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Comparative carbon footprints of buffalo milk produced at smallholder and organised farms in Hisar district of Haryana, India

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ABSTRACT

The present study was conducted to compare the carbon footprint of milk produced in 75 smallholder farms and two organised buffalo farms in Hisar district of Haryana using Life Cycle Assessment approach. Primary data was collected from farmers and farm managers for the study. Functional unit was one litre of milk with system boundary being 'Cradle-to-farm gate'. Methodology prescribed by Intergovernmental Panel on Climate Change was used for estimation of emissions from different sources. Secondary data was also relied upon for synthetic fertilizers and seeds, combustion of fossil fuel, production of concentrates and dry fodders. The average carbon footprint of milk produced in rural smallholder and organised farms were 3.54 and 4.53 kg CO_2-eq./L milk, respectively, indicating superiority of village level production systems. Methane from enteric fermentation was estimated to be contributing nearly half of the total greenhouse gas emissions. It is suggested that rural smallholder production systems should be favoured over organised ones given the lower greenhouse gas emissions.

Keywords: Buffalo milk, Carbon footprint, Commercial farms, LCA, Smallholder

Among the other sources, livestock sector represents a significant source of greenhouse gas emissions worldwide; generating carbon dioxide, methane and nitrous oxide throughout the production process (Steinfeld *et al.* 2006). These long lasting greenhouse gases are more chemically stable and persist in the atmosphere for decades to centuries; their emission has long-term influence on the Earth's climate (IPCC 2007). Greenhouse gas emissions from livestock sector have earlier been estimated as 7.1 gigatonnes CO_2 -eq. per annum, representing 14.5% of total global anthropogenic emissions (Gerber *et al.* 2013). Further, the global demand for milk is increasing and it is estimated to rise by 58% during the coming 40 years (FAO 2011). Thus the number and productivity of livestock will continue to rise in future. However, their impact on environment will be shaped by how we resolve the balance of two competing demands: one for animal food products and the other for environmental services. Both demands are driven by the same factors: increasing population, growing income and urbanization (Gerber *et al.* 2010).

Studies in the past have largely been focussed on estimation of carbon footprint of cow milk and there is a lack of reliable information about carbon footprints of buffalo milk. It becomes all the more important given the fact that India has highest buffalo population in the world. These buffaloes are mostly reared in mixed farming system although there is an increasing trend of commercialization, intensification and delinking crop livestock production systems.

Further, an argument is generally put forth that the animals in organised farms emit less GHGs as compared to rural production systems. On the other hand, these smallholder crop livestock integrated production systems (smallholder) are intuitively less polluting given the fact that they involve less alterations in the natural cycles. In the absence of reliable information, one cannot choose a pathway for climate friendly production systems. In such a situation, a reliable estimation of carbon footprints and comparative assessment between commercialized and village level (generally smallholder integrated crop livestock) production systems becomes important. The present study was conducted with the view to compare carbon footprints of buffalo milk produced at village level (smallholder) and commercialized milk production systems.

MATERIALS AND METHODS

Locale of the study and data collection: The present study was conducted in Hisar district of Haryana, India. It is classified as hot arid eco-sub-region lying in Trans Gangetic plain region (Western agro-climatic zone) with an average altitude of 234 m above mean sea level (GoI 2015). The region is famous for its jet black coat coloured Murrah breed of buffalo. A large majority of

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farmers rear Murrah buffaloes in rural areas. The city also has a number of commercial dairy farms which cater to the local milk demand including a few organised buffalo farms run by public sector institutions. Primary data was collected from randomly selected 75 smallholder farms and two organised farms. Three villages were selected from a list of villages in a district using simple lottery method. The selected villages were – Bherian, Ravalwas and Sisai. Twenty five farmers were then selected randomly from each village. Thus primary data was collected from 75 smallholder farmers. One organised buffalo farm of Lala Lajpat Rai University of Veterinary and Animal Sciences (LUVAS) and one private commercial farm were selected randomly. A semi-structured interview schedule and observation sheet was developed with the provisions for all the relevant information. The data was collected from all the respondents from October 2015 to March 2016. During the interview, detailed information about household, agriculture farm size, fodder cultivation for livestock, manure and synthetic fertilizer use, seed application rate for fodders, herd composition of buffalo farm, feeding and management practices, milk production and manure management were collected for a period of one year. The data from organised farms was obtained from farm managers.

