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Modelling Manure Production in Beef Calves: Development, Evaluation, and Application of a Complete vs. Simplified Prediction Model

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Abstract: There has been increased interest in quantifying the manure production of livestock, primarily driven by public authorities, who aim to evaluate the environmental impact of livestock production, but also at the farm level, to manage manure storage and availability of fertilizer for crop production. Moreover, current manure production estimates from intensively reared beef calves are higher than actual production due to changes in farming systems, advances in animal genetics and feed efficiency. This study aims to redefine and update manure production estimates in intensively reared beef calves to predict manure production as a policy and planning tool, as there are no current models available. A trial was conducted to collect data on manure production during the growing-finishing period (243 d) of 54 Limousine calves (from 346.7 to 674.0 kg live weight, LW). Such data were used to develop two models to predict manure excretion: (1) a complex mechanistic model (CompM), and (2) a simplified empirical model (SimpM). Both models were evaluated against an independent dataset including a total of 4,692 animals on 31 farms and 5 breeds. Results from CompM require interpretation because the model does not output a single value but a range of manure production (minimum, medium and maximum), and would therefore be more suitable for professional use. The SimpM could be considered simple, reliable, and versatile for predicting manure excretion at farm level. SimpM could be refined and improved by including data from other studies on beef cattle with distinct characteristics and management.

Key words: Beef cattle, growing-finishing calves, manure production prediction, process-based model, empirical model.

1. Introduction

"The animals are to be regarded just like machines which to by far the greater part convert feed into manure" [1]. This affirmation, pronounced by one of the most famous agronomists of the nineteenth century, highlights some main challenges of the livestock industry: the production, management, storage and utilization of manure. These aspects are relevant not only because of the potential environmental impact on air, soil and water, but also because of their ecological role, e.g., in sustaining or improving soils and habitats or in preserving habitats or agroecosystems characterized by a deficiency of nutrients or in preserving soil from the loss of organic matter.

Models that can accurately predict manure production are useful to manage organic crop fertilization and the supply of organic matter to the soil (eventually considering integration with mineral fertilizers) but are also useful to help determine the requirements for manure storage (e.g., size the solid manure store or pad) to guarantee adequate period of storage and maturation for manure and to reduce building costs. Several nations worldwide have a storage of cattle manure that is close to or exceeds 60% of the total manure produced, such as Canada (57%) and the United States of America (65%) in North America, and France (56%), The Netherland (79%), Germany (85%), Austria (90%), Greece (91%), Italy and Denmark (95%) among Western European countries [2].

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Accurate estimates of manure production are also needed to estimate renewable bioenergy production from manure or project the bioreactors. Finally, such a model could be considered as a livestock efficiency and welfare indicator (especially if correlated to an adequate litter quantity) or a useful tool for policy makers concerned with environmental regulations or pollution control activities.

Manure production is usually estimated using empirical equations that were established many years ago [3, 4]. For example, some equations add up the bedding and forage quantities, then multiply this amount by a coefficient ranging between 2 and 2.40 (2.30 according to Thaer, 2.20 according to Pabst, 2.40 according to Berti Pichat, as reported by Medici [3]). These coefficients, sometimes established more than half a century ago, were applied in quite simple equations and do not consider the recent progress that has been made in animal genetics, and they were often based on lower intensity beef production systems than are currently being used. For example, a simple live weight multiplier is often used to quantify manure production [5, 6]. However, several factors affect manure production, such as breed characteristics (animal size, gastro-intestinal volume, animal tissue ratio, etc.), the feed conversion rate (FCR), as well as the type and amount of bedding.

As interest in creating sustainable solutions to environmental and economic challenges linked to manure management in an increasingly regulated environment is becoming more important, the need for methods usable to predict the impacts of livestock activity and to develop management strategies is becoming more urgent. As far as cattle production is concerned, several models that simulate N excretion in dairy and beef cattle [7-14], manure excretion in dairy cattle [15, 16], or process-based models that simulate nutrient fluxes, gas emissions or environmental impact (e.g. CNCPS 6.5 by Cornell University, DAYCENT by Colorado State University, Manure DNDC by New Hampshire University, APEX by Texas A&M University, or IFSM 4.2 by USDA US Department of Agriculture), also considering the manure excretion and management, have been proposed but no models have been introduced to estimate manure production from intensively reared beef calves in recent years.

For these reasons the Italian public authorities (i.e., Piedmont Region Local Government) commissioned a study to verify the actual production of manure from beef herds as the values reported in literature clearly overestimated production on the basis of the empirical farm evidences. The aim of this study was to develop and compare the applicability and level of reliability of a complex model (CompM), a mechanistic model which uses a complete set of variables referable to animal, feed, and environmental conditions, with that of a simplified model (SimpM), to predict manure excretion in growing and finishing cattle including the lowest possible number of variables. CompM is based on (and which attempts to understand) the causes of certain phenomena, starting from a holistic analysis of the structure under investigation by means of a study of the behaviour of each individual component of the system and of their interactions. SimpM is an empirical model in which experimental data are used directly to quantify the relationships between variables. Both are not limited to national or regional specific rearing conditions because they are verified over different livestock, environmental and management conditions or adjusted by correction factors when required as specified below.

