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POTENTIAL REDUCTION OF ECOLOGICAL FOOTPRINT, CO_2 EMISSIONS AND GWP USING AUTO TANDEM PARLOUR SYSTEM WITH HEAT EXCHANGER

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ABSTRACT

The intensification of milking production has led to activities that profoundly influence the ecosystem not only due to the fodder processing and farm management but also in milking and milk cooling, thus the estimating of environmental impact is essential. In our study, the Sustainable Process Index (SPI) was used for estimating ecological footprint, CO_2 emissions and Global Warming Potential (GWP) on two farms equipped with different milking and milk cooling systems. On the farm 1 the old milking pipeline with 2 jars, electric boiler and refrigerating system is used. Contrary, the farm 2 is equipped with modern 2 x 3 auto tandem parlour system with heat exchanger, which serves for cooling down the milk and successively heat the water for cleaning the systems. The farm 1 produces annually on the average 6,000 kg of milk per cow, while on the farm 2 the average annual production is 8,000 kg of milk per cow. On the first farm the ecological footprint for milking and cooling of 1 litre of fresh milk amounts to 8.3846 m^2 anno/l and on the second farm to only 2.7050 m^2 anno/l. Moreover, on the farm 2 also the total CO_2 and GWP emissions for milking and cooling of 1liter of milk is smaller for 67.67% and 67.82%, respectively, than on the farm 1. The results of our research proved that the modern milking systems not only requires less time and manual labour, but also significantly reduce negative effects on the environment.

Keywords: *milking pipeline, auto tandem parlour, ecological footprint, Sustainable Process Index*

INTRODUCTION

Increasing demand for daily fresh milk products has tremendously driven on increase in milking production in Europe since 1960s till nowadays. However, in the new century a fundamental objective of milk production is to assure net income for dairy farmers (VandeHaar and St-Pierre, 2006). Due to the wagging milk prices, in many parts of the developed world, dairy producers aim to increase farm income by maximizing milk yield per cow. This is usually accomplished by offering cows nutritionally precise diets in confinement and through improving genetic merit (Arsenault et al., 2009; Capper et al., 2009).

Besides other inputs, energy usage on dairy farms has grown gradually in the past 20 years due to increases in farm sizes, use of automated equipment, and around-the-clock operation. Dairy farms in the USA consume between 800 and 1,200 kilowatt-hours (kWh) per cow annually. About 50% of the total energy used on a dairy farm is spent for milk-production equipment, which includes milk cooling 25%, vacuum pump 17%, and water heating. Lighting and ventilation account for most of the remainder of energy used. In Ireland, for instance, electricity accounted for 60% of the direct energy use, whereby mainly resulted from milk cooling (31%), water heating (23%), and milking (20%).

Because of the large number of processes that contribute to electrically driven equiment, the evaluation of the whole value chain would extend the knowledge about the broader environmental performance of ecological impact cauased by milking and cooling of milk on fram. In early 1990s life-cycle assessment (LCA) was introduces for evaluating the environmental effects (air, water, and land) associated with any given activity, beginning with the initial gathering of raw materials from the environment to the point at which all residuals are returned to the environment known also as cradle-to-grave analysis (Romero-Gámez et al. 2012).

The Sustainable Process Index (SPI) belongs also to ecological footprint family and it was specially developed and customized for agriculture by Krotscheck and Narodoslawsky (1996). The concept of calculating the ecological footprint assumes that a sustainable economy might be built only on solar radiation as natural input and the earth's intact surface as the resource for the conversion of solar radiation into products and services. Since the global surface area is a limited resource, the area required to embed a certain process sustainably into the ecosphere is a appropriate measure for ecological sustainability.

To assess the ecological footprint of milk from particular dairy systems, it would be necessary to adopt a life cycle approach. This approach, referred to as life-cycle assessment (LCA), involves quantifying CO_2 and GHG emissions generated from all stages associated with a milk, from raw-material extraction through production, use, recycling, and disposal within the system boundaries (ISO, 2006a,b). Several studies have applied LCA methods to compare carbon footprints of milk from confinement and grass-based dairy farms (Belflower et al., 2012; O'Brien et al., 2012, Flysjö et al., 2011b). However, the results of these studies have been inconsistent.

