Life Cycle Assessment of Dairy Buffalo Calves in an Italian Farm

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Abstract: The aim of this paper was to examine the environmental consequences of raising buffalo calves, as assessed by life cycle assessment. Life cycle assessment has been widely used to assess the environmental impact of different livestock production systems. The primary data were collected from 32 animals aged 0-90 days. Calves were allowed to uptake colostrum before separation from their mothers within 24-h after birth. After separation, the animals were kept individually (1 x 2 m) for 8 weeks and then housed in groups of 8 in straw-bedded pens (5 x 8 m). According to the results of the analysis, the contributions from all calves to global warming potential, acidification potential, eutrophication potential, non-renewable energy use was high. In particular, the impact generated from global warm potential was 7 kg CO_2 – eq per day, and the impact of non-renewable energy use was 38 MJ – eq per day. Our results estimated for the first time the environmental impact generated from buffalo calves. We conclude that the strategies to mitigate the effects on the environment impact must start from the birth of the buffalo calves and then continue throughout its life cycle.

Keywords: Life cycle assessment, buffalo calf, global warming potential, environmental sustainability, dairy farming.

INTRODUCTION

The water buffalo (*Bubalus bubalis*, referred hereafter as buffalo) is important to the economy of several countries in Asia and South America and partly in north Africa (e. g. Egypt) and Europe (e.g. Italy). The buffalo is an important contributor to milk, meat, power and leather production in many developing countries. Buffaloes can be categorized into River and Swamp buffalo [1]. The contribution of methane derived from ruminal fermentations to agriculturally greenhouse gas emissions has led to increasing efforts to develop strategies for the reduction of ruminant methane production [2]. The carbon footprint has been defined as the total amount of greenhouse gas (GHG) directly and indirectly produced by a particular individual, in a particular event or during a particular productive process, and expressed as CO_2-eq. Countries adhering to the Kyoto Protocol—[3] agreed to reduce the emissions of GHG as estimated in 1990. The main GHG emissions attributed by the International Panel of Climate Changes (IPCC) to the agricultural sector are CH_4 and N_2O. Animal enterprise are responsible for the production of GHG under the form of CH_4 from enteric fermentations (EF), N_2O deriving from the use of nitrogenous fertilizers, and CH_4 and N_2O emitted from manure managed under intensive farming conditions or direct manure deposition on pastures in more extensive systems. Animal productions are responsible for 8–10% of GHG emissions as assessed by IPCC. Based on life cycle analysis livestock enterprise give a contribution of up to 18% of total emissions [4]. Within the animal production sector meat and meat products are the goods with the highest environmental impact, whereas dairy products represent the second group of animal products with the highest impact. They are deemed to cause 5% of GHG emissions, determine 10% of eutrophication potential, contribute with 5% and 4% to the acidification and photochemical ozone creation potentials, respectively [5].

Progress in technology and the adoption of improved agricultural practices can promote the reduction of GHG emissions from livestock production enterprise. In the near future dairy enterprise will have to meet increasing environmental regulations including limits on GHG and noxious gas emissions (e.g. NH_3) and restrictions on nitrate leaching and phosphate runoff [6]. In the last ten years Life Cycle Assessment (LCA) has been used in several studies to assess the environmental impact of different milk production systems across Europe. In particular, LCA allowed the comparison between intensive and extensive systems [7, 8] as well as the evaluation of the environmental performance of typical dairy enterprise.

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ISSN: 1927-5196 / E-ISSN: 1927-520X/18

For animal based production enterprise the identification of best practices from an environmental point of view is not simple as different systems often imply tradeoffs between different forms of impact. For instance, some systems may favor biodiversity conservation and carbon sequestration, in others food production may be more efficient.

In Italy, one of the most important dairy enterprise is represented by buffalo farming and mozzarella cheese production within the trademark “Mozzarella di bufala Campana – DOP”. In the recent past the population of Italian Mediterranean Buffalos has significantly increased almost reaching 420,000 head [9]. Despite the economic relevance of buffalo farming in Italy and the increasing interest in this species worldwide and despite nutritional management of calves is an important phase of the dairy buffalo enterprise, no study on the environmental impact of buffalo calves as assessed by LCA has been conducted. Therefore, the present study aims to evaluate the effects on the environment of buffalo calves, as assessed by LCA.