2. Material and Methods

All procedures involving animals were conducted according to the Italian laws on animal welfare in scientific experiments [17].

2.1 Data Collection during the Experimental Trial

The models used to predict manure excretion in growing and finishing cattle were constructed using data collected during an experimental trial with 54 Limousine (L) calves of the same initial age (328 ± 29

d) and weight (347 ± 35 kg), homogeneously divided into 6 groups (9 animals per group). The Limousine was chosen because in Europe, and in Italy as well, it is a widespread specialised beef breed. All the calves were reared, following one of the most common beef cattle intensive rearing systems, in pens with concrete floors and straw litter under the same environmental conditions, and with a space availability of 5 m^2 per calf. The rearing period of 243 d was divided into 4 periods (SP1, SP2, SP3, SP4), on average lasting 60.8 ± 13 d each. Moreover, the SP1 period was further divided in 2 sub-periods: low (SP1a) and high (SP1b) litter amount. In the following sub-periods after SP1, because the cattle have a higher live weight (more than 400 kg), to ensure the most favourable conditions of animal welfare and cleaning only one amount of litter (high) was used, increasing it for each subsequent period based on the average live weight of the calves. The trial was conducted at the farm of the Department of Agricultural, Forest and Food Sciences at the University of Torino (Carmagnola, Torino, Italy; 44°51′002″ N, 7°43′002″ E, at an altitude of 240 m above sea level).

The calves were fed a fixed amount of hay of polyphite meadow (1.67 kg d^{-1} as feed; energetic concentration expressed as French Meat Forage Unit, UFV, 0.55 UFV kg^{-1}) and an increasing but rationed amount of concentrate (0.90 UFV kg^{-1}) to meet the increasing energy and protein requirements, according to the Institut National de la Recherche Agronomique (INRA) scheme for late maturing beef breed bulls [18]. The feed characteristics are shown in Table 1. Data were recorded per group: feed intake was recorded daily weighing feed supplied and rejected; wheat straw weight strewn as litter was recorded as applied weekly (straw characteristics are reported in Table 1); live weight of each calf was recorded at the beginning and at the end of each period of the trial. At the end of each period the manure (including bedding) was collected, weighed, and sampled to determine the dry matter (DM).

The data described above, representing the inputs of the two proposed models, and collected during the experimental trial, were used to estimate manure production and to preliminarily evaluate (before to use the independent dataset) the reliability with the actual production. Always to evaluate the two models, they were applied over different seasons on several commercial cattle farms that differed according to the management, the genetic type of the animals, and the litter materials as detailed below.

2.2 Development of the Complete Model

CompM was based on National Research Council (NRC) prediction equations [19] and existing computer models [9, 20] developed to improve beef cattle nutrient management.

Table 1 Chemical composition of feed and bedding (% as fresh matter) used during the experimental trial.

	Feedstuff	Hay	Straw
Dry matter	87.9	91.7	92.6
Crude protein	13.9	12.4	11.4
Ether extract	2.7	1.3	1.3
Crude fibre	7.3	25.9	38.2
Ash	9.0	13.8	10.6
Neutral detergent fibre	17.6	67.9	68.5
Acid detergent fibre	8.5	33.9	43.8
Acid detergent lignin	1.7	4.3	7.5
Starch	32.8	-	-
Calcium	12.7	0.30	0.44
Phosphorus	6.1	3.3	1.8

The theoretical basis of the model is that, starting from the initial live weight (ILW; kg) of a calf and knowing its average daily gain (ADG; kg), it is possible to estimate its live weight at any time (actual live weight, ALW; kg) as the sum of the ILW and the accumulation of the ADG for the considered period:

$$ALW = ILW + \int ADG \quad (1)$$

Once the initial age (IA; d) of the calf is known, it is possible to calculate the actual age (AA; d) as follows:

$$AA = IA + (ALW - ILW) \times ADG^{-1} \quad (2)$$

When the IA of a calf is not known, the AA can be estimated assuming a birth weight of 40 kg, as follows:

$$AA = (ALW - 40) \times ADG^{-1} \quad (3)$$

The experimental data were first used to verify the prediction of feed dry matter intake (DMI; kg) of the calf. Successively, the maximum and the minimum faeces excretion, data useful to calculate manure production, were calculated. The maximum production of faeces was calculated by multiplying the feed DMI by the difference between 1 and the forage digestibility (as summed as average tabular value of organic matter digestibility of polyphite meadow hay; F_{max}). The minimum production of faeces was assumed to correspond to feed DMI multiplied by the difference between 1 and corn meal digestibility (assumed as average tabular value of organic matter digestibility; F_{min}). The latter represents a feed with one of the highest digestibility and, also as grain, the main component of rations for fattening cattle.

