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Review

In pursuit of sustainability in dairy farming: A review of interdependent effects of animal welfare improvement and environmental impact mitigation

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ABSTRACT

The welfare of dairy cows and their emission potential are two distinct and yet intertwined aspects determining the sustainability of dairy farming. Along with numerous measures to mitigate the sector's environmental impact, good health and welfare are suggested to keep emission levels low. More recently, scientists in both fields have pointed to potential trade-offs for animal welfare arising from the implementation of environmental impact mitigation measures. Research has since focused on the qualitative evaluation of these welfare implications, but little is known about the actual magnitude of the effects on welfare of emission mitigating measures. Moreover, potential environmental impacts associated with welfare improvement measures have hardly been investigated so far, although estimates of respective increases in emission levels associated with various cattle diseases suggest the importance of welfare improvement in pursuit of integral sustainability improvement in dairy farming. For a comprehensive enhancement of the sector's sustainability, a careful balancing of interdependent effects is thus suggested.

This review aims at providing the first inclusive overview on measures of both greenhouse-gas and ammonia emission mitigation and welfare improvement relevant in terms of respective interdependencies. Derived from the literature in both fields, attempts are also made to quantitatively evaluate the interdependent effects. Our findings confirm, that mitigation measures such as breeding for increased genetic yield potential, the use of rumen modifiers and the increase of concentrate ratio in the diet are potentially harmful for the animals' health and welfare, while an increased amount of fat in the diet and the adaptation of the protein ratio to the yield level offer welfare neutral mitigation potential. By contrasting frequently suggested welfare improvement measures with determinants of emission formation, we identified the increase of space allowance and cleanliness, as well as temperature management and access to pasture as welfare measures with potential environmental impact. As for the evaluation of interdependencies, we found that to some extent a quantification of trade-offs is possible for welfare relevant health disorders, such as lameness and mastitis, for which both the effect of welfare improvement measures on their prevalence and an impact range in terms of emissions have already been described in literature. Although further research is needed for a comprehensive balancing of trade-offs, we conclude, that a careful distinction between the effect of an improvement measure and the effect of its impact as suggested in this review may serve as a basis for further research and improve decision-making in dairy farming in terms of sustainability.

1. Introduction

In pursuit of sustainability, the dairy farming sector faces the challenge of producing at minimum environmental impact (**EI**) and reasonable costs, while ensuring good welfare (Place and Mitloehner, 2014). The global climate agreement (UNFCCC, 2015) as well as consumers' acceptance of dairy production (Tucker et al., 2013) are major driving forces in this context. Three of the main determinants of the sector's EI considered in this review are the greenhouse-active gases methane (**CH_4**) and nitrous oxide (**N_2O**) as well as ammonia (**NH_3**), adding to the pollution of air, water and soil (Novak and Fiorelli, 2010). As its contribution to overall anthropogenic emissions is considerable, dairy farming is attributed a significant share in achieving global sustainability goals (Llonch et al., 2016; Place and Mitloehner, 2014). Enhancing production efficiency is no longer promoted for economic reasons only, but also as a potent means of minimizing its EI. However, with the intensification of dairy farming, public scrutiny of the ethics and humaneness of production has increased (Barkema et al., 2015).

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Especially in developed countries, where production levels are already very high, environmental impact mitigation measures (**EIMM**) which aim at further productivity enhancement have been pointed out as potentially detrimental for the welfare of dairy cows, as they might increase the risk for production diseases such as mastitis and lameness (de Boer et al., 2011; Llonch et al., 2016; Oltenacu and Broom, 2010). While good health and welfare are broadly acknowledged as essential regarding productivity (Fall et al., 2008), health impairment has repeatedly been shown to increase the sector's EI (ADAS, 2015; Skuce et al., 2016).

Therefore, both animal welfare and environmental scientists have called for the simultaneous pursuit of animal welfare improvement (**AWI**) and environmental impact mitigation (**EIM**) when striving for more sustainable dairy farming (de Boer et al., 2011; Llonch et al., 2016; Place and Mitloehner, 2014; Tucker et al., 2013). While numerous improvement measures have been described in each field independently, only a few synoptic studies addressed potential interdependencies by pointing out synergetic and antagonistic effects (e.g. de Boer et al., 2011; Llonch et al., 2016; Place and Mitloehner, 2014). For the benefit of an integral sustainability improvement, that takes different aspects of sustainability into account, especially antagonistic interdependencies need to be identified and quantified, to determine potential trade-offs. So far, the scarce knowledge about such interdependent effects primarily relates to welfare impacts resulting from EIMM, while potential environmental impacts of animal welfare improvement measures (**AWIM**) have hardly been investigated yet.

In order to comprehensively address such interdependent effects, we distinguish a primary and a secondary level of effect associated with improvement measures. In terms of EIM, the primary effect level means the implications for AW arising from a certain EIMM (e.g. breeding for increased yield), while the secondary effect level describes the implications of reduced EI on AW. Research in this field is mainly focused on the primary effect level and the qualitative description of welfare implications arising from their implementation (see de Boer et al., 2011; Llonch et al., 2016). Regarding AWI, however, the almost undivided research focus is on the secondary effect level, which addresses the impact of improved health and welfare on emissions, while little is known about potential effects of the implementation of an AWIM (e.g. increasing space allowance) on the EI. Several studies quantitatively assessed the ranges of emission reduction associated with curing specific diseases (ADAS, 2015; Chatterton et al., 2014; Chen et al., 2016; Hospido and Sonesson, 2005; Mostert et al., 2016; Özkan et al., 2015; Skuce et al., 2016), but it is largely unexplored whether AWIM, such as increasing space allowance or providing access to pasture, do per se affect the EI of dairy farming.

