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Energy intensity in livestock operations – Modeling of dairy farming systems in Germany

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ABSTRACT

The world's population and food consumption are increasing drastically while natural resources are decreasing. In particular, energy use is an important component of reaching sustainability in agricultural production processes because of its shortage as resource, its influence on air pollution and its role in the economics of production. This study used system modeling to examine interactions between crop and livestock procedures and between levels of different input factors and their effects on yields in order to determine agricultural energy intensity. A method based on direct and indirect energy inputs within the livestock operation and plant production is used. A sensitivity analysis is done to investigate the influence of site conditions on the energy intensity of milk production and to highlight recommendations for management practices in livestock operations to reduce the energy use on dairy farms in Germany. An uncertainty analysis is used to evaluate the results of this study.

Plant production, which consists of feed-supply and diet composition, constitutes the main influence on energy intensity in dairy farming. The energy intensity of feed-supply is strongly dependent on the quality of land and its management. An increasing use of concentrate in the dairy diet leads to a higher energy intensity for the process. Livestock operation accounts for one third of the energy intensity in milk production.

The rearing period of a heifer at a dairy farm requires an energy input of 13–16 GJ. The share of the energy intensity of the rearing period of the heifer per kg of milk changes, depending on the service life of the dairy cow. The service life of the cow increases, while the share of the energy intensity of the process section replacement decreases.

Noting the influence of the energy intensity of machines and technical facilities in dairy farming is useful for overall energy use reduction. Here, also, the pasture is shown as a possibility for reducing the fossil energy input on-farm. The animal houses influence the energy intensity only marginally.

Based on the sensitivity analysis of farm management and land quality, the energy intensity varies between 3.0 and 3.6 MJ kg^{-1} energy corrected milk for an average milk yield of 8000 kg ECM cow^{-1} $year^{-1}$. Increasing milk yields lead to a reduction of the energy intensity per kg ECM. But this effect is reduced with rising milk yields because of higher energy inputs needed for the feed-supply, due to a higher share of concentrate and a typically higher replacement rate for the herd.

1. Introduction

The population on earth is increasing drastically, projected to reach up to 9.5 billion humans in 2050. This considerable increase of the population requires the production of sufficient food with high quality as well as a low input of resources. For example, the demand for dairy products is projected to increase by 80% in 2050 (Steinfeld et al., 2006). Sustainable agriculture has an important influence on environmental protection. In agriculture, the efficient use of energy is one of the priorities for sustainability. Energy efficient agricultural processes permit fossil resources preservation, a decrease in air pollution, and financial savings. The use of raw materials and fossil energy in agricultural production has increased consistently due to the intensification and mechanization of production technologies. But the increase of yields is not commensurate to the energy input in the processes (Pimentel et al., 1973). Pervanchon et al. (2002) state that the evaluation of agriculture requires a consideration of efficient energy use and the identification and assessment of major sources of energy wastes.

Several approaches concerning the energy efficiency in agricultural production already exist, including investigations into the energy efficiency of dairy farming systems. To improve the energy

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efficiency in dairy farming processes it is necessary to examine the main processes of energy use within the dairy farming system and to determine its influence on the energy efficiency of the process. These studies are mainly focused on the feeding system in dairy farming, which is related on calculations within the field of plant production (Bockisch, 2000; Cederberg and Mattsson, 2000; Grönroos et al., 2006; Meul et al., 2007; Thomassen, 2008). Fewer investigations focus on energy use of livestock operations (Procé, 1986; Reitmayr, 1995; Abel, 1997; Lünzer, 1997; Refsgaard et al., 1998; Dalgaard et al., 2001). Furthermore the results of these studies are not, or are only partially, comparable, due to different system boundaries. Wechselberger (2000) stated that generally applicable methods for calculating energy input in animal husbandry are still missing. There is a particular lack of information in the energy studies about the influence of the service life of the dairy cows and therefore the replacement rate of the dairy herd. The influence of different animal housing systems, particularly in typically used barns, and the machines used in animal husbandry, are mainly neglected and variations are not discussed. The improvement of our knowledge about the energy input of production technologies in livestock operations is crucial to setting achievable targets for efficient energy use at the farm.