To predict DMI, different equations were used for several types of cattle. The adjustments made for a range of factors are given in Table 2 [19].

The following Eq. (4) was used for growing calves:

$$DMI = ((SBW^{0.75} \times (0.2435 \times NEma - 0.0466 \times NEma^2 - 0.1128)) \times NEma^{-1}) \times 0.94 \times (BFAF \times BI \times T \times MUD) \quad (4)$$

where SBW is the shrunk body weight (kg), NEma the net energy for maintenance (Mcal kg^{-1}), BFAF the body fat adjustment factor or the empty body fat effect, BI the breed adjustment factor for the breed intake capacity, T the temperature factor, and MUD the mud factor, as shown in Table 2 [19]. The SBW is assumed equal to ALW.

The mud factor was included in the model because of the known impact of muddy pens on cattle NEma requirements: the higher the mud depth, the higher the NEma, as it reduces the insulation ability of the animal and increases the energy needed to maintain body temperature. The following Eq. (5) was used for growing yearlings:

$$DMI = ((SBW^{0.75} \times (0.2435 \times NEma - 0.0466 \times NEma^2 - 0.0869)) \times NEma^{-1}) \times 0.94 \times (BFAF \times BI \times T \times MUD) \quad (5)$$

To predict the total DMI (TDMI; kg) over the experimental period and the average daily DMI (ADMI; kg), the following Eqs. (6) and (7) were used:

$$TDMI = \int DMI \quad (6)$$

$$ADMI = TDMI \times ((ALW - ILW) \times ADG^{-1})^{-1} \quad (7)$$

Table 2 Adjustment factors to predict dry matter intake (DMI) in different types of cattle.

Adjustment factor	Multiplier	Adjustment factor	Multiplier
Breed (BI)		Temperature (T)	
Holstein	1.08	> 35 °C	0.65
Holstein x beef	1.04	25 to 35 °C	0.90
Beef	1.00	15 to 25 °C	1.00
		5 to 15 °C	1.03
Empty body fat effect (BFAF)		-5 to 5 °C	1.05
21.3 (350 kg EBW)	1.00	-5 to -15 °C	1.07
23.8 (400 kg EBW)	0.97	Mud (MUD)	
26.5 (450 kg EBW)	0.90	None	1.00
29.0 (500 kg EBW)	0.82	Mild (10-20 cm)	0.85
31.5 (550 kg EBW)	0.73	Severe (30-60 cm)	0.70

EBW: empty body weight.

The maximum and minimum amount of DM produced as excreta (DMEmax, DMEmin; kg) and from manure (DMMmax, DMMmin; kg) were obtained by means of the following equations, using the previously mentioned maximum and minimum coefficients of digestibility (Fmax, Fmin):

$$DMEmax = DMI \times Fmax \quad (8)$$

$$DMMmax = LI + \int DMEmax \quad (9)$$

$$DMEmin = DMI \times Fmin \quad (10)$$

$$DMMmin = LI + \int DMEmin \quad (11)$$

where LI is the litter weight (kg).

Finally, the estimated manure production (DMMmax and DMMmin) was compared, both in the controlled study than for the independent database, to the actual production measured collecting, weighting, and analysing for DM the effective manure production.

The conceptual development is shown in Fig. 1 to facilitate comprehension of the CompM. The inputs include adjustment factors for the breed intake capacity (BI), empty body fat effect (BFAF), temperature (T), mud amount (MUD), maintenance net energy (NEma), initial age (IA), initial live weight (ILW), average daily gain (ADG) and litter weight (LI). Among these inputs those directly measured are ILW, ADG, IA and LI, while those estimated from literature are BI, BFAF, T, MUD and NEma.

