Sources of variation of the environmental impact of cereal-based intensive beef finishing herds

Marco Berton, Giacomo Cesaro, Luigi Gallo, Maurizio Ramanzin and Enrico Sturaro

Dipartimento di Agronomia Animali Alimenti Risorse Naturali e Ambiente, University of Padova, Padova, Italy

ABSTRACT

This study aimed to investigate the effect of beef category, feedstuffs self-sufficiency (SELF), crude protein (CPI) and phosphorus (PI) daily intake on the environmental impact of the beef fattening system typical of north-eastern Italy according to a partial Life Cycle Assessment. The reference unit was the batch (group of animals homogeneous for genotype, sex, fattening farm, finishing period). The study involved 245 batches (64 ± 34 heads) herded in 17 fattening farms. The system boundaries were set from animals arrival at the fattening farm to the sale to the slaughterhouse. The functional unit was 1 kg BW gain (BWG). Data on animal performance and farm input were collected for each batch and farm, respectively. Data on feed intake, ingredient formulation and chemical composition of diets were monthly collected for each batch. Impact categories assessed were (mean ± SD per kg BWG in brackets): global warming (8.8 ± 1.6 kg CO2-eq), acidification (142 ± 22 g SO2-eq) and eutrophication (55 ± 8 g PO4-eq) potentials, cumulative energy demand (53 ± 18 MJ), land occupation (7.9 ± 1.2 m2/year). Beef category and SELF, CPI and PI classes significantly affected all the impact categories, with lower values observed with decreasing values of CPI and PI and increasing values of SELF as well as more productive beef categories. This study evidences that beef category and diet-related factors affect the environmental impact of cereal-based intensive beef finishing herds. In conclusion, there is space to develop mitigation strategies based on enhancing the self-sufficiency rate of the diet and lowering the daily intake of crude protein and phosphorus.

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Introduction

Livestock production is considered responsible for the exploitation of a notable share of natural resources and as an important driver of the emission of various environment-altering pollutants, such as greenhouse gases (GHG), with complex effects on natural ecosystems (Steinfeld et al. 2006; Gerber et al. 2013). In the last decade, Life Cycle Assessment (LCA; ISO 2006) has emerged as one of the most suitable methodologies to evaluate the environmental impact due to the production of livestock outputs such as meat and milk (de Vries and de Boer 2010). Consequently, a variegated set of mitigation strategies has been proposed in order to develop consistent, economically feasible ways to reduce the impact of the different livestock production sectors. These mitigation strategies can be addressed to the reduction of the environmental footprint of livestock products (farm-level point of view) and/or to the modification of consumer behaviour (consumers-level point of view, Garnett 2013). At the farm level, actions aiming to improve the efficiency of feedstuffs (Smith et al. 2007) and of animal production (de Boer et al. 2011) or to enhance the carbon sequestration capacity of permanent grasslands (Soussana et al. 2010) have been explored. In particular, the mitigating effect of the optimisation of the nutrients (e.g. nitrogen and phosphorus) utilisation has been widely investigated (Rotz 2004; de Boer et al. 2011). Other characteristics of the beef diets, such as the feedstuffs self-sufficiency rate, have been less studied (Lebacq et al. 2015). The implementation of mitigation strategies at the farm level has to be shaped on the specific characteristics of each regional livestock system (Gerber et al. 2015). This is the case of the beef fattening system in the north-eastern Italy, which gives a notable contribution to the European beef supply.
In order to contribute to the understanding of such variability, the aim of this study was to assess the effects of beef category (genetic line × gender) and diet-related factors on the environmental impact of the north-eastern Italy beef fattening system computed according to a partial LCA method.

**Materials and methods**

**Data collection**

Data for this study originated from 245 fattening batches (i.e. a group of animals homogenous for genetic type, sex, origin, fattening farm and finishing period) involving 15,614 beef bulls and heifers (64 ± 34 heads per batch on average) reared in 17 fattening farms in north-eastern Italy during 2014. The methodology developed in this study improves the approach used in Berton et al. (2016). To study the sources of variation affecting the impact categories values, a new database was collected and considered, and, for each batch, an accurate monthly recording of the ingredient and chemical composition of the diets was performed.