The focus of this study is the calculation of the energy intensity in animal husbandry using the example of dairy farming in Germany. The energy intensity is expressed as the ratio of the energy inputs (EIP) per amount of the produced milk. The major aims of the study are:

- To determine the energy intensity of dairy farming in Germany, including direct and indirect energy inputs by using a methodology which includes the whole farming process, considering all energetic aspects within animal husbandry and plant production.
- To study the influence of the animal housing system on the energy intensity (e.g., buildings, machines).
- To determine the energy input for the supply of heifers for dairy farming.
- To investigate the sensitivity of the energy intensity in dairy farming related to variations of management practices (e.g., plant production, animal housing, machines and technical facilities, milking and replacement), the service life of dairy cows and milk yield.
- To discuss uncertainties of calculations of energy intensity in agricultural systems with regard to the three process sections: feeding, replacement and milking.
- To highlight possibilities to reduce the energy intensity of milk production.

2. Methodology

2.1. Definition of dairy farm characteristics

In this study, a dairy farming system is used for the calculation of the energy intensity, based on recent developments of milk production in Germany. The calculations are done using the example of a defined dairy farming process to show the influence of varying management and site conditions in milk production. A selection of characteristics of the dairy farm system is presented in Table 1.

It is assumed that all heifers needed to maintain the herd size are raised at the farm. To allow comparisons of alternative systems of milk production, it is necessary to consider that only products with similar functions can be compared. The energy input in this study is related to the unit of milk produced. The milk is corrected for its energy content to a standard of 3.5% protein and 4.0% fat (Table 1).

Table 1
Dairy herd structure and basic assumptions of the dairy farm system.

Inputs	Values used in this study
Herd size	180 dairy cows
Milk production	8000 kg ECM[a] cow^{-1} year^{-1}
Milk protein	3.5%
Fat protein	4.0%
Body weight of adult dairy cow	650 kg
Race	Holstein–Friesian
Lactation period	305 days
Dry period	60 days
Calving interval	1 calf cow^{-1} year^{-1}
Replacement rate	44% (LKV, 2006, 2007)
Rearing period of heifer	25 months (Spiekers and Potthast, 2004)
New born female:male ratio	50%
Barn	Free-stall barn for 188 cows
Manure disposal	Liquid, with slurry channels
Feeding	Total mixed ration with 180 days half-day grazing year^{-1}
Milking system	Herringbone milking parlor (2 × 8)
Milk cooling system	Direct cooling
Location	North-East Germany

[a] Energy corrected milk.

The milk yield per cow and year has a strong influence on the results within the calculations of the energy intensity of the dairy farming process. In this study, an average milk yield of 8000 kg ECM cow^{-1} year^{-1} is defined. In Germany, the annual milk yield per cow varies across different breeds but also by different management practices at the farm. The average milk yield of the dairy cows, which are part of the German measurement system of milk yield and milk quality, is 8093 kg cow^{-1} year^{-1} (DLQ, 2010).

The calculations of the energy intensity of the livestock buildings and storage facilities, the machines and technical facilities, and the rate of replacement are strongly influenced by the number of head at the farm system. Therefore the number of head is defined according to the trend of growing herd sizes in Germany. In Germany, the number of dairy cows has been decreasing since 1999 (Statistisches Bundesamt, 2004). But the number of head on farm is steadily increasing. A continuous increase is seen for farm sizes of 100–199 dairy cows (Fig. 1).

The free-stall barn has become standard for dairy housing in Germany. Meanwhile, more than 64% of the dairy cows are kept in these barns (Statistisches Bundesamt, 2004) and its use is continuously increasing, because it provides benefits with regard to labor and animal health. In Germany, more than three quarters of the dairy cows are kept in barns with liquid manure removal (Statistisches Bundesamt, 2004).

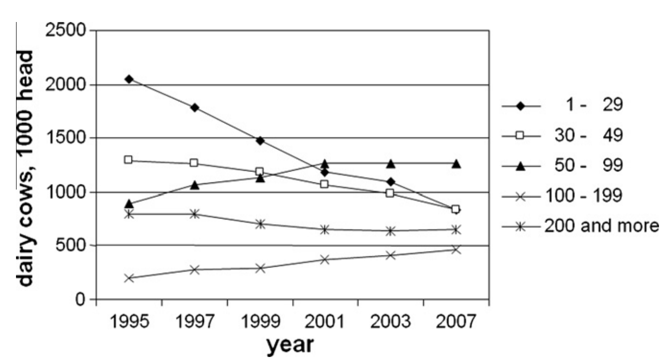

Fig. 1. Dairy farm structure related to farm size (Statistische Jahrbücher 1997, 1999, 2005, 2008).