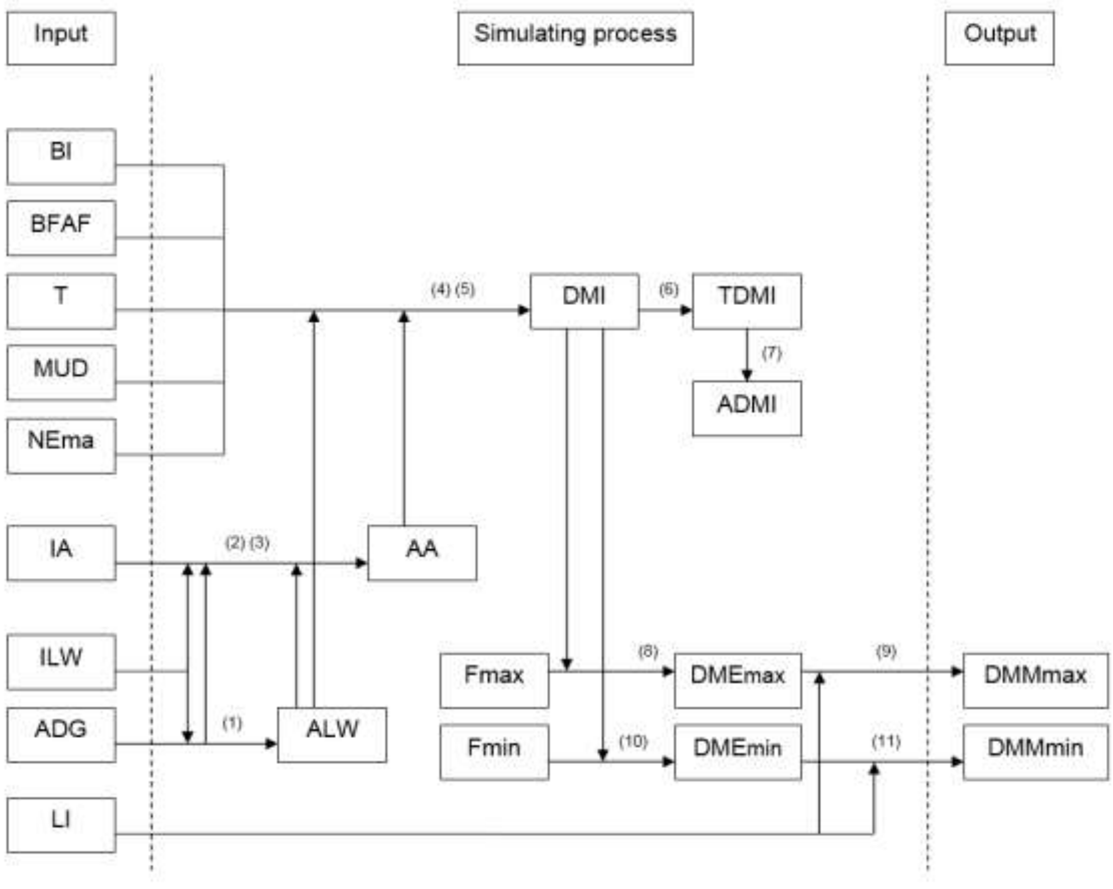

Fig. 1 Conceptual development of the complete model (CompM).

Numbers in brackets identify the correspondent equations in the text. AA: actual age; ADG: average daily gain; ADMI: average dry matter intake; ALW: actual live weight; BFAF: empty body fat effect; BI: breed adjustment factor for dry matter intake; DMEmax: maximum DM produced with excreta; DMEmin: minimum DM produced with excreta; DMI: dry matter intake; DMMmax: maximum DM in manure; DMMmin: minimum DM in manure; Fmax: maximum faeces production; Fmin: minimum faeces production; IA: initial age; ILW: initial live weight; LI: litter weight; MUD: mud factor; NEma: net energy for maintenance; T: temperature factor; TDMI: total DM intake.

2.3 Development of the Simplified Model

The theoretical basis of SimpM is that it is possible to derive a relationship between feed DMI and manure DM output in a calf, as per the following general Eq. (12):

$$\text{DMI} + \text{DM} \times \text{Litter} = \text{DM Live Weight Gain} + \text{DM Manure} \quad (12)$$

The gaseous production from digestive activity and manure fermentation was not considered in this simplified model, as it is not easily measurable at farm level and would represent, anyway, a constant percentage. It has also been recognized that DM excreted with manure is strongly related to DMI [13].

The most important variables that affect this balance are breed, feed intake, ADG and litter amount. These variables are considered in the SimpM for the estimation of manure production as follow: the first variable is correlated to the productivity (i.e., lean tissue gain) and efficiency of feed conversion of an animal; the second one depends on the intake capacity and live weight of the animal; the third one depends on the adopted feeding level; the fourth one depends on the management system. All the variables are already known or can easily be collected by the farmers or by public controllers.

It is possible to simplify model utilization by estimating the DM of live weight gain (DMWG) and litter (DMLI), based on the average DM content, as follows:

$$\text{DMWG} = 0.30 \times \text{ADG} \quad (13)$$

$$\text{DMLI} = 0.90 \times \text{LI} \quad (14)$$

where ADG is the average daily gain (kg d^{-1}) and LI the litter weight (kg d^{-1} as sampled).

