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Methods to determine the relative value of genetic traits in dairy cows to reduce greenhouse gas emissions along the chain

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ABSTRACT

Current decisions on breeding in dairy farming are mainly based on economic values of heritable traits, as earning an income is a primary objective of farmers. Recent literature, however, shows that breeding also has potential to reduce greenhouse gas (GHG) emissions. The objective of this paper was to compare 2 methods to determine GHG values of genetic traits. Method 1 calculates GHG values using the current strategy (i.e., maximizing labor income), whereas method 2 is based on minimizing GHG per kilogram of milk and shows what can be achieved if the breeding results are fully directed at minimizing GHG emissions. A whole-farm optimization model was used to determine results before and after 1 genetic standard deviation improvement (i.e., unit change) of milk yield and longevity. The objective function of the model differed between method 1 and 2. Method 1 maximizes labor income; method 2 minimizes GHG emissions per kilogram of milk while maintaining labor income and total milk production at least at the level before the change in trait. Results show that the full potential of the traits to reduce GHG emissions given the boundaries that were set for income and milk production (453 and 441 kg of CO₂ equivalents/unit change per cow per year for milk yield and longevity, respectively) is about twice as high as the reduction based on maximizing labor income (247 and 210 kg of CO₂ equivalents/unit change per cow per year for milk yield and longevity, respectively). The GHG value of milk yield is higher than that of longevity, especially when the focus is on maximizing labor income. Based on a sensitivity analysis, it was shown that including emissions from land use change and using different methods for handling the interaction between milk and meat production can change results, generally in favor of milk yield. Results can be used by breeding organizations that want to

include GHG values in their breeding goal. To verify GHG values, the effect of prices and emissions factors should be considered, as well as the potential effect of variation between farm types.

Key words: life cycle assessment, economic value, milk yield, longevity

INTRODUCTION

The need for strategies to reduce greenhouse gas (GHG) emissions from human activities, mainly consisting of carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), has been highlighted (IPCC, 2007). Use of fossil fuel and land use change are identified as the primary sources for increased levels of atmospheric CO₂, whereas agriculture is identified as the primary source for increased levels of CH₄ and N₂O (IPCC, 2007). The majority of CH₄ emissions from agriculture relate to enteric fermentation of ruminants. About half of the total GHG emissions along the dairy production chain are enteric CH₄ (Hörtenhuber et al., 2010). To reduce CH₄ emissions, different strategies have been proposed; one of these strategies is increasing the productivity and efficiency of the dairy herd by selective breeding (Buddle et al., 2011; De Haas et al., 2011).

Productivity and efficiency can be increased by genetic improvement of traits such as milk yield, feed efficiency, longevity, and calving interval (Bell et al., 2011). Increasing milk yield per cow, for example, reduces CH₄ emissions per kilogram of milk by diluting CH₄ formed during fermentation of feed related to maintenance (Bannink et al., 2011; Bell et al., 2010, 2011). Bannink et al. (2011) showed that a 33% increase in production of fat- and protein-corrected milk (FPCM), from 17.2 kg/d in 1990 to 22.9 kg/d in 2008, reduced enteric CH₄ per kilogram of FPCM by 13%, from 17.6 to 15.4 g. Increasing longevity reduces CH₄ per kilogram of milk by reducing the number of female replacements producing CH₄ for maintenance and growth, without producing milk (Garnsworthy, 2004; Wall et al., 2010). Wall et al. (2010) showed that increasing longevity from an aver-

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age of 3.0 to 3.5 lactations can reduce enteric CH₄ per kilogram of milk by 4.4%.