Beef bulls and heifers were grouped into beef categories (genetic line × gender) as follows (the number of batches is given between brackets): Charolais bulls (137), Limousin bulls (43), Irish crossbred bulls (34), French crossbred bulls (21) and beef heifers – Charolais and Limousine – (10). For each batch, the following information was collected: the number of animals, the arrival and sale dates, the body weight at the arrival (BWI) and at the sale (BWF), the number of animals that left the farm for death, illness or injury during the fattening cycle, and the average purchase and sale prices per head. The average daily gain (ADG, kg/day) was computed as the difference between total BWF and BWI divided by the animal total presence (heads × days), and the length of the fattening cycle was computed as the difference between the mean sale date, weighed by the number of animals sold at each date, and the arrival date. The BW gain (BWG) was computed as the difference between total BWF and BWI.

Information concerning the manure management systems, the agricultural input used for on-farm feed production (organic and chemical fertilisers, pesticides, seeds and fuel for agricultural machines), the feeds produced on-farm and those bought on the market, the bedding and industrial materials (lubricant, plastic and fuel for animal handling) used in the farm were acquired by the same operator through monthly visits to the farms (see Supplementary Tables 1 and 2).

Ingredient composition and daily allowance of diets fed were recorded monthly. Samples of each diet were collected monthly and used for assessing the contents of moisture, crude protein (CP), ether extracts, ash, starch and neutral detergent fibre using the NIRS method. Non-starch carbohydrates content was obtained as difference between the whole dry sample and the sum of CP, ether extracts, ash and neutral detergent fibre (as dry matter). The phosphorus (P) content was obtained according to the AOAC (2003) procedure (AOAC 999.10, 2000 and ICP-OES). The gross, digestible and metabolisable energy contents of the diets were calculated according to INRA (2007). Monthly total feed allowance per head was obtained as the mean daily allowance between two subsequent monthly records multiplied by the period occurred between them, and total feed allowance during the whole fattening cycle as the sum of the monthly feed allowances. The average daily dry matter intake (DMI) was estimated as the total dry matter allowance per head divided by the length of the fattening cycle, and the same procedure was used to compute the daily intakes of CP and P (CPI and PI, respectively).

The self-sufficiency rate of the diet (SELF) was computed as the ratio between the DMI from feeds produced on-farm and the total DMI. The gain-to-feed ratio (G:F) was calculated as the ratio between the ADG and DMI. The nitrogen (N) input-output flow was calculated for each batch according to Ketelaars and Van der Meer (1999), as follows: the N intake was calculated as the mean daily allowance between two subsequent monthly records multiplied by the period occurred between them, and total feed allowance during the whole fattening cycle as the sum of the monthly feed allowances. The average daily dry matter intake (DMI) was estimated as the total dry matter allowance per head divided by the length of the fattening cycle, and the same procedure was used to compute the daily intakes of CP and P (CPI and PI, respectively).

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calculated for each batch. The gross margin (€/kg BWG) was computed as the difference between the values at sale and at purchase (€/head), divided by the difference between BWF and BWI (per head). The cost of the diets (€/kg BWG) was computed as the sum of the feedstuffs consumed per head/day multiplied by the relative prices per 1 kg, divided by ADG. The seasonal average prices per feedstuff (€/kg DM) were derived from the official reports of the commodities trading market of the Mantova province (considered as reference for Italian market) for the second half of 2013, the whole 2014 and the first half of 2015. Finally, IOFC was computed as the difference between the gross margin and the diet cost.