The proposed model is therefore the following:

$$\text{MP} = k \times \text{BF} \times (\text{DMI} - \text{DMWG} + \text{DMLI}) \quad (15)$$

where MP is the true manure production on the pen floor (kg d^{-1} as sampled), k is a constant (correlation coefficient between variables and MP), BF is the breed factor (equal to 1 for the Limousine, to be checked for the other beef breeds) and DMI is the feed dry matter intake (kg d^{-1}).

The conceptual development of this model is illustrated in Fig. 2 where it can be seen that the inputs include only 4 variables, i.e. BF, DMI, ADG and LI. Among these inputs those directly measured are DMI, ADG and LI, while BF is assumed according to the breed-type.

2.4 Verification of the Models

The proposed models, CompM and SimpM, were tested and evaluated using the data set collected over 1 year (so as to test them in different climatic conditions) on 31 livestock farms, with 5 genetic types of animals (Blonde d'Aquitaine, BA: 11 herds; Charolaise, CH: 4 herds; Limousine, L: 9 herds; Piemontese, P: 5 herds; beef × dairy crossbreed, CB: 2 herds) and 5 litter types

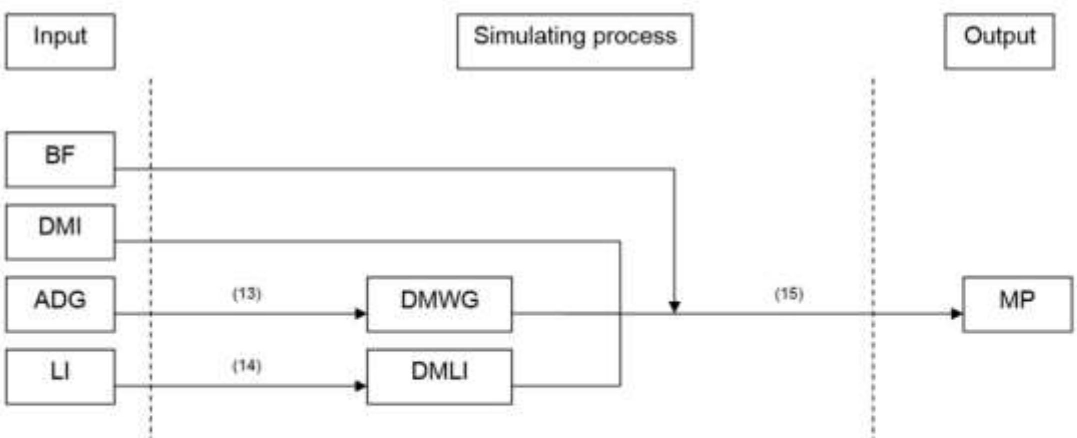

Fig. 2 Conceptual development of the simplified model (SimpM).
Numbers in brackets identify the correspondent equations in the text. ADG: average daily gain; BF: breed factor; DMI: dry matter intake; DMLI: dry matter of litter; DMWG: dry matter of live weight gain; LI: litter weight; MP: manure production.

(straw, corn stalks, sawdust, husks of rise and mixture of several litter materials used in different rearing phases). In total, the evaluation dataset consisted of data from 4,692 animals, equivalent to 2,161 metric ton of live weight. The data were collected under the supervision of the technicians of the Department of Agricultural, Forest and Food Sciences of the University of Turin. Recorded data were: length of the fattening period; animal initial and final weight; feed consumption; litter type and quantity; daily temperatures; manure weight. Feed, litter, and manure were sampled and analysed for the proximate composition in the chemical laboratory of the same Department.

2.5 Statistical Analysis of Results

The data collected in the experimental trial were analysed for the descriptive parameters (mean and standard deviation) and the variables that affected manure production were calculated for SimpM using the Linear Regression procedure [21], according to the following model:

$$y = \beta_o + \beta_1 x_i + \varepsilon_i$$

where y is the dependent variable; β_o is the intercept; β_1 is the regression coefficient; x_i is the independent variable; ε_i is the random error effect.

All the data collected in the livestock farms were analysed by means of the General Linear Model (GLM) Univariate Analysis procedure [21], according to the following model:

$$y = \mu + \alpha_i + \varepsilon_{ij}$$

where μ is the general mean; α_i is the tested effect (season, genetic type, litter type, and rearing systems, respectively); ε_{ij} is the random error effect.

Differences in mean values were tested by means of Duncan's multiple range test, using a first-class error α = 0.05 to establish the differences as significant.

3. Results and Discussion

The data collected during the experimental trial, shown in Table 3, have made it possible to evaluate and improve the CompM and SimpM.

Table 3 Live performance, litter consumption and manure production recorded during the sub-periods (SP) of the experimental trial (mean ± standard deviation). All values are presented on a *per capita* basis.