The main goal of our research was focused on ecological footprint, CO_2 emissions and global warming potential (GWP) caused during milking and cooling of milk on two types of farm tipically represented in Slovenian dairy production; i) a tied-stall system with pipeline and 2 milking units and ii) the free-housing system with auto-tandem milking parlour (2 x 3).

MATERIAL AND METHODS

Farm 1

The milking system consists of a tied-stall system with pipeline and 2 milking units. The milked milk flows directly into the 1000 l refrigerating cooling tank, placed in the special part of the dairy. The milk is cooled to 4 ° C and stored for 48 hours before it is pumped to the collecting tank on the van. In the same room, a washing machine with associated washing heads for soap units is attached to the wall, and there is also a vacuum pump. The milking begins by cleaning the udder and obligatory removal of the first jets. Whole herd milking of 17 cows lasts about 1 hour. The most important task is to prepare milking units and equipment for the next milking. Immediately after milking, milking units and equipment are cleaned using a washing machine. In the majority of cases, the system is cleaned in the morning with basic, and in the evening with acid detergent. Washing machine works approximately 90 minutes. After the washing was completed, the machine automatically switches off and the equipment is ready for the next milking. In addition, every second day, when the cooling tank is empty, then cleaning of tank is done. The tank is not cleaned with the washing machine but manually. Like other equipment, the cooling tank is cleaned alternatively once with basic and secondly with acid cleaner.

Farm 2

This farm owns a new free-housing system with auto-tandem milking parlour (2 x 3). In the adjacent area of the dairy, there is the cooling tank with a volume of 2000 litres, and a washing machine with washable heads. The milking begins with the automatic opening of the gate to the dairy. When the cows are ready for milking, the wipes are washed and wiped off with paper towels, followed by the obligatory removal of the first jeans; then the dairy unit is installed in the wake. The entire herd's milking of 42 cows lasts for about 1.5 hours. After that the milking units are roughly washed to remove larger, rough dirt, which lasts for about 45 minutes. The overall cleaning of the system depends mainly on the water temperature. When the washing is complete, the machine is switched off automatically. Milk is stored in the tank for approximately 48 hours, and the removal to the dairy is guaranteed for at least another day. The milk that comes directly from the parlour system to the tank has got temperature between 22 and 23 ºC. Milk is cooled to 4 ºC temperature.

SPIonWeb tool

The SPIonWeb tool developed at TU Graz (http://spionweb.tugraz.at) is a license free software for estimating the ecological footprint, CO_2 emissions and GWP. The ecological footprint of each milking and cooling system was estimated by including environmental impacts related to fossil-C, air, water, soil, non-renewable, renewable and area resources.

Calculation of fossil-C assumed sedimentation of carbon to ocean beds, which requires about 500 m² of sea ground per year to put 1 kg of carbon back into the long-term (fossil) storage of the seabed.

The footprint for emissions to water is based on a replenishment rate, which is calculated on the precipitation rate in a specific geographic region of the compartment and a natural concentration of the emitted substance. In the SPI concept, the concentrations found in ground water are the reference for each natural compartment. The footprint of a given emission flow is therefore the area that is necessary to provide so much pure water via the seepage rate that may dilute the emission to the reference concentration of the emitted substance in ground water.

The footprint for emissions to soil is similar to the footprint for emissions to water, and it is calculated based on the regeneration rate of the compartment soil calculated as compost generated from grassland and the natural concentrations of the emitted substances in the top soil.

The footprint for emissions to air does not have a natural replenishment rate as do the other compartments, but the natural emissions of gaseous substances by forests are taken as a reference. The footprint for emissions to air is calculated as the area of forest that emits the same amount as the emission in question

One kilogram of CO_2 emissions or releases are calculated from the "Area for fossil carbon", where the extracted fossil carbon and carbon based materials are assumed to be oxidized to CO_2 over the life cycle and finally to end up as CO_2 emission to the atmosphere.