**Partial LCA structure and computation of the impacts**

The partial LCA model was derived from that used by Berton et al. (2016). The reference unit for computing the environmental impact was the batch and, within each batch, 1 kg BWG was taken as the functional unit. The system boundaries were set from the arrival of the animals at the fattening farm to their sale to the slaughterhouse, which includes the impact due to animal and manure management and on-farm feed production, and that due to the background systems related to the off-farm production of feeds and other materials purchased. The problem of allocating inputs derived from multifunctional processes (e.g. soybean meal as co-product of soy oil extraction) was resolved using an economic allocation method (de Vries and de Boer 2010).

The impact categories assessed were global warming (GWP, kg CO2-eq), acidification (AP, g SO2-eq) and eutrophication potentials (EP, g PO4-eq), cumulative energy demand (CED, MJ) and land occupation (LO, m2/year). Global warming potential was computed using the equations proposed by the International Panel on Climate Change (IPCC 2006) for methane (CH4) and nitrous oxide (N2O) emissions from manure storage and cropland soils. Enteric CH4 was computed according to the equation proposed by Ellis et al. (2007), where CH4 emission varied in function of feed intake and chemical composition of the diet. The emissions of ammonia (NH3), nitrogen oxides (NOx) and sulphur dioxide (SO2) due to the manure storage and crop fertilisation were included into the AP category. Acidifying emissions were estimated using the equations from IPCC (2006). Nitrogen volatilisation factors were derived from ISPRA (2011). Eutrophying compounds such as leaching nitrate (NO3) and P lost at soil level were accounted in the EP category. Nitrate leaching was obtained as difference between N input and N output (i.e. N harvested and N volatilised). Phosphorus loss was computed using the equation of Nemeczek and Kagi (2007).

The impact of agricultural inputs (fertilisers, pesticides, seeds) for the on-farm feed production was computed by applying the impact factors derived from the Ecoinvent (Ecoinvent Centre 2015) and Agri-footprint databases (Blonk Agri-footprint BV 2014). The impact caused by burning the fuel used for farm activities was derived from the EEA (2013) and Ecoinvent databases. The Ecoinvent and Agri-footprint databases were also used to derive the impact factors for computing the impact due to the off-farm inputs and related background processes. The origin and transport of soybean meal, maize by-products and sugar beet by-products were supposed equal to those described by Berton et al. (2016). All the single pollutant emissions computed for GWP, AP and EP were aggregated into the common unit of each impact category by using the conversion factors adopted in Berton et al. (2016).

**Data editing and statistical analysis**

The impact categories values were compared using the hotspot analysis, which aims to identify the contribution of the different production stages to each impact category (European Commission 2010).

Prior to statistical analysis, the multicollinearity of the independent variables (BWI, SELF, CPI, PI) was preliminary checked (PROC REG, SAS 2012), assuming a variance inflation factor lower than 2 as a threshold for the absence of multicollinearity. Afterwards, the records were classified as follows:

- season of arrival, according to four classes computed grouping the months of arrival into ‘winter’ (December, January and February), ‘spring’ (March, April, May), ‘summer’ (June, July, August) and ‘autumn’ (September, October, November);
- class of BW at arrival, SELF, CPI and PI, according to three classes computed within beef category as ‘low’ (batches with trait value lower than mean – 0.5 SD), ‘intermediate’ (batches with trait value included between mean – 0.5 SD and mean +0.5 SD) and ‘high’ (batches with trait value greater than mean +0.5 SD).

Beef performance traits, ingredient and chemical composition of the diets, SELF, CPI and PI were analysed according to the following mixed model (PROC MIXED, SAS 2012):

