



HAL
open science

Data paper: Performance of fattening Charolais bulls fed iso-net energy, fibre vs starch rations based on haylage or maize silage, at two levels of intake

Bernard Sepchat, I. Ortigues-Marty, Cécile Martin, M.M. Mialon, J. Agabriel

► To cite this version:

Bernard Sepchat, I. Ortigues-Marty, Cécile Martin, M.M. Mialon, J. Agabriel. Data paper: Performance of fattening Charolais bulls fed iso-net energy, fibre vs starch rations based on haylage or maize silage, at two levels of intake. *Animal - Open Space*, 2026, 5, pp.100128. <10.1016/j.anopes.2026.100128>. <hal-05586836>

HAL Id: hal-05586836

<https://hal.inrae.fr/hal-05586836v1>

Submitted on 10 Apr 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY-NC-ND 4.0 - Attribution - Non-commercial use - No Derivative Works - International License



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

animal - open space

journal homepage: www.elsevier.com/locate/anopes



Data paper

Data paper: Performance of fattening Charolais bulls fed iso-net energy, fibre vs starch rations based on haylage or maize silage, at two levels of intake



B. Sepchat ^{a,*}, I. Ortigues-Marty ^b, C. Martin ^b, M.M. Mialon ^b, J. Agabriel ^b

^a Herbiopole UE1313, INRAE, 63122 Saint-Genès-Champanelle, France

^b UMR1213 Herbivores, INRAE, Université Clermont Auvergne, VetAgro Sup, 63122 Saint-Genès-Champanelle, France

ARTICLE INFO

Article history:

Received 30 June 2025

Revised 15 January 2026

Accepted 16 January 2026

Handling editor: Tony Waterhouse

Keywords:

Beef cattle

Behaviour

Carcass composition

Efficiency

Growth

ABSTRACT

Reduction of cereals in ruminant diets contributes to reducing the feed-food competition, and new strategies are required to reduce the use of maize silage while preserving profitability of beef fattening production systems. Haylage from permanent pasture is an interesting alternative to maize silage as the main forage in the diet although possibly leading to lower fat deposition and higher methane emissions than maize silage because of differences in the profile of absorbed nutrients. The present paper presents data from an experiment with young growing Charolais bulls fed two iso-net energy and iso-CP rations based on haylage or maize silage and differing in their proportions of starch and fibre, offered at two levels of net energy intake. Two trials were conducted. In a feeding trial, 36 weaned bulls were individually fed over the whole fattening period, and slaughtered at the same final BW of 700 kg at 15–18 months of age. Intake, weight gain, adiposity (body condition score and adipocyte size), 6th rib composition and behaviour (eating, drinking, social encounters, standing still, moving, lying) of the animals were measured. The tissue and chemical composition of the whole body and carcass at slaughter were calculated from the rib composition. A balance trial, conducted in parallel, used eight bulls to measure diet digestibility, nitrogen balance, and the production of enteric methane. The data obtained in the two trials describe the impact of the nature of the dietary net energy on performance and fat deposition and separate it from the influence of net energy intake level hence of growth rate; it is of interest to develop nutritional strategies for beef cattle. Scientifically data are of interest to test the limits of existing feeding systems or growth models and predict dynamic changes in body and carcass composition with time. From an applied point of view, data show a lower efficiency of use of the haylage ration.

© 2026 The Author(s). Published by Elsevier B.V. on behalf of The animal Consortium. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Reader comments

We invite you to comment on the article on the PubPeer platform by clicking on this link [discuss this article](#).

Specifications table

Subject	Nutrition and Quality of animal products
Specific subject area	Ruminants, fattening bulls
Type of data	A table with one glossary and 15 spreadsheets

How data were acquired	Data were acquired from a feeding trial with 36 young Charolais bulls and a balance trial with eight young bulls.
Data format	Raw and pretreated data
Parameters for data collection	Data acquired are intakes, weight gain, adiposity (body condition score and adipocyte size), 6th rib composition (to determine the tissue and chemical composition of the whole body and of the carcass), behaviour, digestibility, nitrogen balance, and enteric methane emission.
Description of data collection	Data were acquired from a feeding trial with 36 young Charolais bulls and a

(continued on next page)

* Corresponding author.