GWP (global warming potentials) are calculated on the basis of GWP factors i. e. carbon dioxide equivalent (CO_{2e}), where exhausts gases components are converted to CO_{2e} by multiplying their amounts for instance (CH_4 has 25 and N_2O 298 higher GWP then CO_2 itself). The sum of CO_2 life-cycle-emissions equivalents of all input processes and other GWP relevant impacts is the total GWP measured in kg CO_2 equivalent Kettl (2013).

Input data

Data for this study was retrieved from interviews as well as measurements of working process on two different types of milking farm, whereby the one-week lasting chronometric measurements were considered as a basis for estimation of ecological footprint. The following input parameters were first measured chronometrically: time of milking per cow (min), amount of milk per cow (l), the average amount of energy spent for milking one cow (kW), the average amount of energy spent for 1 liter of milk per cow (kW), the amount of energy spent for cooling of 1 liter milk (kWh) and the amount of water required per washing of all equipment (l).

RESULTS AND DISCUSSION

The average quantity of milk per cow

Table 1 represents the average quantity and standard deviation of milk per cow per one milking on each farm. As seen, on average 9.55 l per cow was produced on farm 1 and 11.43 l per cow on farm 2. The difference of 1.88 l depends on better fodder quality, variety, day of lactation as well as type of housing, which is strongly connected with animal behavior.

Table 1 Average quantity of milk per cow

	Cows (n)	Average (l)	St. deviation (l)	CV (%)
Farm 1	17	9.55	2.18	22.82
Farm 2	42	11.43*	3.26	28.52

*significant t-test at $p<0.05$

The average time of milking per cow

The total time of milking took on average 1 hour for herd on farm 1 and 1 hour and 30 minutes for herd on farm 2 (Table 2). Contrary, the milking of one cow took 7.46 minutes on farm 1 and 6.42 minutes per cow on farm 2, respectively, which means that the outflow of milk was quicker in herd 2. The main reason lies probably in the varieties of cow, because 20% of all animals is Holstein-Frisien breed on the farm 2, while on farm 1 all cows belongs to Simmental breed.

Table 2 Average time of milk per cow

	Cows (n)	Average (min)	St. deviation (min)	CV (%)
Farm 1	17	7.46	2.27	30.43
Farm 2	42	6.43 $^{n.s.}$	2.43	37.79

$^{n.s}$ not significant t-test at $p<0.05$

The average electricity consumption per milking of one cow

The average electricity consumption amounts to 0.083 kWh per one milking of one cow on farm 2 and 0.088 kWh per one milking of one cow on farm 1 (Table 3). The quantity of electrical energy is directly correlated to average time of milking, since the nominal power of vacuum pumps is similar on both farms.

Table 3 Average amount of electrical energy per cow and one milking

	Cows (n)	Average (kWh)	St. deviation (kWh)	CV (%)
Farm 1	17	0.088	0.027	30.68
Farm 2	42	0.083 $^{n.s.}$	0.032	38.55

$^{n.s}$ not significant t-test at $p<0.05$

However, the outflow of milk differs significant between the cows inside the same herd. For instance, on the farm 1, for milking of cow 'Boka' only 0.048 kWh was spent and contrary 0.142 kWh per milking of cow 'Riba'.

The average electricity consumption per milking of 1 liter of milk

The average electricity consumption amounts to 0.0073 kWh per milking of one liter of milk on farm 2 and 0.0092 kWh per one milking of one cow on farm 1, respectively (Table 4). The smaller amount of electrical energy per one liter of milk on herd 2 is primary connected with higher average quantity of milk per cow and quicker milk outflow and not with milking system itself.

Table 4 Average amount of electrical energy per cow and one milking

	Cows (n)	Average (kWh)	St. deviation (kWh)	CV (%)
Farm 1	17	0.0092	0.0020	22.73
Farm 2	42	0.0073 n.s.	0.0023	28.92

n.s not significant t-test at $p<0.05$

The electricity consumption for cooling of 1 liter of milk

On the farm 1 for cooling and storage of milk in 1000 l tank 5.956 kWh was spent on average in 48 hours during our measurements, which means 0.0059 kWh per 1 liter of milk. However, in warmer part of the year the energy consumption can be even for 12% higher. On the other side, for cooling the milk in the modern 2000 l tank on average 61.45 kWh was spent on farm 2, which amounts to 0.0031 kWh per 1 liter of milk.