Data from all the 75 smallholder farms was pooled to arrive at an average which was taken as one representative farm for smallholder production systems. Again, in case of two organised farm, the same process was followed. This was done to increase representativeness, precision and reliability of data.

Methodology adopted: Use of life cycle assessment (LCA) is generally accepted method to evaluate the environmental impact during the entire life cycle of a product (Guinee *et al.* 2002). LCA methodology is well-adapted to evaluate agricultural systems because it provides an objective method of defining the production system and quantifying impacts in terms of the outputs of a production system (Casey and Holden 2005). The method has been used in number of studies estimating the impact of livestock products like meat, pork, chicken, eggs and milk. LCA provides an adequate instrument for environmental decision support and is well defined in the ISO standards 14040 and 14044 (ISO 2006). The present study also relied on the LCA for estimating carbon footprint (CF) of milk. There are four phases in an LCA: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and life cycle interpretation (ISO 2006).

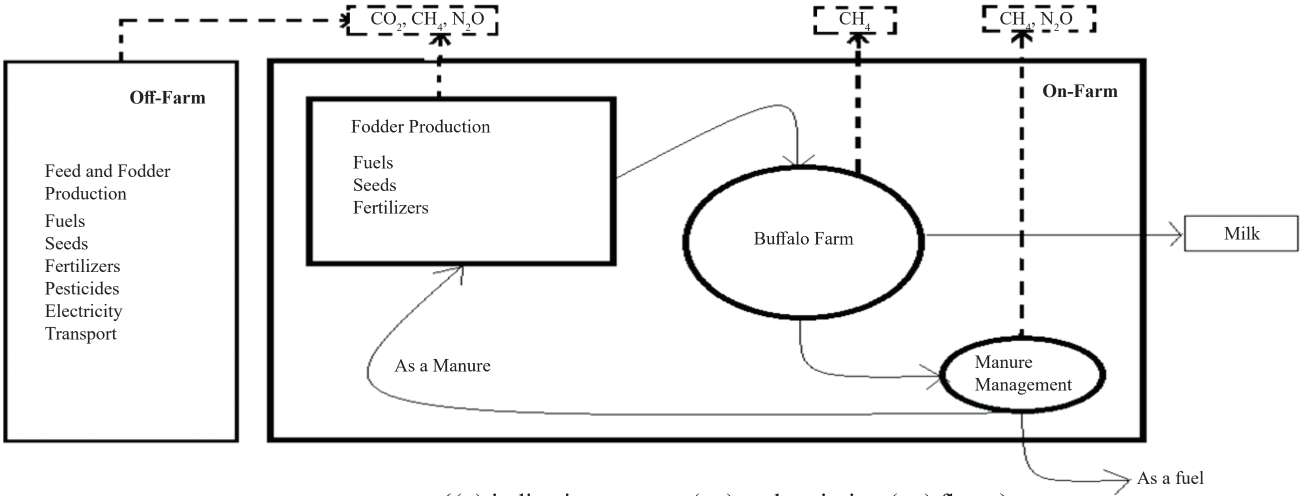
Goal and scope definition: The primary goal of the present study was comparison of CF of buffalo milk obtained from village level and organised milk production systems. The Functional Unit (FU) in the present study was One litre of milk. The system boundary followed in this study was 'cradle-to-farm gate' (i.e. greenhouse gases emissions for the production of buffalo milk up to farm gate only).

Since in both the production systems (smallholder and organised) nearly similar practices of feeding animals, manure management and fodder sources (cultivation) are followed, hence only one model was formed which sufficiently served the purpose. The model applied in the study was same as adopted by Garg *et al.* (2016) and it has been illustrated in Fig. 1. In the model, both on-farm and off-farm processes related to buffalo milk production were included. The on-farm process included- activities on buffalo farm, agriculture farm (for fodder cultivation for buffaloes only) and manure handling and storage. Similarly, off-farm process included production of dry fodder and concentrates used. The GHGs emissions from both systems were calculated for:

(1) On-farm methane (CH_4) emissions from enteric fermentation, manure handling and storage at buffalo farm.

