 12 kg per day with H3, reduced the emission intensity within grass silage quality. By contrast, the highest concentrate level within all silage qualities, 12 kg for H1 and H2 and 16 kg for H3, increased the emission intensity, but was still less than the lowest concentrate level (0, 4 and 4 kg, respectively) (Figure 1). Even so, emissions intensities were lowest for the H1 silage, and highest for the H3 silage, independent of concentrate levels. For example, the emission intensity for H1 silage with 4 kg of concentrates was lower than the H2 silage with 8 kg of concentrates and H3 silage with 12 kg concentrates. The combination H1 silage with no concentrates also had a lower emission intensity than all concentrate levels within the H2 and H3 silages.

The effects of improved grass silage quality was larger when going from the H3 quality to H2 than from H2 to H1. For example, there was a 0.14 kg CO_2-equivalents/ kg FPCM reduction from H3C4 to H2C4, while the reduction from H2C4 to H1C4 was 0.11 kg CO_2-equivalents (Figure 1).

The most important emission sources per kg FPCM (Figure 2) were CH_4 from enteric fermentation, CH_4 and N_2O from manure and N_2O from soils, included indirect emissions from leaching and volatilization. H3C4 resulted in higher emissions from enteric fermentation and manure, compared to H1C8 (Figure 2). There were small differences for soil N_2O and CO_2 from feed production and energy use between the two treatments, while soil sequestration was higher for H3C4 (Figure 2).

3.2 Emission intensities for finished young bull carcasses

The highest emission intensity resulted from H3 without concentrate supplementation, while a 35% lower emissions intensity from H1 with concentrates was the lowest (Figure 3). For H1 and H2, the effect of concentrate supplementation was small, only a 0.25 and 3% reduction in the emission intensity, respectively, but for but for H3 reduction was 14%. The effect of improved roughage quality was largest from H3 to H2 without concentrates, with a reduction of 4.2 kg CO_2-equivalents per kg finished young bull carcass. In comparison, the difference between H2 and H1 without concentrates was 1.4 CO_2-equivalents per kg finished young bull carcass. The emission intensity for H1 without concentrates was 9% lower than H2 with concentrates.

3.3 Total emissions

The number of dairy and suckler cows needed in order to meet the domestic production targets for milk and beef for the included grass silage qualities and concentrate levels differed considerably (Figure 4). H1C0 had the lowest need for suckler, while H1C8 had an additional need of 103,396 suckler cows in order to meet the beef production target. The lowest annual total GHG emission was obtained from the combination of H1C0 in the dairy production with H1 with concentrate supplementation for bulls, while the highest was from the H3C4 in dairy production and H3 without concentrates for bulls, a difference of 788,772 tons CO_2-equivalents (Figure 5).

4 DISCUSSION

4.1 Grass silage quality, productivity, fertilizer use, area availability and profitability

The superior grass silage quality (H1) gave the highest productivity (Randby et al., 2012; Randby et al., 2010) and resulted in the lowest emission intensities in both dairy and beef production independent of concentrate levels, as argued by Hristov et al. (2013a). Increasing the concentrate level could not compensate for lower grass silage quality. For example, a milk yield per cow of approximately 7,000 kg was obtained on H3 with 12 kg concentrates, H2 with 8 kg concentrates and H1 with 4 kg concentrates, while the emissions intensities were 0.943, 0.853 and 0.758 kg CO_2-eq., respectively. Similarly, a yield of approximately 6,300 kg per cow was obtained with H3 with 8 kg concentrates or H2 with 4 kg concentrates. The emissions intensities was 0.975 and 0.873, respectively. A realistic improvement from the average Norwegian grass silage quality, which corresponds to the H3 silage, to H2 could thus reduce the emission intensity by approximately 10%. At the same time, this will reduce the concentrate use and increase the grass silage consumption (Table 3). Similarly, for young bull carcass, the emission intensity may be reduced by approximately 17% when going from the H3 silage with concentrates to H2 without concentrates. This indicates that improving grass silage quality may be a potential mitigation option, while at the same time giving the opportunity to reduce the use and dependence on concentrates, without reducing animal performance.