E-mail address: bernard.sepchat@inrae.fr (B. Sepchat).

	balance trial with eight young bulls. All animals were individually fed. In the feeding trial, carcass composition at slaughter was determined from the dissection of the 6th rib. In the balance trial, faeces and urine were collected from animals in individual stalls, allowing total faecal collection and equipped with a harness for urine collection; methane emission was measured using the sulphur hexafluoride tracer method.
Data source location	Institution: INRAE City/Town/Region: Theix, Saint-Genès Champanelle Country: France Latitude and longitude (and GPS coordinates, if possible) for collected samples/data: 45°43'8.94" N 3°01'7.93" E
Data accessibility	Repository name: https://entrepot.recherche.data.gouv.fr Link: https://entrepot.recherche.data.gouv.fr/privateurl.xhtml?token=a59c3fb5-424b-4293-9d26-50971e047013
Related research article	Sepchat B., Ortigues-Marty I., Mialon M. M., Faure P., Agabriel J., 2013. Croissance et nature des dépôts de jeunes bovins charolais recevant en engraissement des rations à base d'enrubannage ou d'ensilage de maïs. Rencontres Recherches Ruminants, 20, 169–172

Value of the data

- The data offer performance results (growth, body composition, digestibility, N balance and methane emission) of fattening bulls fed individually in controlled conditions according to an experimental design that separates the effects of nature of the net energy from those of the level of net energy intake.
- Data are of interest to researchers in nutrition and growth for the development of nutritional strategies for beef cattle.
- Data can be used to test the limits of existing feeding systems or growth models.
- The data can also be used in meta-analyses on the use of forage, both haylage and maize silage, based rations in fattening diets of beef cattle.

Data description

The Excel file contains one glossary and fifteen spreadsheets, which report (Fig. 1).

- The history of the animals used in the feeding trial (A_Animal history),
- The history of the animals used in the balance trial (B_Animal history),
- The feeds and diets used in the feeding and the balance trials (A&B_Feeds & diets)

- The intake of animals used in the feeding trial (A_Individual intakes),
- The time budget for different activities by animals used in the feeding trial (A_Activity time budget),
- The feeding behaviour of animals used in the feeding trial (A_Feeding behaviour),
- The liveweights of animals used in the feeding trial (A_Liveweights),
- The liveweight gains of animals used in the feeding trial (A_Liveweight gains),
- The body condition scores of animals used in the feeding trial (A_Body Condition Score),
- The adipocyte size and calculated body composition of animals used in the feeding trial (A_Adipocytes-body composition),
- The calculated feed efficiency of animals used in the feeding trial (A_Feed efficiency),
- The slaughter data of animals used in the feeding trial (A_Slaughter data),
- The calculated energy deposit of animals used in the feeding trial (A_Energy deposit at slaughter),
- The diet digestibility and N balance of animals used in the balance trial (B_Digestibility_N balance) and
- The methane emissions of animals used in the balance trial (B_Methane)

Trial A refers to the Feeding trial (with 36 animals, including one (#2011583) that did not finish the trial because of lameness) while trial B refers to the Balance trial (with eight animals). Animal #2011583 (treatment **MH**, Maize silage-High) was taken out of the Feeding trial on the 6th of Mars 2012, and its data are not reported.

Experimental design, materials and methods

Study design

The experiment was performed in the INRAE Herbiopôle experimental unit <https://doi.org/10.15454/1.5572318050509348E12> between November 2011 and September 2012. It involved a total of 44 young Charolais bulls, weaned at 8 months of age in two trials: a feeding trial and a balance trial. In both trials, four treatments were applied, arranged in a 2 × 2 factorial design, two forage sources [maize silage (**M**) vs haylage (**G** for 'grass')] × two net energy intake levels [achieved thanks to two energy densities in diets, High (**H**) or Low (**L**)].