MATERIALS AND METHODS

Life Cycle Assessment

LCA is a compilation and evaluation of the inputs, outputs and environmental impacts of a production system throughout its life cycle [10]. The LCA analysis was conducted according to ISO standards [11, 12] in 4 steps. Goal and scope definition, inventory analysis and impact assessment were addressed in Material and Methods, and interpretation was addressed in Results and Discussion.

Goal and Scope Definition

The aim of this study was to assess the environmental impact of management system on Mediterranean Italian buffalo calves. The analysis included the life cycle of the period of time from birth to 90 days of age. All the processes related to the on-farm activity (i.e. production of forages and crop, use of energy, fuel and electricity, management of manure and livestock) and related emissions were taken into account. Emissions and energy consumption from off-farm activities, such as production of fertilizers and pesticides, fodders and bedding materials, feed concentrate, electricity and fuel were included in the estimation. Transports associated with the production and delivery of purchased feed (both commercial feed and roughages) and bedding material were included in the estimate. As suggested by [13], 1 day of the period was used as functional unit.

Inventory Analysis

The inventory comprised the data from 32 buffalo calves homogenous for age and body weight (32 ± 3 kg), at Eboli in the Salerno province, SW Italy (15°03’E, 40°37’N; ~5m above sea level). Calves were allowed to ingest colostrum and then they were separated from their dam within 24-h after birth. After separation, the animals were kept in individual cages (1 x 2 m) for 8 weeks and then housed in groups of 8 in straw-bedded pens (5 x 8 m). They were fed reconstituted milk (6 l/calf/day at 18% DM). After 4 weeks, the amount of milk substitute was gradually reduced while meadow hay and concentrate administration increased. The data were collected from birth (0 days) to the age of 90 days. The live weight at the end of the trial was (118 ± 3 Kg). The components and chemical composition of the ration offered to the animals are reported in Table **1**. Methods and emission factors are listed in Table **2**.

Table 1: Inventory Analysis for Feed and Chemical Composition (on Dry Matter Basis)

	0-90 days
Feed consumption (kg DM[1]/head)	
Milk powder	100
Maize flour	7
Meadow hay	25
Soybean meal	3
Barley flour	2
Sun flower	3
Feed nutritional value, % DM[1]	
Crude protein	23.1
Crude fiber	7.2
Neutral detergent fiber	14.4
Ash	7.0
Starch	5.2
MFU[2]	0.93

[1]DM = Dry matter.
[2]Units/kg dry matter; one Milk Forage Unit = 7.11 MJ of net energy for lactation.

Carbon dioxide (CO_2) emitted during energy consumption, either directly from the combustion of fossil fuels or indirectly from electricity use, was estimated taking into account the amount of diesel fuel in litres and the amount of electricity in kWh consumed

Table 2: Equations and Emission Factors for the Estimation of Emissions

Pollutant	Source	Amount	Emission Factors	Reference
kg CH_4	Enteric	CH_4= kg DMI herd^{-1} * 18.45 (Gross Energy MJ kg^{-1} DMI) * Ym%/55.65	Ym (6.5% ±1.0%)	[15]
	Storage a	CH_4=VS *B_0 * 0.67 * MCF/100 * MS	MCF pit storage: 27	[15]
kg N_2O direct	Storage	N_2O = Nex (conf. syst.) * MS * EF * 44/28	0.02	[15] [17]
kg N_2O indirect	Storage	$N_2O_{(G)}$= Nvolatilization * EF * 44/28	0.01	[15]
Kg NH_3	Storage	Nvolatilization = Nex (conf. syst.) * MS * Frac_GasMS/100 *17/14	Frac_GasMS solid storage: 40	[15]
Kg CO_2-eq	Diesel use	CO_2-eq. = l diesel * EF	3.13	[29]
	Electricity use	CO_2-eq. = kWh * EF	0.47	[30]

throughout farm operations. The amounts of purchased fuel were summed up to estimate the fuel used for general agricultural practices and animal feeding. As suggested by [14], we used a standard value of 0.85 kg per litre as diesel density, and a 3.13 eq. emission factor to estimate CO_2 release from the combustion of 1 kg of diesel. As it was not possible to get primary data concerning the consumption of diesel fuel and electricity consumptions of individual animals, we measured these data at farm level and then allocated them on the basis of the livestock units (LU) involved in each phase.

