A dynamic simulation model for evaluating the impact of dairy management decisions on herd-level cash flows and gas emissions

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This supplement summarizes the original stochastic simulation model (Kok et al., 2017), that was used as a starting point in the current study.

Key assumptions of the model

The model of Kok et al. 2017 was developed in R version 3.3.1 and simulates individual cow lactations within a dairy herd with 100 cow places. Each of the cow places contains one individual cow at a time, that is simulated per lactation.

Each lactation starts with the birth of a calf, either from a healthy cow that remained in the herd or from a replacement heifer, and ends with next calving or culling of the cow. Time steps in the model are of variable length, starting and ending when a cow calves or is culled, and when a new calendar year starts, thus allowing aggregation of herd data per calendar year. Per time step per cow place, the model records the produced milk, calves, and culled cows, and computes the associated energy requirements.

Lactation curves

Each simulated cow is assigned a production level. Each lactation a cow is stochastically assigned to a healthy lactation and continuation to the next lactation, or to being culled and replaced by a new heifer. For each lactation, milk production was modelled until the moment of dry-off or culling using a Wilmink lactation curve, that was shifted up or down according to the cow's production level. Milk production of each cow was computed per cow space per time step, using the integral of the milk production function.

The original model simulated culling for failure to conceive and culling for other reasons using fixed probabilities per lactation; and did not explicitly include specific diseases or milk production losses due to disease. These were adapted in the current model as described in the main text, through inclusion of modelling the AI events, mastitis and lameness. Calving intervals in the original model were sampled from a dataset, whereas in the current model they are determined by the stochastic success of AI.

Energy requirements

Energy requirements for maintenance, milk production, growth, and gestation were computed per time step according to the Dutch net energy evaluation system in VEM (1,000 VEM = 6.9 MJ of net energy), using the parity, weight, milk production, and pregnancy status of the cow. The current model assumed growth from 540 kg to mature weight of 650 kg in the 24 months following first calving, as adjusted in Kok et al., 2019. It was assumed that the lactating cows were grazing for 8 hours per day for 170 days per 365 days (the summer period), and that grazing increased energy requirements for maintenance by 6.7%.

Feed requirements were computed by dividing the energy requirements in each timestep by the energy content of feed. This was done using fixed rations for the summer (170 d; 6.5 MJ/ kg DM) and winter period (195 d; 6.8 MJ/ kg DM). Roughage consisted of grass, grass silage and maize silage, and was supplemented with by-products and concentrate. Using this fixed composition, greenhouse gas emissions of feed production and of enteric fermentation were also computed per unit of feed.

Partial cash flows

Cash flows in the analysis included revenues from sold milk, calves, and culled cows, and costs from buying or producing feed and rearing youngstock. These cost inputs were updated in the current manuscript.

Greenhouse gas emissions

A life cycle approach was used to assess the impact of management strategies on greenhouse gas emissions. Emissions of carbon dioxide, methane, and nitrous oxide were computed for feed production, enteric fermentation, and manure management.

Emissions related to feed production included: production of inputs (e.g. fertilizer and machinery), cultivation, harvest, and processing of the feed products, and transport to farms. Economic allocation was used in case of a multiple output process (e.g. production of soybean meal also results in soybean oil). Emissions related to enteric fermentation were calculated with feed specific emission factors (Vellinga et al., 2013).

Emissions related to manure management were calculated from the volume of manure and the nitrogen excretion. Nitrogen excretion was computed as the difference between nitrogen intake from feed and nitrogen retention for milk production, growth, and gestation (RVO, 2105). Factors for N_2O, NH_3, NO_x and CH_4 emissions and NO_3^- leaching from manure on pasture and in the stable were taken from Dutch national inventory reports (De Mol and Hilhorst, 2003; de Vries et al., 2011; Velthof and Mosquera, 2011; Vonk et al. 2016), and emission factors from NH_3, NO_x and NO_3^- to N_2O (i.e. indirect N_2O emissions) were taken from IPCC guidelines (Dong, 2006). All emissions were converted to CO_2 equivalents, based on their equivalence factor in terms of CO_2 (100-year time horizon): 1 for CO_2, 28 for biogenic CH_4, 30 for fossil CH_4, and 265 for N_2O (Myhre et al., 2013). System expansion was used to account for the production of meat from calves and cows. The production of meat from surplus calves (as white veal) and cows was assumed to substitute the production of other meat on the basis of kg edible product.

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