To the authors’ knowledge, no other studies have estimated emission intensities using farm scale models based on results from feeding experiments. However, studies using life cycle assessments (LCA) have demonstrated diminished emission intensities with increasing animal productivity both in dairy (e.g., Casey & Holden, 2005; Gerber et al., 2011) and beef production (e.g., Capper, 2011; Wiedemann et al., 2015). Beauchemin et al. (2011) investigated the mitigation potential in improved forage quality for a breeding stock of beef cattle during the winter in a simulation study using a farm model LCA. Thus, in contrast to our study, the effect of forage quality on emissions from fattening animals were not considered. The authors assumed in their calculations that an earlier harvest date decreased grass yield (10% reduction), increased DM digestibility and decreased Ym, similar to our approach.

The lower grass yields of earlier harvested grass silage may be a challenge from a practical point of view, as the farmer is dependent on a sufficient amount of grass silage for the long indoor feeding season, which is approximately 8 months in Norway. Even so, there is a large potential to increase yields through improved grassland management and agronomical practices, and the grassland yield potential ranges from about twice the current yield in the central and southwestern parts of Norway to 3.5 times in northern Norway (Bakken et al., 2014; Steinshamn et al., 2016).

In this study, it was assumed that the same grass silage quality was obtained for all subsequent cuts. This is of course a simplification and the grass silage quality of the subsequent cuts may vary according to factors such as weather conditions, cutting regime etc. (Bakken et al., 2009). The results are valid, however, to demonstrate the mitigation potential of improved grass silage quality.

For simplicity, a fertilizer application of 69 kg N per ha for all cuts and grass silage qualities was used in our calculations, even if N application is usually higher for the first cut (Bakken et al., 2009). This gave a total N application of 207 kg N per ha for H1 and H2 (three annual cuts), and 138 kg N for H3 (two annual cuts). This is lower than the recommendations of Yara (2018). The average annual fertilizer application on grasslands in Norway is 177 kg N per ha, but is higher (208 kg N per ha) for dairy farms, according to Bye et al (2016). In the studies of Bakken et al. (2009), high grass silage qualities for the first cut corresponding to H1 were obtained on a lower fertilizer level of 120 kg N per ha, however the total yield was 10-15% lower compared to a fertilization level of 240 kg per ha. The assumptions on N application is obviously important as it determines the N_2O emissions from soils. The N application assumed in the present study and the resulting N_2O emissions for the H3 silage may be underestimated compared to the average values given by Bye et al. (2016). Likewise, based on the higher recommendations of Yara (2018), the N_2O emissions for the H1 and H2 silages may also be underestimated.

As pointed out by Hristov et al. (2013a), profitability is the determining factor for the possible adoption of any mitigation option. Bonesmo & Randby (2011) found that using the very early harvested silage (H1) for fattening bulls only gave a marginal higher profit than the H2 silage. Flaten et al. (2014) compared the profitability of differing harvesting regimes in dairy farming and concluded that no harvesting regime is superior under all conditions, but that this depends on the availability of land and other fixed farm resources such as milk quota and housing capacity. High quality silages (H1) were only more profitable when there were no restrictions in land availability and other fixed farm resources. Thus, from an economical viewpoint, advocating the use of a very early harvested grass silage as a mitigation option may not be preferable under current external production conditions.

4.2 Emission intensities

Reductions in emission intensity for milk with increased grass silage quality and concentrate levels were mainly related to higher milk yield and thus fewer cows needed to meet the production target (Table 1 and 3), thereby reducing methane emissions from enteric fermentation and manure. The opposite effect (lower milk yield and a higher number of cows to meet production target) explained the increase in emission intensity for the highest concentrate levels within each grass silage quality. The differences between H1C8 and H3C4, the treatments with the lowest and highest emissions intensities, respectively, were mainly explained by differences in emissions of methane from enteric fermentation and animal manure, while there were small differences for soil N_2O, and CO_2 from feed production and energy use (Figure 2). Uptake of carbon in the soil was lower for H1C8 than for H3C4 (Figure 2). This was due to a smaller grass area (Table 3), a lower C residue yield (2,751 vs. 3,520 kg per ha), less C from manure (2,890 vs. 3,004 kg per ha) and thus lower total C inputs to soil (5,640 vs. 6,524 per ha). For the other emission sources, only small differences between the two treatments was observed.

