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The influence of dairy management strategies on water productivity of milk production

Michael Krauß[a,*], Simone Kraatz[a], Katrin Drastig[a], Annette Prochnow[a,b]

[a] Leibniz Institute for Agricultural Engineering Potsdam-Bornim, Max-Eyth-Allee 100, Potsdam, 14469, Germany
[b] Humboldt-University of Berlin, Faculty of Life Sciences, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Hinter der Reinhardtstr. 8-18, 10115 Berlin, Germany

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ABSTRACT

Livestock production is the main user of water resources in agricultural production. The objective of this study is to quantify the effects of dairy management strategies such as feeding strategies, milk yield and replacement rate on the water productivity of milk. The study is based on site conditions of North-East Germany. The water input is considered as the sum of crop transpiration from precipitation, the total irrigation water and the drinking water of the animals. Four feeding strategies, based on the maximization of grass silage, maize silage, pasture and concentrate, were analyzed. The milk yield varied between 4000 and 12,000 kg fat corrected milk (FCM) cow^{-1} year^{-1} in steps of 2000 kg. Feed water productivity on a dry mass (DM) base varied widely between 1.5 kg(DM) m^{-3} of water input for grass silage and 2.6 kg(DM) m^{-3} for maize silage, 0.8–1.8 kg(DM) m^{-3} for grain and 0.4 kg(DM) m^{-3} for soybeans from Brazil. The water productivity of milk increased with an increasing milk yield. The lowest water productivity was calculated at 4000 kg(FCM) with 1.1 kg(FCM) m^{-3} water input. At a milk yield of 8000 kg(FCM) the water productivity was 1.5 kg(FCM) m^{-3} and at 10,000 and 12,000 kg(FCM) it was 1.6 kg(FCM) m^{-3}. The most beneficial conditions related to water productivity in dairy farming exemplarily for site conditions of North-East Germany are found to be with a milk yield about 10,000 kg(FCM) and a grass silage and maize silage based feeding.

1. Introduction

The increase of the world population to 10 billion people in 2050 (Lutz et al., 1997) and the change in human diets, to include more animal products (Delgado, 2003), will lead to an increasing food demand by 70–90% in 2050 (Rosegrant and Cline, 2003). There will be a competition for water among agricultural, domestic and industrial uses (Postel, 2000). Agricultural practices have to be improved to increase the efficient use of natural resources such as water, in order to meet the challenges of global change. Water is a major resource in agricultural production. In livestock operations, water plays a role as drinking water for the animals as well as in the feed production. Dairy farming is the most complex type of livestock operation (Descheemaeker et al., 2010; Kraatz, 2012), since it includes the production of feed, milk and meat.

Generally, water productivity is defined as the relation of output to water input (Bouman, 2007). However, the details of the calculations of water productivity can vary from study to study. In order to make comparison of results possible, Bessembinder et al. (2005) suggested that the method for determining output and water input be described meticulously. The output can be the product in dry or fresh weight or in an economic value (Bessembinder et al., 2005). The output can also be on a feed energy, feed protein, food energy or food protein base (Renault and Wallander, 2000). Beside the concept of crop water productivity (Bouman, 2007; Bouman and Tuong, 2001) a concept of livestock water productivity was developed (Peden et al., 2007). This concept uses the net livestock-related benefits as output of the system (e.g. Cook et al., 2009; Descheemaeker et al., 2010; Peden et al., 2009). The water input has to be described precisely as well, which includes the transpiration, the evapotranspiration, the irrigation water, etc. (Bessembinder et al., 2005). An increase in water productivity means that an increased amount of products and services are produced with the same amount of water or that the same amount of products are produced with less water (e.g. Bossio et al., 2010; Molden and Sakthivadivel, 1999; Renault and Wallander, 2000). Perry (1999) sees the concept of water productivity with more "crop-per-drop" as "the most important performance indicator in

* Corresponding author. Tel.: +49 3315699855; fax: +49 3315699849.
E-mail address: mkrauss@atb-potsdam.de (M. Krauß).

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many countries", while Zoebl (2006) proposes that it is not the only meaningful indicator of agricultural production. For a comprehensive recent discussion of the water productivity concept see Pereira et al. (2012).

The regional focus of the investigations analyzing options to improve water productivity of livestock production was in Africa (e.g., Descheemaeker et al., 2010; Haileslassie et al., 2009; Rockström et al., 2010), Asia (e.g., Haileslassie et al., 2011; Singh et al., 2006) and Oceania (e.g., Armstrong et al., 2000; Moore et al., 2011; Zonderland-Thomassen and Ledgard, 2012). For Western Europe a case study on water productivity in dairy farming is available (Prochnow et al., 2012).

Several options have been reported to increase water productivity in dairy farming. An increasing performance of the cows can improve water productivity at Ethiopian conditions, since the share of maintenance related to the performance is reduced (Peden et al., 2009). An increasing share of crop residues and by-products in the diets can also increase the livestock water productivity (Descheemaeker et al., 2010). Diets should contain high digestible components and the nutrient composition has to be near the demand of the animals (Blümmel et al., 2009). Haileslassie et al. (2011) describe an increasing water productivity in the Indo-Ganga basin with intensifying the milk production up to 2000 l cow^{-1} $year^{-1}$. For Australian conditions a milk yield of 5350 kg cow^{-1} $year^{-1}$ showed a higher water productivity than a 1500 kg lower milk yield (Armstrong et al., 2000). This was caused by a better feed conversion into milk and a higher utilization of the pasture. It has been found that feed production accounts for the main share of water input in livestock production (Singh et al., 2003). Feed management and animal management are seen as important measures for increasing the water productivity in livestock farming (Descheemaeker et al., 2010; Drastig et al., 2010).