\[ y_{ijk} = \mu + \beta C_i + S_j + f_{iak} + e_{ijk} \]
Results

As expected, beef category significantly affected most beef performance traits \((p < .05, \text{ Table 1})\). The BW at the beginning and at the end of the fattening period ranged from 299 to 394 kg and from 521 to 731 kg, respectively, with the greatest values for Charolais and Irish crossbred bulls, intermediate values for French crossbred bulls and the lowest values for Limousine bulls and beef heifers. The fattening cycle ranged from 220 to 233 d, with no differences among beef categories. Average daily gain ranged from nearly 1 kg/d in beef heifers to nearly 1.5 kg/d in Charolais and Irish beef bulls, with a trend among beef categories similar to that found for BWF. On average, the DMI of Charolais, Irish crossbred and French crossbred bulls was nearly 1.5 kg/d greater than that of Limousine bulls and beef Heifers \((p < .05)\). About the gain-to-feed ratio, Charolais, Irish beef and Limousine bulls showed the best values, whereas French crossbreds showed intermediate and beef heifers the worst feed efficiency. On average, SELF approached 43%, resulting in the highest for beef heifers (49%) and the lowest for Limousine bulls (40%), and intermediate for the other beef categories. The gross margin ranged from 1.71 to 2.24€/kg BWG. Beef heifers had greater values than the beef bull categories, among which Limousine bulls had better values than the other beef categories. Since the costs of the diet per unit of BWG were highest for beef heifers and lowest for Charolais and Irish crossbred bulls, the trend of IOFC differed from that of gross margin. Limousine beef bulls showed the greatest and French crossbreds the worst IOFC per unit of BWG, whereas Charolais, Irish crossbred bulls and heifers were intermediate.

The ingredient and chemical composition of the diets are shown in Table 2. All diets were based on maize silage (from 27% DM for French crossbred bulls 40% DM for beef heifers), with occasional addition of other cereal silages (sorghum, wheat, barley), and included fibrous feeds (7–11% DM) to ensure ruminal activity. Maize grain, as dried whole or ground, but also as grain or ears silage, provided the energy supplementation (from 14% DM in heifers to 28–31% DM in beef bulls). Protein supplementation, originated from protein–mineral supplements, soybean meal and occasionally other sources, ranged between 17 and 20%. Sugar-beet and maize by-products, other cereal

![Table 1. Least squares means of beef categories for farm performance traits \((N = 245 \text{ batches})\).](image-url)
grains (e.g., barley grain) and fat supplementation completed the beef diets. In general, diets fed to beef bulls were richer in non-structural carbohydrates, in particular starch (from +23% to +27%), and in ether extract (from +13% to +22%), and poorer in NDF content (−11%) than those fed to beef heifers. The CP content (g/kg DM) was the greatest in the diets fed to beef heifers and Limousine bulls (139–140 g/kg DM) and the lowest in the diets fed to Charolais bulls (136 g/kg DM), with Irish and French crossbred bulls showing intermediate values. The P content was the greatest in the diets fed to Limousine bulls, the lowest in those fed to Charolais, Irish crossbred and French crossbred bulls, and intermediate in the diets fed to beef heifers.

The results of the environmental impact categories computed according to the LCA methodology and the contribution of each production stage to the impact categories values are reported in Figure 1. Mean GWP was 8.8 kg CO₂/kg BWG and the production of 1 kg BWG needed nearly 53 MJ of energy and 8 m²/year of land. The coefficient of variation within impact category was nearly 15–18% for all the impact categories, except in the case of CED (25%). The on-farm production stages outweighed those off-farm greatly for AP and slightly for GWP and EP. The opposite pattern was observed for CED and LO. The enteric CH₄ emissions and the N volatilisation due to manure management were the main contributors to the on-farm stages for GWP and AP, respectively, whereas feed production was the first on-farm contributor for EP and LO. Within the off-farm stages, the feedstuffs production was the first contributor for all impact categories, whereas the transport of the inputs had a notable importance only for CED and GWP.