	SP1a	SP1b	SP2	SP3	SP4	Total period
SP length (d)	64	64	48	78	53	243
ILW (kg)	347.0 ± 17.5	346.3 ± 18.5	432.0 ± 7.2	496.5 ± 11.6	601.2 ± 8.91	346.7 ± 16.1
FLW (kg)	431.0 ± 11.5	433.0 ± 10.5	496.5 ± 11.6	601.2 ± 8.91	674.0 ± 6.4	674.0 ± 6.4
Average LW (kg)	389.0 ± 14.5	389.7 ± 14.5	464.6 ± 9.3	548.6 ± 10.7	637.5 ± 6.53	553.3 ± 6.6
DMI feed (kg d^{-1})	6.71 ± 0.05	6.71 ± 0.02	9.97 ± 0.09	9.62 ± 0.76	9.66 ± 0.94	9.01 ± 1.54
Litter (kg d^{-1})	0.68 ± 0.06	1.00 ± 0.02	1.42 ± 0.13	1.32 ± 0.10	3.16 ± 0.43	1.68 ± 0.93
Manure (kg d^{-1})	8.13 ± 0.21	9.70 ± 0.70	11.02 ± 1.13	10.10 ± 0.88	12.80 ± 1.61	10.71 ± 1.61
Manure DM (%)	32.60 ± 1.14	31.17 ± 3.19	28.55 ± 2.78	25.83 ± 1.88	23.38 ± 3.32	27.41 ± 4.05

ILW: initial live weight; FLW: final live weight; LW: live weight; DMI: dry matter intake.

Table 4 Diet, cattle and management characteristics of the farms selected for the models evaluation (mean ± standard deviation). All cattle and management values are presented on a *per capita* basis.

	L	BA	CH	P	CB
Diet DM (%)	75.76 ± 16.36	85.20 ± 5.29	58.38 ± 4.23	87.01 ± 0.50	69.27 ± 15.79
Diet CP (%)	13.32 ± 2.57	15.18 ± 0.64	12.41 ± 0.60	15.69 ± 0.71	12.92 ± 2.36
DM intake (kg d^{-1})	8.10 ± 1.09	7.17 ± 1.84	10.60 ± 1.49	7.24 ± 1.56	8.08 ± 0.99
Average LW (kg)	502.7 ± 93.53	437.3 ± 130.10	577.1 ± 14.89	396.78 ± 123.10	419.9 ± 87.99
ADG (kg d^{-1})	1.28 ± 0.19	1.51 ± 0.14	1.45 ± 0.14	1.12 ± 0.05	1.41 ± 0.07
Surface (m^2)	5.79 ± 2.08	3.50 ± 0.53	4.93 ± 1.07	3.68 ± 0.63	4.92 ± 1.72
Bedding (kg d^{-1})	2.91 ± 1.24	1.91 ± 0.84	2.57 ± 0.58	1.50 ± 0.29	2.29 ± 0.57

CP: crude protein; LW: live weight; ADG: average daily gain; L: Limousine; BA: Blonde d'Aquitaine; CH: Charolaise; P: Piemontese; CB: Crossbreed.

To evaluate CompM, it was sufficient to replace the collected data with the variables in the proposed model. The application of CompM to the selected farms made it possible to estimate the daily minimum, maximum and average manure production per animal. The difference in manure production among animals is due to the differences in the digestibility of the diet fed. Table 4 lists diet, cattle, and management characteristics of the animals and farms used for the evaluation. Therefore, it was possible to verify the model error by comparing the observed manure production with the CompM estimates of average, maximum and minimum manure production for each scenario.

The errors (%) and standard deviations resulting from the CompM application are +17 (±23), +45 (±36), -11 (±23) for the estimated average, maximum and minimum manure production, respectively. The large variability of the values that are obtained is implicit of the model, which calculates the range within which the quantity of produced manure is located rather than the most likely value, which instead happens with the SimpM model. Moreover, the maximum and minimum production of faeces represent the highest and lowest limits of the system, reachable with diets based only on polyphite meadow hay or on corn meal. These diets are not used in actual feeding plans.

To verify the reliability of SimpM, it was indispensable to first find the k and BF values of Eq. (4). Then, knowing the variables considered for SimpM and using the DM balance Eq. (12) result, obtained from the effective values of DMI, DMWG and DMLI, it was possible, starting from the effective MP, to find the k constant, assuming the BF is equal to 1 (Limousine is the reference breed). Applying formula derived from Eq. (15):

$$k = \text{MP} \times (\text{DMI} - \text{DMWG} + \text{DMLI})^{-1} \quad (16)$$

the k value is equal to 1.2826, and its inverse can be considered as the mean moisture content of the manure (i.e., $1.2826^{-1} = 0.78$ or 78%). The general Eq. (17) of SimpM is:

$$\text{MP} = 1.2826 \times (\text{DMI} - \text{DMWG} + \text{DMLI}) \quad (17)$$

This Eq. (17) should obviously only be considered applicable for the Limousine breed reared in the specific experimental conditions; to extend its applicability, Eq. (17) needs to be verified for other breeds and other rearing conditions.