The aim of this study is to quantify the influence of feed and livestock management strategies on the water productivity of milk in dairy farming for European conditions with milk yields up to 12,000 kg cow^{-1} $year^{-1}$. Various diets are combined with different milk yields and replacement rates to investigate their influence on water productivity of milk.

2. Materials and methods

2.1. System boundaries and data

This study analyzed the water productivity for milk production from cradle to farm-gate. The system comprises a defined number of dairy cows and their replacement. The replacement are calves and heifers, which are reared to recreate the dairy herd and to improve the genetics of the herd (Thornton, 2010). The system includes cow specific parameters, such as age at first calving, but also herd specific parameters, such as replacement rate. The replacement rate reflects the ratio of animals coming into the dairy herd to the average herd size (Kraatz, 2012). Pre-chains for the production of fertilizer, machines and buildings were excluded as well as transport and processing of milk and the water for cleaning, since they were found to be negligible (De Boer et al., 2012; Döring et al., 2013). Hence only water for feed production and drinking was considered in this study (Fig. 1.). The whole amount of water input was allocated to the milk as main product. In a case study for a commercial dairy farm in North-East Germany it was found that the contribution of slaughter cows to the revenues from the whole livestock system was about 10% only (Prochnow et al., 2012).

A typical dairy system located in Brandenburg, a part of North-East Germany, is modeled for the years 2008–2010. The herd size is assumed with 180 dairy cows of the race Holstein-Friesian and the milk yield is 8000 kg fat corrected milk (FCM) cow^{-1} $year^{-1}$ (Kraatz, 2012). A kg(FCM) contains 4% fat and 3.4% protein. The replacement rate is defined with 40% according to the average replacement rate for the German state of Brandenburg (LKV BB, 2011). The female calves and heifers are reared at farm in a period of 25 months to become a cow (Spiekers and Potthast, 2004). The male calves are leaving the farm 14 days after their birth. The lactation period is 305 days with an additional 60 day dry period. The feed is presented as total mixed ratio (TMR) and a free-stall barn is considered as keeping system. The feed production is considered at typical sites of Brandenburg.

2.2. Calculation of water productivity

2.2.1. Definition of water productivity

This study provides several expressions of the water productivity of milk, such as kg fat corrected milk, food energy, food protein and Euro per m^3 of water input (W_{input}). W_{input} [m^3] is calculated according to Prochnow et al. (2012) as the sum of crop transpiration from precipitation $W_{prec\text{-}transp}$ [m^3], the irrigation water W_{irri} [m^3], and the drinking water of the animals W_{drink} [m^3].

$$W_{input} = W_{prec\text{-}transp} + W_{irri} + W_{drink} \quad (1)$$

This approach includes in the water input that fraction of precipitation that contributes to plant biomass generation, that is, transpiration. Soil evaporation is excluded from the water input as it is not involved in biomass generation and should be minimized. In contrast, the total amount of irrigation water is considered as water input since withdrawal, distribution and application are controlled and paid for by the farmers. Furthermore, irrigation water is distracted from its natural flow, which might cause environmental impacts.

The water productivity of the milk WP_{milk} [kg(FCM) m^{-3}] is defined by the *milk yield* in kg(FCM) per cow in a year related to the water input W_{input} [m^3].

$$WP_{milk} = \text{milk yield}/W_{input} \quad (2)$$

The water productivity of the food energy of milk $WP_{milk\text{-}energy}$ [MJ m^{-3}] is defined by the *food energy* of milk produced per cow in a year [MJ] related to the water input W_{input} [m^3]. The food energy of milk is 2.85 MJ $kg(FCM)^{-1}$ (USDA, 2013).

$$WP_{milk\text{-}energy} = \text{food energy}/W_{input} \quad (3)$$

The water productivity of the food protein of milk $WP_{milk\text{-}protein}$ [kg crude protein (CP_{food}) m^{-3}] is defined by the *food protein* of milk produced per cow in a year [kg(CP_{food})] related to the water input W_{input} [m^3]. The food protein content of milk is 34 g(CP_{food}) $kg(FCM)^{-1}$.

$$WP_{milk\text{-}energy} = \text{food protein}/W_{input} \quad (4)$$

The water productivity of the milk on monetary base $WP_{milk\text{-}revenues}$ [€ m^{-3}] is defined by the *revenues* of milk produced per cow in a year [€] related to the water input W_{input} [m^3]. The average milk price of the years 2008, 2009 and 2010 is 0.3087 € $kg(FCM)^{-1}$ (MIL, 2012).

$$WP_{milk\text{-}revenues} = \text{revenues}/W_{input} \quad (5)$$

The water productivity of feed production WP_{feed} [kg dry matter (DM) m^{-3}] is defined as the water input W_{input} [m^3] for on-farm feed production and purchased feed production, e.g. soy bean meal. The output of feed is defined by the production of *dry matter* [kg(DM)] of single crops and feedstuffs related to their water input W_{input} [m^3].

$$WP_{feed} = \text{dry matter}/W_{input} \quad (6)$$

The water productivity of feed energy $WP_{feed\text{-}energy}$ [MJ net energy for lactation (NEL) m^{-3}] is defined as the feed energy