In the feeding trial (Trial A), 36 bulls were used in a complete randomised design experiment. Nine weeks after weaning, the young bulls were allocated to the four treatment groups of nine animals each, such that age, liveweight, liveweight gain from birth to weaning, and rate of maturing of the father were balanced across treatment groups. There were nine pens in the open shed; each treatment was allocated two pens, and one pen had one animal on each treatment. Animals within a treatment were randomly assigned to the relevant pens.

In parallel, eight bulls were used in a balance trial (Trial B) according to a duplicated 4 × 4 Latin Square design. At the beginning of the trial, they were blocked in two blocks according to age, liveweight, liveweight gain from birth to weaning, and each block was randomly assigned to a Latin Square. Within each Latin Square, animals were randomly assigned to stalls in the barn.

Animals and housing

In the feeding trial (Trial A), the 36 bulls came from the same herd with controlled genetic origin (INRAE experimental unit of

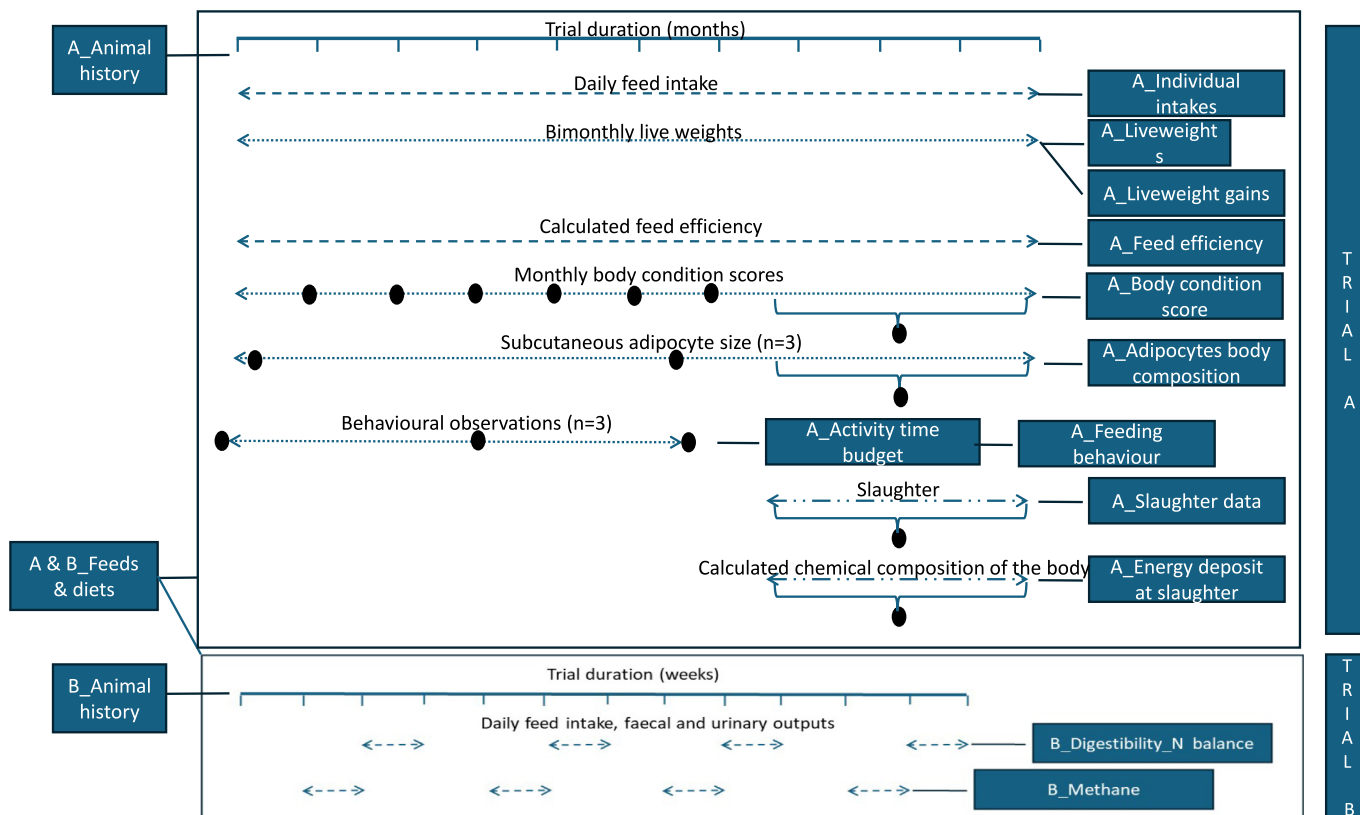


Fig. 1. Schematic representation of the different measurements applied to young Charolais bulls fed diets differing in forage [maize (M) vs haylage (G)] and net energy concentration (High (H), Low (L)). The blue boxes represent the spreadsheets reporting the relevant data as listed in the Data Description section; 'A.' and 'B.' refer to Trials A and B, respectively. ● depicts the days of measurement when unrequent.

Le Pin-au-Haras, France, UE0326, <https://doi.org/10.15454/1.5483257052131956E12>). They were weaned at 8 months of age and had a weaning weight of 360 ± 33 kg; they had not received any supplementation before weaning. The bulls were housed in an open shed with free stalls on semi-mulched area. Each animal had access to its individual trough via an electronic feed gate (Dairy Gate 3; E.F.E.I., 89100 Villeroy, France), and individual feed intake was measured. The whole experiment started when animals were 269 days of age with an average weight of 362 kg and lasted 221 days. Bulls were slaughtered at a similar target liveweight of 700 kg, corresponding to a target carcass weight of 420 kg. As a result, the age of bulls at slaughter varied from 15 to 18 months. All animals but one (#2011583, treatment MH) because of lameness completed the trial.

In the balance trial (Trial B), the eight bulls were used to assess diet digestibility, nitrogen emissions and the production of enteric methane. Animals originated from INRAE Herbipôle-Laqueuille experimental facility (<https://doi.org/10.15454/1.5572318050509348E12>), they had been weaned at 7 months old and 323 kg liveweight. At the beginning of the experiment, they were 10 months old and weighed 405 ± 26.5 kg. They received an anti-parasitic treatment (IVOMEC D 1 ml/50 kg BW administered subcutaneously). Animals