(2) On-farm nitrous oxide (N_2O) emissions during manure handling, storage at buffalo farm and from managed soils owing to cultivation of fodders for buffaloes.

(3) Off-farm GHG emissions (CO_2 -eq.) from feed and fodder production like concentrates and dry fodders.



{(–) indicating process (→) and emission (--›) flows}

Fig. 1. Model depicting system boundaries followed in the present study [Source: Garg *et al.* (2016)].

(4) On-farm GHG emissions (CO_2 -eq.) owing to production and processing of synthetic fertilizers and seeds and emissions due to combustion of fossil fuel for running machinery at agricultural farm.

The allocation procedure described by ISO (2006) states that, whenever possible, allocation should be avoided. Accordingly, no allocation strategy was adopted in the study. Earlier, other researchers have also used no allocation method, for example, Phetteplace *et al.* (2001) and Capper *et al.* (2009). The attributional approach of LCA was followed because it required average data use with current production conditions only. Attributional LCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems (Finnveden *et al.* 2009) but does not consider indirect effects arising from changes in the output of products.

Life cycle inventory analysis: Life cycle inventory (LCI) analysis involves compilation and quantification of inputs and outputs for a product throughout its life cycle (ISO 2006). The results of the inventory analysis serve as input for impact assessment.

The data related to herd composition, feeding of animals, manure handling and storage, production of milk and cultivation of fodders for animals was collected directly from the farmers and farm manager. The secondary data were obtained from peer-reviewed literature, textbooks and reports. Information about feeding of each animal in buffalo farm and milk production of each lactating animal was collected for a period of one year. The detailed information about cultivation of each fodder crop was also obtained from primary sources. For each fodder crop, information about use of synthetic fertilizer and seed application rate was also collected. Information about purchased concentrates and dry fodders were also obtained directly. Likewise, it was also obtained for composition of concentrates being fed to animals. The data about land use, fuel and manure application was taken from secondary sources. The GHGs emissions from on and off farm activities were estimated using Intergovernmental Panel on Climate Change (IPCC 2006) guidelines. The emission factors (CO_2 -eq./ kg of input material) for production of concentrates and dry fodders, combustion of fuel, production and processing of fertilizers and seeds were taken from secondary sources (Supplementary Table 1).

For the estimation of methane emission, the feed consumption in the form of daily dry matter intake (kg DM/ day) for each buffalo was calculated by converting it into gross energy intake (MJ/ day). Tier 2 approach of emissions estimates of IPCC standard for methane calculation was used (equation 21, IPCC 2006). Gross energy (GE) was calculated by multiplying dry matter intake of feeds (kg/ day) with energy density of the feed. For energy density, a default value of 18.45 MJ/kg of dry matter was used because feed specific information was not available. Buffalo methane conversion factor (Ym) = 6.5% ± 1.0% was used. Average dry matter intake (kg/day) of each feed and fodder given to animal was calculated by dry matter weight factors based on Ranjhan (1991) and Banerjee (2012), (Sorghum, oat, berseem, maize, pearl millet, china cabbage, local grass, wheat straw and concentrates contains dry matter weight factor used was 35, 18.2, 13, 25, 25, 20, 20, 90 and 100 % of total weight of fodder, respectively).

Methane emission from solid manure storage and following application on land was also estimated using Tier 2 approach prescribed by IPCC (IPCC 2006). Manure methane was estimated as proportion of maximum methane potential (B_o) of manure volatile solids (VS) excreted (IPCC 2006; Equation 10.23). Excreted VS of manure was calculated by using gross energy intake (MJ/ day) and manure methane conversion factor (MCF).

The nitrous oxide (N_2O) is produced directly and indirectly, during the storage and treatment of manure. Tier-1 approach of IPCC methodology was used to estimate N_2O from solid system of manure management. Equation 10.25 of IPCC (2006) was used to estimate direct N_2O emissions by calculating Nex (annual N excretion) with use of estimated weight of animals [500 kg for lactating and non-lactating buffaloes, 235.06 and 363.7 kg for heifer (1-2 year age) and for heifer (2-3 year age), respectively]. Equations 10.27 and 10.29 were used for indirect N_2O emissions which are due to volatilisation and leaching of nitrogen from manure, respectively.