Changing a trait, such as milk yield or longevity, however, can affect the whole farm, including feeding strategy, management practices and purchases of inputs, such as concentrate and fertilizer (Bell et al., 2010; Wall et al., 2010). Evaluating the effect of a genetic improvement, therefore, requires modeling the whole farm. Moreover, optimization of farm management before and after a change in trait is required to prevent under- or overestimation of the effect of genetic improvement (Groen et al., 1997). Finally, if the effect concerns GHG emissions, the analysis should include emission along the chain (i.e., from production of farm inputs up to the farm gate) to avoid pollution swapping. By evaluating the effect of one unit change in individual traits on GHG emissions at the chain level, the relative value of each trait to reduce GHG emissions along the chain can be determined. A similar approach is used to calculate the relative economic value of traits (Groen, 1988; Koenen et al., 2000).

Two studies evaluated the effect of improving individual traits in dairy cows on GHG emissions at farm or chain level. Wall et al. (2010) evaluated the effect of increasing longevity on CH₄ and N₂O emissions at farm level, whereas Bell et al. (2011) evaluated the effect of increasing feed efficiency, milk yield, calving interval, and longevity on GHG emissions at the chain level. Both Wall et al. (2010) and Bell et al. (2011), however, did not optimize farm management with changing levels of genetic traits.

Farm management can be optimized based on different objectives, such as maximizing labor income (i.e., the main interest in deriving breeding objectives) or minimizing GHG emissions per unit product. It is not clear how a difference in objective affects the relative value of individual traits to reduce GHG emissions per kilogram of FPCM.

The objective of the current study was to compare 2 methods to determine the relative value of genetic traits in dairy cows to reduce GHG emissions along the milk production chain (i.e., up to the farm gate). Both methods are based on a whole-farm dairy model, use linear programming (LP) to optimize farm management, and include all GHG emissions along the chain, up to the farm gate. The first method is based on maximizing labor income of the farm family; the interrelated consequences for GHG emissions are evaluated as a side-effect. The second method is based on minimizing GHG emissions per kilogram of milk. We compared both methods by assessing the consequences of an increase in milk yield and longevity of cows on an average Dutch dairy farm on sandy soil.

METHODS

The first method is based on the exact same principle that is used to calculate economic values. A dairy farm LP model with the objective to maximize labor income was used to determine the economic benefit per unit change in milk yield and longevity. The effect on GHG emissions (i.e., the GHG value) was considered as a consequence. This method, therefore, shows the effect of economic optimization, which is currently the main interest in deriving breeding objectives, on GHG emissions. The second method uses the same model, but now minimizes GHG emissions per kilogram of milk along the chain (i.e., up to the farm gate), to determine the maximum GHG reduction per unit change in milk yield and longevity while maintaining initial labor income and milk production at the farm level (i.e., before trait improvement). This method, therefore, determines the full potential of a genetic trait to reduce GHG emissions along the chain, given the boundaries that were set for income and milk production. Results might change when reducing GHG emissions yields additional income. At this moment, however, no carbon-pricing scheme exists for agriculture.

Dairy Farm LP Model

The dairy farm LP model used is based on Berentsen and Giesen (1995). This static year model includes all relevant activities and constraints that are common to Dutch dairy farms, such as on-farm feed production, purchase of feed products, and animal production, including rearing of young stock. The model distinguishes a summer and a winter period regarding feeding. Dietary options include grass from grazing, grass silage, maize silage, and 3 types of concentrates that differ in protein levels (i.e., standard, medium, and high). Nutritional values of the feed ingredients are in Table A1. Available land can be used as grassland or as maize land. Constraints of the model include fixed resources of the farm (e.g., land area, family labor), links between activities (e.g., fertilizer requirements of grass and arable land with available nutrients from manure and purchased fertilizers), and environmental policies [e.g., limits to the application of total mineral nitrogen and phosphate (P₂O₅) fertilization]. For a more detailed description of the model, see Van Middelaar et al. (2013a).

The central element of the LP model is an average dairy cow from the Holstein Friesian breed with a given milk production and longevity, calving in February, and conditions representing the dairy cattle of the farm. Feed requirements (energy and protein) and intake capacity of this average cow were determined using the bio-economic model of Groen (1988). The same model

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