were housed indoors in individual tie stalls (concrete floor with rubber mats) equipped for total faecal collection. Animals were tied short, and a faecal collection tray was placed at the back of the stall, i.e. at the back of and 10 cm below the rubber mat. For urine collection, animals were equipped with a harness attached to a vacuum pump. At the beginning of the experiment, they underwent a transition period of 4 weeks. Subsequently, each of the four treatment periods lasted 3 weeks, and detailed measurements occurred over the last 6 days. All animals completed the trial.

Diets and feeding

After weaning, animals went through a 4-week transition period during which the proportion of the weaning diet [hay from permanent mountain pasture offered ad libitum plus 2 kg commercial concentrate, 0.92 **UFV** (*Unité Fourragère Viande* or Forage Unit for Meat) and 187 g CP/kg as is] decreased from 75% to 0% while the proportion of the fattening treatment diet in the ration increased progressively from 25 to 100% of DM intake. The transition period was used to determine the intake capacity of the animals with the objective of avoiding refusals during the experimental periods.

The four treatment rations, and not diets, were formulated for each increment of 100 kg BW because the fill value of the rations and the intake capacity of the animals as well as its evolution with age were taken into consideration as per the INRA feeding system (INRA, 2018), besides the nutritional feed characteristics. Daily rations H and L were designed to achieve the same theoretical concentrations in net energy (UFV or MJ /day) and CP and the same fill values for a given net energy density based on initial analyses of the chemical composition of the ingredients. The two net energy density rations (H and L) differed by the nature of the forage (maize silage, $41 \pm 1.88\%$ DM) vs haylage from semi-permanent mountain pasture, first cut, harvested in fine weather, early heading stage and wilted ($64.7 \pm 4.90\%$ DM), the nature of the concentrate (rapeseed meal with urea vs citrus pulp and wheat malt) and the proportion of the different ingredients. All four rations were formulated to get at the midpoint of the fattening period (1) a 200 g average daily gain difference between the treatments L and H (respective target of 1 400 and 1 600 g/d liveweight gain; INRA, 2018), (2) a minimum difference of 10% concentrate in the rations (DM basis) and 3) similar theoretical average net energy intakes per day within the L and H treatments. As a result, the four

treatment rations differed by their composition in ingredients and nutritive values. Tables 1 and 2 report the average ingredient and chemical composition and the nutritive values of the four rations, as measured and analysed during the experiment. For a given feeding level, net energy concentration of rations was achieved at ±3%.