In the present study, Global Warming Potential (GWP100) for each greenhouse gas (kg CO_2-eq./kg gas) was used for estimating carbon footprints based on recommendations of IPCC (2007)

RESULTS AND DISCUSSION

Information related to Herd composition and production characteristics of both representative farms are depicted in Table 1. In this aspect first five entries are drawn as aggregated values while others are taken as cumulative value of average.

Table 1. Herd composition and production characteristics of smallholder and organised farms

Herd composition	Smallholder farm	Organised farm
Lactating buffalo	109	62
Non- lactating buffalo*	23	35
Heifer (1-2 year age)	17	41
Heifer (2-3 year age)	40	19
Buffalo calf (up to 1 year age)	104	60
Age of milking buffalo (years)	5.84	5.29
Lactation (th)/Parity	3	2
Milk fat %	7.59	7.2
Milk produced in a year (L)	2584.24	2753.03

Different types of feed and fodders available with total amount of each one round the year was estimated. Further, from total requirement of green fodders for both farms, cultivation area needed for yearly fodder production was also estimated (Supplementary Tables 2-4).

Table 2. Life Cycle Inventory of inputs and milk produced

System input and outputs	Material used (Unit)	Quantity (Smallholder farms)	Quantity (organized farms)
On-Farm inputs	Synthetic fertilizers (kg)	1456.80	1364.16
	Fuel (Diesel) (L)	180.55	174.93
	Seeds (kg)	1039.35	1193.84
Off- Farm inputs	Wheat straw (kg)	390269.6	206042.5
	Cotton seed cake (kg)	108222.6	-
	Cotton seed (kg)	34884.79	-
	Gram hull (kg)	16691.3	-
	Wheat bran (kg)	87914.71	12446.5
	Wheat flour (kg)	46214.88	38452.39
	Wheat grain (kg)	-	38452.39
	Pearl millet grain (kg)	2369.99	-
	Barley grain (kg)	810.3	22390.62
	Maize bran (kg)	-	14306.94
	Mustard cake (kg)	-	40808.95
	Soya bean meal (kg)	-	9013.905
	Groundnut cake (kg)	-	10572.99
	Deoiled rice polish (kg)	-	40601.11
	Rice polish (kg)	-	12446.5
	Oat grain (kg)	-	2790.66
Out-put	Milk production (L)	281682.34	170687.56

* >3 years, include nulliparous mature and multiparous non-lactating buffalo.

On-farm and off-farm contribution to GHG emissions: Table 2 summarizes the inventory of inputs and output in smallholder farm and organised farm, respectively.

Life cycle impact assessment (LCIA)

Life Cycle Interpretation: As is evident from Table 3, CF of milk from organised farm was 4.53 kg CO_2 -eq./L of milk which is more than the smallholder farm (3.54 kg CO_2 -eq./L). At least, some of these differences can be attributed to varying emissions from enteric fermentation, off-farm concentrate and dry fodder production and finally nitrous oxide from managed soils (Fig. 2). The contribution in percentage terms however appears similar.

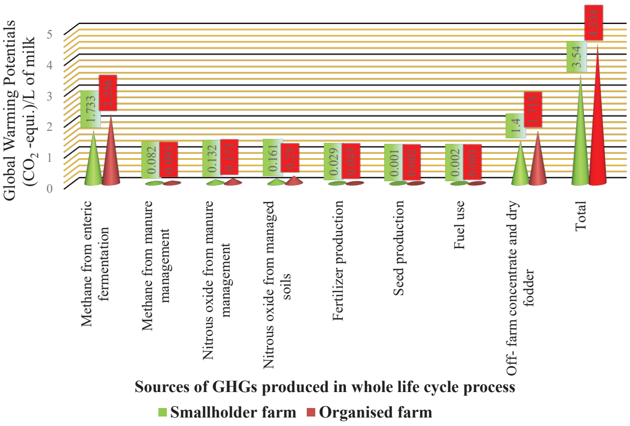


Fig. 2. Comparison of carbon footprint of milk between smallholder and organised farm.