Methane (CH_4) emissions from EF were calculated according to the method Tier 2 [15] which is based on dry matter intake (DMI). CH_4 emissions from stored manure were calculated on the basis of IPCC guidelines following the Tier 2 method [15].

Calculations for direct nitrous oxide (N_2O) emissions from manure storage were based on excretion of nitrogen (N) given as the difference between total N intake (the calculation was based on the dry matter ingested by the animals and the N content of the diet) and the N output in products (live weight in kg). We used the emission factors as proposed by [15] for liquid slurry storage. Direct and indirect N_2O emissions from the field also occur after the application of organic and inorganic fertilisers. Direct N_2O emissions were estimated from the inputs of nitrogen in the form of mineral and organic fertilisers, crop residues and N mineralisation as suggested by the [16] Tier 1 method. We estimated the amount of nitrous oxide emitted from manure storage and management based on total N excretion and the country-specific EF of 0.02 kg of N–N_2O/kg of excreted N for Italy [17]. In particular, for indirect deposition from the atmosphere an EF of 0.01 kg N_2O/kg N was used, whereas of 0.025 N–N_2O/kg N was used for N leaching-runoff as suggested an Italian country specific EF by [18]. The volatilisation of nitrogen under the forms of NH_3 and NO_x that occurs during the application of organic and mineral fertilisers was estimated using the default emission factor indicated by Tier 1 in the guidebook [19].

Live Cycle Impact Assessment

For this study the selected impact categories and the related units were:

- Global Warming Potential for a time horizon of 100 years (GWP): kg CO_2-eq
- Acidification: kg SO_2-eq
- Eutrophication: kg PO_4^{3-} -eq
- Non-renewable energy use: MJ-eq

The life cycle assessment was carried out with the assistance of a commercial software package: SimaPro 8.01 PhD. The EPD 1.04 (2008) module of this package was used in the evaluation of GWP, acidification, eutrophication and non-renewable energy use [13].

RESULTS AND DISCUSSION

The results obtained using the functional units are showed in Table **3**. Table **4** gives the total environmental impact of buffalo calves. Both tables show a higher impact generated from global warming as compared with acidification and eutrophication. The use of non-renewable energy was also high despite the fact that it was a very short period. A detailed discussion on the environmental performance is given below.

Global Warming Potential (GWP)

Total emissions were mainly produced on-farm. Each animal produced about 7 kg of CO_2–eq per day of trial (Table **3**). Sabia *et al*. (2018a) [13] in a previous study observed an average environmental impact of intensive dairy buffalo heifers of 8.29 kg CO_2-eq per day. Most probably, the lower environmental impact generated by buffalo calves is due to less use of meadow hay in this stage. Biogenic methane from enteric fermentation and manure was the largest contributor to GWP, followed by emissions of carbon dioxide from fossils. Table **4** shows that the main impact in terms of GWP was from feed consumption (422 kg CO_2-eq) followed by general consumptions (185 kg CO_2-eq). Feeding plays an important role in affecting the environmental impact of buffalo farming, as it is mainly based on maize silage which is a demanding crop in terms of organic and inorganic fertilisation and water for irrigation. This impact may be mitigated by replacing maize silage with a less demanding crop such as triticale silage. The impact generated by buffalo calves through manure emissions is low as compared with other buffalo categories [20], this is probably due to the fact that calves do not have a fully developed rumen and solid feed represent a small proportion of the ration. Sabia *et al*. (2018b), [20] showed that the emission from manure during the entire productive process of dairy buffaloes was the second category of impact in terms of GWP. The main contribution of methane biogenic emissions was due to fermentation. In particular, the rumen is the site where a number of fermentative processes occur thus allowing to obtain nutrients such as fatty acids and proteins of bacterial origin from vegetal fibres [21]. Previous studies indicate that the inclusion of more digestible forages in ruminant diets may reduce CO_2 emissions [22].