The variation in emission intensity of finished young bull carcasses (Figure 3) was closely related to slaughter age, as a function of varying growth rates (Table 2). For H3, slaughter age was reduced from 543 to 454 days with concentrate supplements, while it was only reduced from 450 to 427 days for H1. Norwegian red bulls fed the H1 and H2 silages, were likely close to their genetic potential for growth, which may explain the small effects on emission intensities (Figure 3). Reducing the number of days to slaughter reduced the emissions from enteric fermentation and manure. This highlights the importance of high production efficiency (i.e., growth rates) in beef production, as found in other studies (e.g., Capper, 2011; Wiedemann et al., 2015).

A reduction of Ym with increased grass silage quality have been found in feeding experiments in cattle, similar to what is assumed in HolosNor. Warner et al. (2016) investigated grass silages cut at three stages of maturity (early, mid and late maturity) at two levels of nitrogen fertilization (65 vs. 150 kg N/ha). They found that maturity stage influenced Ym. For example Ym values of 6.8, 7.2 and 7.1% were found for the early, mid and late maturity grass silages at the low level of nitrogen fertilization, respectively. The diet consisted of 20% compound feed. Similarly, Brask et al. (2013) compared two grass silages (early first cut vs. late first cut) supplemented with two levels of fat in the concentrates. Ym for the early and late cut fed with the control (ie., low-fat) concentrate were 6.4 and 6.9%.

4.3 Total emissions

Even though the effect of grass silage quality on emission intensity is clear, the effects of improved grass silage quality on the total emissions from the cattle population is not as obvious due to the relationship between milk yield per cow, beef production from the dairy enterprise and the need for suckler cows. The lowest emission intensities for milk and beef were found for H1C8 and H1 with concentrates, respectively (Figure 1 and Figure 3). Interestingly, this combination did not result in the lowest total greenhouse gas emission (Figure 5), which was found for H1C0 combined with concentrates for bulls (only minor differences with no concentrates for bulls). This was because of the higher need for suckler cows to meet the production target of beef for H1C8 (Figure 4). H1C0 for dairy cows combined with concentrates for bulls, gave the lowest total greenhouse gas emissions due to a combination of low milk yield per cow (Table 1) giving high beef production from the dairy enterprise due to a high need for dairy cows (Figure 4), a low emission intensity for finished young bull carcass (Figure 3) and a low need for suckler cows (Figure 4). The highest total emission from beef and milk production was found for H3C4, without concentrates for bulls. Interestingly, milk yield per cow was only slightly higher for H3C4 compared to H1C0 (5,100 vs. 5,500 kg). This was mainly due to larger emissions from the dairy beef production, due to the higher emission intensity of finished young bull carcass (Figure 3). In addition, there was need for more suckler cows (Figure 4), and a higher emission intensity for milk (Figure 1). These results demonstrates that the lowest emission intensities does not necessarily results in the lowest total emission and highlights the importance of looking at both milk- and beef production in relation to each other when investigating potential mitigation options, as pointed out by Åby et al. (2016). As no effect of improved grass silage quality was included for the suckler beef, the total effect of high grass silage quality on greenhouse gas emissions may be underestimated.

5 CONCLUSIONS

Emission intensities for milk and beef were lowest for the superior H1 grass silage and highest for the normal quality H3 grass silage, independent of concentrate levels. Higher concentrate levels did not prevent increased emission intensities for lower grass silage quality (H3). Realistic improvements in grass silage quality from H3 to H2 was shown to maintain milk yields per cow at lower concentrate levels while reducing emissions intensity for milk by approximately 10%. For young bull carcasses, the potential was a reduction of emission intensity by 17%. Cutting the grass at an earlier maturity stage will improve grass silage quality, have beneficial effects on emission intensities for milk and beef, and simultaneously reduce the need for concentrates. The silage quality-concentrate combination that yielded the lowest emission intensity for milk and highest milk yield (H8C0) did not result in the lowest total greenhouse gas emission from the national cattle population. The link between milk yield and beef production must be considered when investigating potential mitigation options for cattle.