Earlier, Pirlo *et al.* (2014) reported carbon footprints of buffalo milk as 3.75 kg CO_2– eq./ kg of FPCM after a study in Italy. Whereas, Garg *et al.* (2016) reported the average carbon footprint of buffalo milk as 3.0, 2.5 and 2.7 kg CO_2 –eq./ kg of FPCM on mass, economic and digestibility basis allocation, respectively based on a study on 60 smallholder dairy farms in Anand district of Gujarat state, India. It has earlier been held that comparison of LCA results from various studies should be considered with great caution because of differences in methodology (functional unit, characterization factor for GWP, allocation method, emission unit, time period, etc.) and assumptions (de Boer 2003, Thomassen *et al.* 2008, Beauchemin 2013, Mc Geough *et al.* 2012). Also, there is likelihood that these differences were due to differences in breed, productivity, manure handling and storage, concentrates use and dry fodder feeding practices. Global cradle to farm gate average emission intensity of buffalo milk has been reported as 3.2 kg CO_2 –eq./ kg of FPCM for mixed farming system (Gerber *et al.* 2013). The average milk

Table 3. Estimated yearly GHG emissions per litre of milk produced and their total global warming potential emissions using 100 year characterizations.

Sources of Emissions (kg CO_2 -eq.)	Total GWP emissions		Carbon footprint of Milk	
	Smallholder farm (kg CO_2 -eq.) (%)	Organised farm (kg CO_2 -eq.) (%)	Smallholder farm (kg CO_2 -eq./L of milk)	Organised farm (kg CO_2 -eq. /L of milk)
Methane from enteric fermentation	488123.2 (48.95)	385033.8 (49.71)	1.733	2.256
Methane from manure management	22977.04 (2.30)	15904.25 (2.05)	0.082	0.093
Nitrous oxide from manure management	37075.71 (3.72)	29530.01 (3.81)	0.132	0.173
Nitrous oxide from managed soils	45403.34 (4.55)	42727.24 (5.52)	0.161	0.250
Fertilizer production	8245.53 (0.83)	7721.14 (1.00)	0.029	0.045
Seed production	311.81 (0.03)	358.152 (0.05)	0.001	0.002
Fuel use	565.13 (0.06)	547.5309 (0.07)	0.002	0.003
Off- farm concentrate and dry fodder	394483.1 (39.56)	292705.5 (37.79)	1.400	1.715
Total	997183.5 (100)	774527.6 (100)	3.540	4.538

emission intensity range from 3.2 (in South Asia) to 4.8 kg CO_2 –eq./kg FPCM (in East and Southeast Asia) (Gerber *et al.* 2013). However, FAO estimates considered N_2O emissions from direct deposition of manure by grazing stock and scavenging animals, indirect CO_2 emissions due to direct on-farm energy used during manufacturing of building materials for on-farm structures (buildings and equipment) and CO_2 emissions due to direct on-farm energy used for livestock (e.g. cooling, ventilation and heating). On the contrary, it was observed in the present study that a majority of buffaloes were reared in stall fed and housed in low input based shed in contrast with FAO assumptions.

The emissions appear to be on higher side when compared with reports from developed countries. For example, Thomas *et al.* (2013) after study on 536 dairy farms of USA reported Carbon footprint of milk using cradle to farm gate approach in USA as 1.23 kg CO_2 –eq./kg FPCM. Similarly, 1.02 kg CO_2 –eq./kg of milk was reported by Vergé *et al.* (2007) with no allocation method used in LCA in Canada. In Italy, it was 1.13 kg CO_2 –eq./kg of FPCM (Penati *et al.* 2010) and 0.89-1.22 CO_2 –eq./ kg of FPCM (Pirlo *et al.* 2013). Thomassen *et al*. (2008a) reported 1.4-1.5 kg CO_2 –eq./kg of FPCM in the Netherlands.

The study attempted to compare carbon footprints of milk produced in village setting and commercial milk production system. The results of study clearly indicate that smallholder village level production systems are desirable at least from point of view of GHG emissions. However, it is emphasized that the GHG emissions are not the only undesirable environmental consequences of livestock.

It is concluded that the rural production systems should be favoured as a matter of policy goal given the fact that these entail less distortions in the environment and are efficient given their relatively lower GHG emissions. The major source of GHG production in buffalo farms is methane from enteric fermentation. Thus it can be argued that enhancing the productivity in the longer run would prove useful for minimizing GHG emissions.

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