Water consumption for cleaning the system

The average consumption of water per one cleansing of pipeline system amount to 56 l, while per cleansing of parlour system 50 liters or 10.6% less is spent after each milking, so annual amount is 4.380 liters less than on the farm 1.

Table 5 Average split of dairy farm electricity use in kWh per 1 liter of milk/lactation

	Farm 1 1 litre milk (n=17)	Farm 2 1 litre milk (n=42)	Farm 1 Lactation (n=17)	Farm 2 Lactation (n=42)
Water heating	0.0079	Heat exchanger	47.3143	Heat exchanger
Water pumping	0.0076	0,0002	45.3429	1.5762
Milk cooling	0.0059	0.0031	35.4857	24.8000
Milking	0.0092	0.0073	55.2000	58.4000
Lighting	0.0010	0.0000	5.9143	0.2056
Other	0.0013	0.0000	7.8857	0.0010
Total	0.0329	0.0106	197.1429	84.9828

Estimation of ecological footprint and other emissions

Estimated ecological footprint, CO_2 release and GWP caused by all processes on a dairy farm (Table 5) during milking, cooling and storage of 1 litre milk on two different milking systems is represented in Table 6. Despite higher lactation of the average cow on farm 2, the ecological footprint for milking on auto-tandem parlour system is for 67.74% smaller than on the pipeline system. The main reason represents the innovative cooling system of milk on one side and heating of processing water on other side, which is based on the heat exchanger and thus save approximately 0.0079 kWh per each litre of milk. The footprint of processing the fresh water needed for cleaning of the milking system is in both cases practically the same and amount to 0.0005 m^2 anno/ for l litre of milk.

The estimated CO_2 release for auto-tandem parlour system is also for 67.67% smaller than the one emitted for milking with milking pipeline (8.3846 m^2 anno/ l). The main reason lies in the SPIonWeb assuming that the fossil fuels is still a dominant energy for producing of electricity.

In the case of global warming potential 0.0102 kg of CO_2 equivalent was estimated for milking on the parlour system and 0.0317 kg of CO_2 equivalent when milking on pipeline system. On this way 67.82% smaller GWP is emitted on the farm 2.

Table 6 Ecological footprint, CO_2 emissions and GWP for all operations during milking and cooling of 1 litre milk

Milking system	Footprint (m^2 anno/ l)	CO_2 (kg)	GWP (CO_{2eq})
Pipeline	8.3846	0.0300	0.0317
Auto tandem parlour	2.7050	0.0097	0.0102

CONCLUSIONS

Slovenian dairy production depends very much on the European market prices, which are wagging for almost second year after the milk quotas were abandonee, so dairy producers aim to increase farm income by maximizing milk yield per cow. However, this is not connected only with higher and better fodder demand, but also with increase cost of energy, manual labor and not least with rising of ecological impact of diary production. In the presented study the ecological footprint, CO_2 emissions and GWP was estimated with SPIonweb software on two Slovenian dairy farms. The results showed significant decrease of all ecological impacts whenever a newel milking and cooling technique (parlour milking system with heat exchanger) is used instead of old milking pipeline and refrigerator system, is used. On the farm 1 the old milking pipeline is used for milking 17 cows, and on the farm 2 42 cows is milked with modern 2 x 3 auto tandem parlour system. It was shown that ecological footprint for the average lactation of 6,000 liters of milk per cow annual footprint amounts to 50,307.6 m^2 anno/ l and it is for 57.99% bigger than on the farm 2 producing on the average 8,000 liters of milk per cow annual. Moreover, despite higher average lactation on the farm 2, the total emissions of CO_2 caused by electricity and water consumption amount to 77.5 kg, which for 56.89% less than on the farm 1. Also, the GWP on the farm 1 is almost double of that on the farm 2 (190.2 kg versus 81.6 kg).

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