Beef category, self-sufficiency of the diet, crude protein and phosphorus intake significantly affected the impact categories values (p < 0.05, Table 3). Charolais, Irish crossbred and Limousine bulls showed the lowest values for all the impact categories, French crossbred had intermediate values and heifers had the greatest values. In particular, French crossbred bulls had higher impacts than Charolais bulls especially for CED (+15%), and less for the other impact categories (from +7% to +10%). Beef heifers showed an opposite pattern (+12% for CED vs from +26% to +36% for the other impact categories). The increase in SELF from the low to the high class resulted in a reduction of all the impact categories ranging from 5 to 25% according to the category considered. As expected, classes of CPI and PI showed an opposite trend, and moving from high to low CPI or PI led to a decrease of 6–12% depending on the impact category. Regarding the effect on

Table 2. Least Squares means of beef category for the average ingredient and chemical composition of diets and of diet-related greenhouse gases emission (N = 245 batches).

| Variables                      | Unit   | CH  | IRE | FRCR | LIM | HEI | SEM |
|-------------------------------|--------|-----|-----|------|-----|-----|-----|
| **Ingredient composition**    |        |     |     |      |     |     |     |
| Maize silage                  | %      | 30b | 29bc| 27c  | 30b | 40a | 6   |
| Maize grain-based feeds⁴      | %      | 29a | 29a | 31a  | 28b | 14c | 5   |
| Protein by-products and supplementes⁵ | %  | 18b | 19ab| 20a  | 20a | 17b | 6   |
| Fibrous feeds⁶                | %      | 8b  | 8bc | 7c   | 9b  | 11a | 3   |
| Sugar beet by-products        | %      | 8   | 9   | 8    | 7   | 7   | 5   |
| Maize by-products             | %      | 4   | 3   | 4    | 3   | 5   | 5   |
| Other cereal silages⁷         | %      | 1.0b| 0.5b| 0.3b | 1.1b| 5.4b| 2.2 |
| Other cereal grains⁸          | %      | 1.3a| 1.9a| 1.8a | 0.4b| 0.5a| 3.7 |
| Fat                           | %      | 0.4 | 0.4 | 0.5  | 0.6 | 0.4 | 0.5 |
| **Chemical composition of diet** |        |     |     |      |     |     |     |
| CP                            | g/kg DM| 136b| 137ab| 138ab| 139a| 140a| 3   |
| P                             | g/kg DM| 3.3b| 3.7b | 3.8b | 4.0b| 3.9b| 0.1 |
| EE                            | g/kg DM| 27a | 26b  | 28b  | 28a | 23b | 2   |
| Starch                        | g/kg DM| 301b| 299b | 300b | 293b| 237b| 14  |
| NDF                           | g/kg DM| 293b| 293b | 291b | 290b| 328b| 9   |
| **GHG emissions**             |        |     |     |      |     |     |     |
| CH₄ enteric                   | g/kg DM| 13.2c| 13.1c| 13.0c| 13.6b| 14.6a| 14.9|
| CO₂-equidiet                  | g/kg DM| 668b| 689b | 740b | 676b| 560b| 143 |

CH: Charolais bulls; IRE: Irish crossbred bulls; FRCR: French crossbred bulls; LIM: Limousine bulls; HEI: beef Heifers; CP: crude protein content; P: phosphorus content; EE: ether extracts content; NDF: neutral detergent fibre content; CH₄ enteric: emissions due to enteric fermentation; CO₂-equidiet: emissions due to the production of the feedstuffs composing the diets.

⁴Maize grain-based feeds: maize grain (whole and ground), maize grain and maize ears silages.
⁵Protein by-products and supplements: soybean meal, cotton seeds, protein and mineral supplements.
⁶Fibrous feeds: straw ad hay.
⁷Other cereal silages: sorghum, barley and wheat silages.
⁸Other cereal grains: barley grain (whole and ground).
Figure 1. Descriptive statistics (mean ± SD) for the impact categories values (expressed per 1 kg BW gain) and contribution (%) of each production stage (on farm stages below the line and off farm stages above the line) to each impact category (N = 245 batches).