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TABLE 1 Effects of grass silage quality and concentrate level on milk yield per cow and milk composition

Silage quality[1]	**Concentrate level[2], kg/d**	**305-day yield[3], kg**	**Milk composition[4]**	
			fat%	**protein%**
H1	0	5100	4.14	3.15
	4	6900	4.13	3.22
	8	8100	4.09	3.28
	12	7200	3.97	3.32
H2	4	6275	4.26	3.20
	8	7000	4.12	3.18
	12	6950	3.96	3.36
H3	4	5550	3.88	3.22
	8	6300	3.95	3.28
	12	7200	3.89	3.22
	16	6775	3.95	3.23

[1] Harvesting time for grass silage: H1=very early, H2=early H3=normal (Randby et al., 2010, 2012)

[2] Concentrate level used in experiment (Randby et al., 2012)

[3] Milk yield used as input in HolosNor (Bonesmo et al., 2013). Average daily milk yield in week 1-16 from Randby et al. (2012) converted to 305-day milk yield using a standard lactation curve of the Norwegian dairy cooperative TINE SA

[4] Milk composition from Randby et al. (2012)

TABLE 2 Effects of grass silage quality and concentrate supplementation on concentrate consumption from 7 months age until slaughter, slaughter age and slaughter weight of growing/fattening bulls (Randby et al., 2010)

Silage quality[1]	Concentrate supplementation	Concentrate consumption, kg	Slaughter age, days	Slaughter weight, kg
H1	Without	0	450	572
	With	495	427	572
H2	Without	0	466	568
	With	498	432	577
H3	Without	0	543	572
	With	564	454	573

[1] See Table 1

TABLE 3 Inputs used in HolosNor for included silage qualities and concentrate levels

	Dairy cow	**Number of**			**Annual feed use**		
Silage quality[1]	**concentrate level[2], kg/d**	**Dairy cows[3]**	**Bulls[4]**	**Ley area[5], ha**	**Concentrate dairy cows[6], FU[7]**	**Concentrate bulls[8], FU**	**Silage, kg DM**
H1	0	36	21	29	0	3836	259976
	4	27	15	21	18148	9509	185898
	8	23	13	18	35011	8100	157359
	12	26	15	17	42735	9113	154005
H2	4	29	17	20	34113	3019	210405
	8	26	15	17	39999	9298	177169
	12	27	15	15	51846	9365	163180
H3	4	33	19	25	28752	2936	275367
	8	29	17	19	45059	10717	209098
	12	26	15	15	60743	9378	167566
	16	27	16	14	80964	9966	152328

[1] See Table 1

[2] See Table 1

[3] The number of dairy cows needed to fulfil a target for annual fat-and protein-corrected milk production on farm (in total approximately 185 000 kg milk per year, equal to 26 cows with average milk yield 7100 ECM kg) based on the 305-days yields given in Table 1

[4] The number of finished young bulls was 0.57 per cow and year based on a dairy cow replacement rate of 0.3 calculated as a function of average values for slaughter age of cow, age at first calving, calving interval and calf losses (TINE, 2013)

[5] Estimated grass ley area for each treatment needed to cover the total silage requirement for dairy cows, replacement heifers and finished bulls based on estimated annual grass yield per ha of the three silage qualities

[6] Based on total energy requirements calculated as a function of milk yield (Volden, 2013), and corrected for observed silage intake (Randby et al., 2012)

[7] 1FU, feed unit=6,9 MJ net energy lactation

[8] Based on consumption per bull (with concentrates) in Table 2 plus 228 kg DM per bull before 7 months of age (Berg & Matre, 2007)

Figure legends:

FIGURE 1 Emission intensity in kg CO_2-equivalents per kg fat- and protein-corrected milk yield for the included silage qualities (H1, H2 and H3) and concentrate levels (0, 4, 8, 12 and 16 kg/d)

FIGURE 2 The lowest (H1C8) and highest emission intensity (H3C4), distributed on emission sources

FIGURE 3 Emission intensities in kg CO_2-equivalents per kg beef carcass for the included silage qualities, offered as sole feed (without concentrates) or supplemented with concentrates (with)

FIGURE 4 Number of dairy and suckler cows needed to meet the domestic production level of milk (1500 million liters) and beef (80,000 tons) as a function of milk yield per dairy cow on silage quality H1 with 0 and 8 kg/d concentrate, and H3 with 4 kg/d concentrate

FIGURE 5 Total annual greenhouse gas emissions in CO_2-equivalents from milk and beef from the dairy and suckler populations, for the dairy cow diets including silage quality H1 with 0 and 8 kg/d concentrate, and H3 with 4 kg/d concentrate. Each dairy cow diet is combined with dairy bull diets of the same silage quality without or with concentrates. Emissions are distributed on animal products: Milk from dairy cows, beef from dairy population (dairy cows and bulls) and beef from suckler population. All six feeding regimes fulfill the domestic production level of milk (1500 million liters) and beef (80,000 tons).