Acidification Potential (AP)

Buffalo calves showed a low AP per days of trial (Table **3**). Most of the impact was due to on-farm activities. Soil acidification can alter the biogeochemical cycling of elements and cause negative effects on biota. Acid deposition and application of excessive ammonium (NH^{+4}) based fertilizers are two serious factors that accelerate soil acidification [23]. Also nitrate leaching is a primary cause of soil acidification and is accounted for in both the nutrient management and fertilizer application components of the soil acidification model. Table **4** shows the main emissions responsible of AP. The main process responsible for pollutant emissions was the production of feed, which accounted for 70%, of the total emission, followed by general consumptions in the farm (30%). The cultivation of one ha of corn silage, which is the main concentrate component of the ration, needs about 300 kg of urea and an extensive use of machinery. Ammonia is one of the primary causes of soil acidification and is accounted for in both the nutrient management and fertilizer application components of the soil acidification model. In geese, [24] observed

Table 3: Environmental Impact of Buffalo Calves (0 – 90 Days), Expressed Per Day of Trial

Impact categories	Units	Impact (per day of trial)
Global Warming (100y)	kg CO_2-eq	7
Acidification Potential (AP)	g SO_2-eq	24
Eutrophication potential (EP)	g PO_4^{-3}-eq	30
Non-renewable energy	MJ -eq	38

Table 4: Total Environmental Impact of Buffalo Calves (0 – 90 Days)

Impact categories	Units	Total amount	Feed	General consumptions	Manure
Global Warming (100)	kg CO_2-eq	628	422	185	21
Acidification	kg SO_2-eq	2	1.4	0.6	-
Eutrophication	kg PO_4^{-3}-eq	2	1.8	0.2	-
Non-renewable energy	MJ-eq	3441	2856	585	-

that changing the feeding ration from corn-based to sorghum-based significantly reduced polluting emissions.

Eutrophication Potential (EP)

The total impact for EP was lower compared to the other categories with an impact of 30 g SO_2-eq per day of trial (Table **3**). On-farm EP consisted mainly of nitrate and phosphate leaching, ammonia volatilization during fertilization for on-farm feed production and ammonia volatilization from manure both stored and in the stable. Eutrophication results in a reduction of the oxygen concentration in water or soil through provision of nutrients, which increase the production of biomass [25]. Emissions of nitrogen pollutants (ammonia and nitrate) are major sources for eutrophication, which are generally connected to several agricultural practices and to animal-based productions in particular [7]. Table **4** shows that the main process responsible for pollutant emissions was the production of feed, which accounted for 90%, of the total emission, followed by general consumptions in the farm (10%). Nitrate from the cultivation of maize (41.1% of all nitrate emissions) plays an important role in the potential eutrophication impact as this system is located in the River Sele Plain, which is characterized by coastal and soil erodibility [26], with high to very high soil erosion hazard [27]. The Sele river flows into the Tyrrhenian Sea where P-eutrophication (mainly PO_4^-) may result in excessive growth of algae and higher plants. When these overabundant plants die, their microbial degradation may re-consume part of the oxygen dissolved in the water, thus reducing the water's capacity to support life [28].

Non-Renewable Energy Use

The non-renewable energy category is another important indicator of the sustainability of food production systems, given that it comes from finite resources which will eventually be exhausted beyond the level that can be economically extracted [31]. Non-renewable energy use per functional unit (Table **3**) was 38 Mj-eq. During on-farm activities the majority of non-renewable energy was consumed for the production of maize, due to the consumption of diesel fuel and fertilisers. The substantially greater input of concentrate used for calves led to a higher energy demand. The major impact category (Table **4**) was feed productions (83%), followed by general consumptions (17%). This was mainly because of a large use of diesel fuel at the farm level for the production of maize. The considerably large use of natural gas in the system can be explained on the basis of a high use of synthetic N-fertilisers (urea), whereas coal consumption may be attributed to the refining of protein components such as maize flour and soya bean meal which were primary feed ingredients.

CONCLUSIONS

The farming of dairy buffalo calves from 0 to 90 days, despite the short period, generated a high environmental impact of the polluting agents both in the atmosphere. In addition, high was the impact generated in terms of Non-renewable energy use. The present work showed that the strategies to mitigate the effects of dairy buffalo farming on the environment should be implemented starting from the birth of the calves and then continue throughout the life cycle.

ACKNOWLEDGMENTS

This research was carried out in the framework of the project 'Smart Basilicata' (Contract n. 6386 - 3, 20 July 2016). Smart Basilicata was approved by the Italian Ministry of Education, University and Research (Notice MIUR n.84/Ric 2012, PON 2007e2013 of 2 March 2012) and was funded with the Cohesion Fund 2007e2013 of the Basilicata Regional authority.

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Received on 03-12-2018 Accepted on 19-12-2018 Published on 31-12-2018

DOI: https://doi.org/10.6000/1927-520X.2018.07.03.4