Table 3. Least squares means of beef category, class of diet self-sufficiency rate (SELF), crude protein (CPI) and phosphorus daily intake (PI) for the different impact categories (N = 245 batches).

| Effect | GWP | AP | EP | CED | LO |
|--------|-----|----|----|-----|----|
| Beef category | p Value | <.001 | <.001 | <.001 | <.001 | <.001 |
| CH     | 8.7<sup>a</sup> | 138<sup>a</sup> | 54<sup>a</sup> | 52<sup>a</sup> | 7.7<sup>a</sup> |
| IRE    | 8.7<sup>a</sup> | 135<sup>a</sup> | 53<sup>a</sup> | 53<sup>a</sup> | 7.6<sup>a</sup> |
| FRCR   | 9.5<sup>b</sup> | 150<sup>b</sup> | 58<sup>b</sup> | 60<sup>b</sup> | 8.5<sup>b</sup> |
| LIM    | 8.9<sup>a</sup> | 140<sup>a</sup> | 54<sup>a</sup> | 52<sup>a</sup> | 7.7<sup>a</sup> |
| HEI    | 11.3<sup>c</sup> | 187<sup>c</sup> | 68<sup>c</sup> | 58<sup>c</sup> | 9.6<sup>c</sup> |
| SELF (%) | p Value | <.001 | <.001 | <.001 | <.001 | <.001 |
| Low (34 ± 7) | 9.9<sup>b</sup> | 155<sup>b</sup> | 59<sup>b</sup> | 61<sup>b</sup> | 8.8<sup>b</sup> |
| Intermediate (44 ± 6) | 9.5<sup>b</sup> | 152<sup>b</sup> | 58<sup>b</sup> | 57<sup>b</sup> | 8.4<sup>b</sup> |
| High (60 ± 7) | 8.7<sup>a</sup> | 143<sup>a</sup> | 56<sup>a</sup> | 46<sup>a</sup> | 7.4<sup>a</sup> |
| CPI (kg/head/day) | p Value | <.001 | <.001 | <.001 | <.001 | <.001 |
| Low (1.27 ± 0.06) | 8.9<sup>a</sup> | 144<sup>a</sup> | 55<sup>a</sup> | 52<sup>a</sup> | 7.9<sup>a</sup> |
| Intermediate (1.38 ± 0.07) | 9.4<sup>b</sup> | 152<sup>b</sup> | 58<sup>b</sup> | 55<sup>b</sup> | 8.3<sup>b</sup> |
| High (1.53 ± 0.07) | 9.8<sup>c</sup> | 154<sup>c</sup> | 60<sup>c</sup> | 57<sup>c</sup> | 8.5<sup>c</sup> |
| PI (g/head/day) | p Value | .001 | .001 | <.001 | <.001 | <.001 |
| Low (34 ± 2) | 9.0<sup>a</sup> | 141<sup>a</sup> | 55<sup>a</sup> | 52<sup>a</sup> | 7.8<sup>a</sup> |
| Intermediate (39 ± 2) | 9.5<sup>b</sup> | 150<sup>b</sup> | 58<sup>b</sup> | 55<sup>b</sup> | 8.2<sup>b</sup> |
| High (43 ± 2) | 9.6<sup>c</sup> | 160<sup>c</sup> | 60<sup>c</sup> | 57<sup>c</sup> | 8.6<sup>c</sup> |
| SEM | 1.5 | 19 | 8 | 12 | 1.2 |

GWP: global warming potential; AP: acidification potential; EP: eutrophication potential; CED: cumulative energy demand; LO: land occupation; CH: Charolais bulls; IRE: Irish crossbred bulls; FRCR: French crossbred bulls; LIM: Limousin bulls; HEI: beef Heifers; SELF: self-sufficiency rate class (percentage of dry matter intake produced on farm), mean ± standard deviation for each class is reported in brackets; CPI: daily crude protein intake, mean ± standard deviation for each class is reported in brackets; PI: daily phosphorus intake, mean ± standard deviation for each class is reported in brackets.

<sup>a,b,c</sup> : LS means with different superscripts within column differ significantly (p < .01).
IOFC, the increase in feedstuffs self-sufficiency rate, led to an increase in IOFC, whereas the reduction in CPI and PI did not affect IOFC (data not shown in table).