The GLM Univariate analyses of the data collected on the commercial farms only showed statistical differences for the manure production for the genetic type ($p < 0.05$; Table 5). Therefore, Eq. (17) was applied to the selected commercial livestock considering 5 different European breed-types (BA, CH, L, P, CB), in order to define the BF factor. The herds were randomly reared on 5 different litter types, as above specified.

The application of SimpM resulted in a lower estimated manure production for the farms than observed values (-11.7%). The relationship between the simulated MP (SMP) and the actual MP (AMP) is shown in Fig. 3. The dispersion of the points around the Y=X line is related to the breed effect: some breed-types, such as L or CB, were consistently underestimated, whereas others were more evenly dispersed around the Y=X line.

Table 5 Factors affecting manure production (kg manure t^{-1} LW) in ordinary rearing systems.

Factor	ANOVA				
Genetic type	L	BA	CH	P	CB
	35.5 ± 11.1^a	25.0 ± 6.1^b	31.0 ± 3.3^{ab}	28.3 ± 2.8^{ab}	39.4 ± 3.5^a
Litter type	straw	corn stalks	sawdust	rice husks	mixture
	33.0 ± 9.5	30.2 ± 10.5	30.2 ± 0.3	27.7 ± 2.7	23.3 ± 3.2
Season		Hot (summer-autumn)		Cold (winter-spring)	
		28.5 ± 5.5		33.8 ± 11.1	

L: Limousine; BA: Blonde d'Aquitaine; CH: Charolaise; P: Piemontese; CB: Crossbreed.

[a,b] Means in the same row with different superscripts differ significantly ($p < 0.05$).

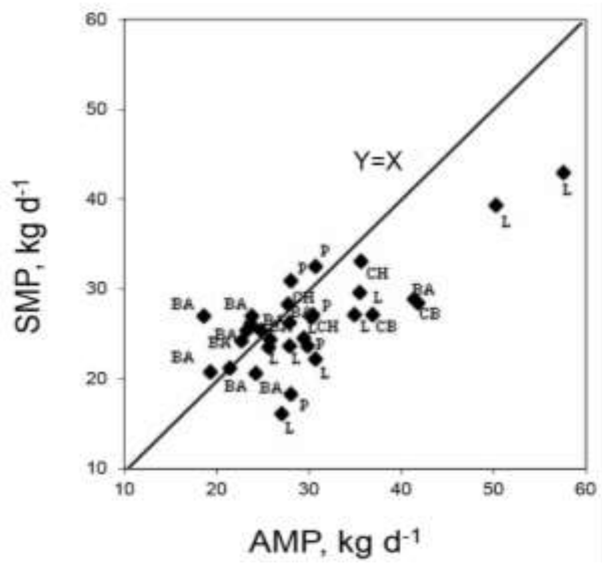

Fig. 3 Relationship between actual (AMP) and simulated (SMP) manure production (kg d^{-1}) in the simplified model (SimpM).

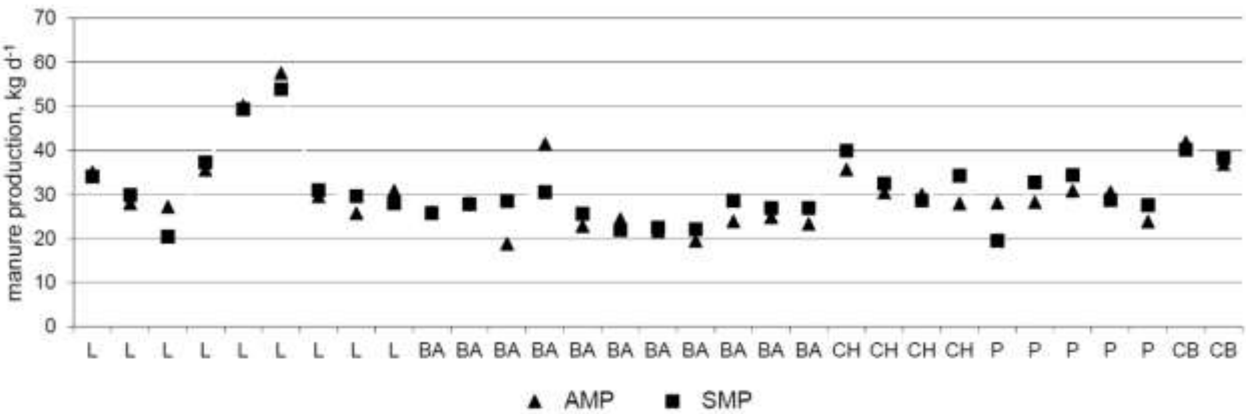

Fig. 4 Comparison between actual (AMP) and simulated (SMP, comprehensive of the overvaluation +2% as requested by public authorities) manure production (kg d^{-1}) in the simplified model (SimpM) in the different farms for each breed-type.
L: Limousine; BA: Blonde d'Aquitane; CH: Charolaise; P: Piemontese; CB: crossbreed.