This review provides the first integral perspective on sustainability improvement in view of both EIM and AWI in dairy farming, including the attempt to quantify respective interdependencies. To this end, we scrutinized the relevant contributions from both research areas regarding explicit and implicit synergies and especially trade-offs at the interface of emission mitigation and welfare improvement. In the first part, we review selected measures to mitigate CH_4, N_2O and NH_3 emissions, for which welfare implications have been described. We quantify their potential impact in terms of both EIM and AW (see Table 1). Similarly, in the second part, we describe selected measures frequently discussed in terms of improving overall dairy cow welfare. In the absence of specific studies, we condensed the findings of both research areas to a substantiated first quantitative evaluation of their EI, as far as data were available (see Table 2). To quantitatively interlink animal welfare and emission mitigation, we chose two of the major welfare problems in dairy farming, i.e. **lameness** and **mastitis** and describe the primary effects of EIMM on changes in lameness and mastitis prevalence. Both health disorders are highly prevalent in dairy industry worldwide (Potterton et al., 2012; Tremetsberger and Winckler, 2015; van Gastelen et al., 2011) and were repeatedly identified as risk factors for increased emission from dairy cows (Chatterton et al., 2014; Chen et al., 2016; Özkan et al., 2015). On the basis of known ranges of EI for lameness and mastitis are known, we contrast changes in EI with the EIM potential of the measure. Similarly, we evaluate the secondary effect of AWIM targeting lameness and mastitis prevalence and contrast it with the emission level associated with these diseases, to determine potential trade-offs between AWI and EIM (see Table 3). Finally, we briefly discuss future implications arising from this integrated perspective. By pointing out current gaps requiring further research, we open up a potential scope of action, in due consideration of the limits of our approach.

2. Impact of environmental impact mitigation in dairy farming on animal welfare

2.1. The environmental impact of dairy farming

The contribution of bovine milk production to global anthropogenic greenhouse gas (**GHG**) emissions amounts to 4.3% (Gerber et al., 2013b). According to an analysis based on data from the International Farm Comparison Network (IFCN), emissions per unit of product range between 0.8 and 3.07 kg carbon dioxide-equivalents (**CO_2-eq**) per kg of energy corrected milk (**ECM**) (Hagemann et al., 2011), reflecting regional differences in emission intensity of a factor of 7 (Gerber et al., 2011). Key determinants of the sector's contribution potential to global warming (**GWP**) are CH_4 and N_2O (Novak and Fiorelli, 2010). Thereof, CH_4 emissions from enteric fermentation represent 71% of the sector's total direct GHG emissions, followed by N_2O emissions from manure accounting for further 25% (Gerber et al., 2013a). Aside from greenhouse-active gases, emissions of NH_3 from bacterial decomposition of nitrogen (**N**) in the manure add to the overall EI potential of the dairy farming sector, by contributing to processes of acidification and eutrophication (Novak and Fiorelli, 2010). According to the European Environment Agency (EEA), 94% of total anthropogenic NH_3 emissions arise from the agricultural sector (EEA, 2016), of which approximately 50% are attributed to cattle activities (Ferm, 1998).

Several factors determine the actual amount of direct emissions originating from the animal or its manure. Regarding the individual animal, its emission potential is associated with its genetic merit for dry matter intake (**DMI**) and (to a minor extent) for residual feed intake (**RFI**) and feed conversion efficiency (**FCE**), as well as its genetic potential for yield and CH_4 emission (Hristov et al., 2013). While a selection for increased DMI and yield (Knapp et al., 2014), and a high FCE (Hegarty et al., 2007; Skuce et al., 2016; Waghorn and Hegarty, 2011) result in declining emissions per unit of product, the factors RFI (Hegarty et al., 2007) and genetic CH_4 emission potential (Lassen and Løvendahl, 2016) have to be reduced to benefit the mitigation of emission intensity on the animal level. As for emissions from manure, notably N_2O and NH_3, the level of emission is significantly influenced by feeding practices and feed quality (Novak and Fiorelli, 2010). From the point of excretion, manure handling and management, as well as cleanliness (Ndegwa et al., 2008) and temperature (Ngwabie et al., 2011), are key factors in determining the actual level of emitted greenhouse gases and ammonia. In general, frequent cleaning, the minimization of the emitting surface, avoiding volatilisation by regulating air temperature, and the separation of faeces and urine can significantly reduce N_2O and NH_3 emissions in dairy farming (Ndegwa et al., 2008).

2.2. Measures of environmental impact mitigation and how they affect animal welfare

To meet dairy farming's share in achieving global climate goals, the implementation of potent EIM strategies is crucial (Bryngelsson et al., 2016). Numerous measures have been suggested to mitigate direct emissions (e.g. Hristov et al., 2013; Knapp et al., 2014; Ndegwa et al., 2008). They affect breeding, feeding, husbandry and animal