Discussion
Different studies have investigated the environmental impact of intensive beef fattening production. Although the results found in this study cannot be precisely compared with those found in other studies because of differences in the LCA modelling and impact computation, the results found for GWP and LO were within the range found in the literature (Pelletier et al. 2010; Nguyen et al. 2012; de Vries et al. 2015). Conversely, the values for AP, EP and CED found in this study were greater than those reported by others (Nguyen et al. 2012; de Vries et al. 2015). This was probably due to greater N and P fertilisation rates for maize and wheat with respect to the values reported in Nguyen et al. (2012) and different N volatilisation rates (for AP and EP), and to the great importance of the transport of the off-farm feedstuffs (CED). Within the north-eastern Italy beef production system, the on-farm production stages outweighed the off-farm stages contribution for GWP, AP and EP, in accordance with the results reported by Beauchemin et al. (2010) and Pelletier et al. (2010) for the beef fattening period. This is due to the fact that on-farm contributions such as the enteric CH₄ (for GWP) and the manure management (for AP and EP) were main drivers of the total emissions. On the opposite, the off-farm stages were more important for CED and LO since feedstuffs production (for which the off-farm contribution was predominant) was the stage more related to input high demanding in energy (such as mineral fertiliser and fuel) and land use.

Beef category as well as SELF, CPI and PI significantly affected all the impact categories values. Differences in production efficiency may explain the differences in impact due to different beef categories. Even if the CO₂-eq emission for the production of 1 kg of DM was 16–24% lower for diets fed to beef heifers than for those of beef bulls, beef bulls evidenced on average 25% greater gain-to-feed ratio than beef heifers, which resulted in an average decrease of impact categories ranging from 7 to 33% (as average value of beef bulls impact categories LSmeans vs beef heifers impact categories LSmeans). The resulting importance of the productive efficiency on the environmental footprint of beef livestock production systems is in accordance to Capper (2011) and Crosson et al (2011).

The mitigating effect of SELF on the impact categories values was connected to the feedsfuffs production stage. Diets containing greater proportions of feedstuffs produced within the farm enabled to reduce the impact due to the feedstuffs production and transports. The mitigating effect of the increase of feedstuffs self-sufficiency rate observed in this study is in agreement with results of Battini et al. (2016). Although that study was focussed on dairy farms of the Po Valley, the crop system described was very similar to that considered in our research. The lower values for all the impact categories found for the class ‘low’ than the class ‘high’ of CPI and PI could be related to a more efficient use of CP and P by animals (the ratio between BWG and CPI varied from 1.18 kg BWG/kg CPI for the CPI class ‘low’ to 0.98 kg BWG/kg CPI for the CPI class ‘high’, and the same trend was observed for classes of PI, data not shown in tables).

Different studies addressed the effects of diet features on the impact of beef fattening bulls. Diet formulation and composition affect enteric CH₄ emission, and differences in ingredient composition such as maize grain or maize silage, and hence in nutrients content, have been related to differences in emission levels (Doreau et al. 2011; Nguyen et al. 2012). In particular, Doreau et al. (2011) and Nguyen et al. (2012) have reported lower enteric CH₄ emission for diets richer in maize-grain-based feeds and poorer in maize silage and fibrous feeds; although our study did not directly aim to this topic, the results obtained in our study suggest a similar trend. However, maize silage is a local, abundant and high-yielding feed resource in north-eastern Italy, whereas a notable part of maize grain is imported. Besides, a reduction in maize silage utilisation does not seem advisable in the northern Italy condition, as it would have detrimental effect on SELF level, which had mitigating effects in this study. Moreover, diets fed to heifers, characterised by greater content in silages, evidenced an average 20% lower CO₂-eq emission/kg DM than those fed to beef bulls, and this was only partially counterbalanced by the 10% greater CH₄ enteric emission estimated for these diets.