Based on this result, a BF multiplier was calculated according to Eq. (15), then increased to obtain a slightly overestimated SMP by 2.0% as compared to average production, as requested by public authorities, to reduce the potential for manure mismanagement. The calculated BF multipliers are: 1.25 for L, 1.05 for BA, 1.20 for CH, 1.05 for P and 1.40 for CB. SimpM application showed an error (%) and standard deviations of +4.0 ± 15.6 for the previously discussed overestimated (+2%) average manure production. On the basis of this calculation the comparison between AMP and SMP as daily production (kg/d) in the different farms for each breed-type is shown in Fig. 4.

CompM has been developed as an extension of the NRC model [19], and it is able to quantify the daily or fattening cycle MP of beef cattle using the same inputs proposed by the afore mentioned model. It has been modified and adapted to a specific beef cattle rearing system after an examination of the structure of the system itself. The proposed model has been designed to be more reliable than the original one. In fact, the application of the original model has shown an average error of 64% (± 41%) while the proposed one only 17% (± 23%). This accuracy can be considered similar to what is achieved by other models studied for dairy cows [13].

Moreover, CompM is a complete model that can also be used as a dynamic one. In this context, several examples of computerised applications in the animal production field have been found [9, 22-24].

Another advantage of CompM is that it quantifies average, minimum and maximum MP production, thus offering an excretion range inside within which it is possible to find the actual beef cattle manure production according to the ration digestibility. This model represents a useful tool for researcher, extension, and farm managers to evaluate the general efficiency of a herd compared to similar intensive beef production systems.

SimpM used to predict MP showed good reliability, as previously reported, and as can be observed in Fig. 4, which compares AMP and SMP values. Although it was decided to introduce a slight overvaluation (+2%) of SMP into the simulation, Fig. 4 points out the same tendency between the AMP and SMP points, the latter always higher than the first, except in few cases (three for L, two for BA, and one for P).

The evaluation of the applicability of the proposed models under typical regional beef cattle management has both advantages and disadvantages. The first fundamental aspect was that the MP per unit of live weight showed differences, but only considering the breed-type of the cattle. The effect of the different litter types and seasons was negligible. This fact has allowed the theoretical models, especially SimpM, to be simplified. In fact, it was quite easy to determine the BF coefficient to adapt SimpM to the breed-type of the herd.

After this adjustment, SimpM resulted in a satisfactory estimation of the MP, which allows a correct planning of other farm activities (e.g., planning the minimum manure storage or the agronomic usage). The simplicity of this model makes its direct use easy for farmers, but overall, it could be useful for extension personnel, researchers and regulatory agencies, eventually after it has been improved by increasing the number of studied breeds.

Moreover, considering the relationship between the DMI and LW of the animal, SimpM could be used to estimate the MP in different moments of the rearing cycle and to obtain an MP curve. This aspect could be useful for fattening centres that have cattle or groups of cattle of the same age (e.g., calf rearing systems) and as a result have an increasing daily MP that follows the cattle growth expressed as live weight.

The drawback of SimpM is of a generic type, which is implicit of this type of model. SimpM, being an empirical model, describes the observed reality and is not necessarily based on any preconceived biological theory. If the model fits the collected data, the equation could be extremely useful, though it would be specific for the conditions under which the data were obtained, and consequently the range of its predictive ability would be limited. Therefore, the proposed model could be susceptible to the effects of the number of collected observations; by enlarging this number, it would be possible to refine the models.

The comparison of the models has shown that CompM requires an interpretation of the results because it does not give one single value, but the minimum and maximum MP values. Thus, the model is highly informative but is more suitable for professional use by researchers. On the other hand, SimpM can be considered more versatile than CompM, because it is simple to use.

4. Conclusions

The models presented in this paper represent a proposed tool useful to farm managers, extension personnel, researchers and regulatory or governmental agencies, affording a higher reliability in the quantification of the manure produced by beef cattle than the formulas now available. The proposed models have shown to be applicable in different contexts: CompM could be useful for public controllers, as well as for planning farm management and evaluating some livestock parameters; SimpM could be useful for manure management planning and farm activities (fertilisations). Both can be considered as a tool for the development of precision farming techniques.

The models have been designed and evaluated for intensive farming systems and for European cattle breed. Both the models could be improved if evaluated on other rearing systems or other beef types, and as based the DM balance is easily adaptable to different productive situations.

In the future the studied models could be transformed into dynamic models. Several software packages that have been studied for application in different research fields could represent useful tools to set up a dynamic modelling system.

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