Crude protein and P are essential nutrients for animal metabolism and growth and levels of these nutrients in the beef diets are generally set in order to ensure a non-limiting level of availability. Schiavon et al. (2010) found that reducing CP from 145 to 108 g/kg DM did not affect the ADG in Piemontese beef bulls and allowed to strongly reduce the N excretion. Results from our study suggest a similar trend to that found in Schiavon et al. (2010), showing that a reduction of CPI had a mitigating effect without detrimental effects on animal productivity, implying not
only a decrease in N excretion, since lower CPI values implies lower N intake values, but also a mitigating effect on the overall impact of the beef fattening system. Similar results were obtained for the P-related elementary flow. More generally, increasing N and P efficiency of use has been suggested as a diet-related mitigation strategy at the farming system level (Steinfeld et al. 2006; de Boer et al. 2011).

However, several constraints have to be taken into account in the evaluation of mitigation strategies (Smith et al. 2007). At methodological level, it is generally recognised that the application of mitigation strategies could result into changes in other production systems that possibly offset the achievable impact reduction. Since the attributional LCA (ALCA) model applied in this study could not consider the marginal impact caused by those indirect changes, the results obtained in this study suggest spaces of impact mitigation and should not be used outside these limits (Brander et al. 2009). At beef production system level, in the last decade the Italian beef sector is experiencing declining levels of production (−24% in 2005–2015 period) and decreasing self-sufficiency rate (53% of the beef demand observed for 2015 was covered by the national production sector, ISMEA 2015). Any mitigation strategy implying detrimental effects on the production level could have further negative consequences on beef herd economic sustainability and on the national beef supply security. To this purpose, the IOFC can be a better indicator of the farm economic profitability than gross margin, because it also takes into account the cost of the diet, which is the main component of total production costs. In this study, IOFC has been expressed per unit of BWG, and its variation could depend both on variation in ADG and in fluctuation of animal prices and feedstuffs costs, which can be of relevance (ISMEA 2015). Data from our study suggest that IOFC was more influenced by the variation in the cost of the diets and in the gross margin than by the variation in ADG. The farmer’s choice of which feedstuffs to purchase is greatly affected by the fluctuation of the prices, and these factors can, therefore, have a detectable effect on the magnitude of impact categories. As a consequence, an indicator of farm profitability, such as IOFC in this study, should be considered in the implementation of mitigation strategies. Based on the results of the same mixed model used to analyse the impact category values, the increase in feedstuffs self-sufficiency and the decrease of CPI and PI may be strategies able to provide positive effects on the impact categories values of beef finishing herds, without any detrimental consequences on the farm economic profitability.

Conclusions

The north-eastern Italy beef system has a remarkable role in the area of the study and is integrated with other supply chains, first of all the suckler cow-calf system located in central France (Massif Central). The results found in this study showed that the environmental impact of finishing beef herds is affected by beef category and by diet-related effects. Beef categories more productive in terms of gain-to-feed ratio showed a lower environmental burden. Besides, strategies based on enhancing the self-sufficiency rate of the diet and lowering the daily intake of crude protein and phosphorus could significantly mitigate GHG, acidifying and eutrophying emissions as well as the amount of resources utilised. Moreover, this impact mitigation could be achieved without affecting the IOFC. The consideration of system aspects different from the environmental impact, such as the farm economic profitability, within the assessment of mitigation strategies, allows taking into account the complex framework of interactions that the results of this study evidenced. Further insights on the overall sustainability of the north-eastern Italy beef system, within the wider consideration of the related supply chains, are desirable.

Ethical approval

Data were collected under routinary work upon breeder’s approval. No experiment were performed on the animals.

Disclosure statement

No potential conflict of interest was reported by the authors.

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ORCID

Marco Berton https://orcid.org/0000-0002-2351-3090
Giacomo Cesaro https://orcid.org/0000-0003-2341-6247
Luigi Gallo https://orcid.org/0000-0002-8908-5105
Maurizio Ramanzin https://orcid.org/0000-0002-8746-7281
Enrico Sturaro https://orcid.org/0000-0001-9508-5622

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