In the feeding trial (Trial A), animals were fed in two meals per day at 0800 and 1530 h. Forages were fed ad libitum (10% refusal) for the four treatments, and the total daily allowance of forage was distributed at the morning meal. Concentrate allowances were recalculated every week based on the intakes of the previous weeks and with the objective to maintain the forage to concentrate ratio constant within treatments. The concentrate allowance for all four rations was distributed equally between the two meals and positioned in each individual trough above the forage.

In the balance trial (Trial B), the animals received two meals per day at 0900 and 1600 h. Forages were distributed at the morning meal only, while concentrates were distributed twice daily. Forages and concentrates were mixed by hand in the trough at distribution. To take account of the growth of animals during experimentation, the quantities of DM offered were adjusted to the liveweight of each animal when changing experimental treatment while the forage/concentrate ratio was kept constant.

Measurements and analyses

Feeding trial (Trial A) – intake and growth

Offered and refused feeds were measured for each animal every day. DM (100 °C, 24 h) was measured twice weekly for ingredients and daily for refusals. Additional weekly samples of offered feeds and refusals were pooled over 2-month periods, ground (concentrate) or stored frozen (wet ingredients) before analyses of total Kjeldahl N (Association of Official Analytical Chemist; AOAC, 2005), organic matter (OM) (AOAC, 2005), NDF and ADF [Van Soest et al. (1991) using the Ankom 200 Fiber Analyzer (ANKOM Technology Corporation, Macedon, NY, USA)], starch (Faisant et al., 1995), ether extract (EE, by extraction with petroleum ether, AOAC, 2005) and gross energy by adiabatic calorimetry (Vermorel et al., 1997). Intake was calculated by the difference between offered and refused feeds. Because the composition of the refusals was very similar to that of the forages, refusals were attributed to the forage when separately calculating the concentrate and forage intakes reported in the A_Individual intakes spreadsheet. Animals were weighed on two consecutive days at the onset and the end of the experiment at 1330 h. In between, they were weighed every two weeks, also at 1330 h.

Table 1
Average measured chemical composition and nutritional values of the feed ingredients used in rations fed to young Charolais bulls.

	DM %	OM g/ kg DM	CP g / kg DM	Starch g/kg DM	NDF g / kg DM	ADF g / kg DM	EE g / kg DM	GE MJ / kg DM
Maize silage	41.0	946	85	351	390	201	ND	18.25
Haylage	64.7	905	106	10	598	324	ND	18.22
Wheat	87.6	982	121	698	143	36	17	18.22
Maize grain	86.8	986	94	742	120	30	43	18.69
Rapeseed meal	88.4	921	380	0	319	221	26	19.31
Citrus pulp	89.2	930	71	33	216	154	25	17.54
Wheat malt	90.9	945	310	100	240	80	56	20.37
Urea	99.9		2 875					

Abbreviations: EE, ether extract; GE, gross energy; ND, not determined; OM, organic matter.

Table 2
Average measured ingredient and chemical composition, and nutritional values of the four treatment rations fed to young Charolais bulls and differing in forage [maize (M) vs haylage (G)] and net energy concentration (High (H), Low (L)).

	MH	GH	ML	GL
Ingredient (% of DM)				
Maize silage	52.5	0	64.8	0
Cereal (2/3 wheat, 1/3 maize grain)	29.4	0	17.7	0
Rapeseed meal	16.1	0	15.8	0
Urea	1	0	0.7	0
Minerals	1	1	1	1
Haylage	0	42.8	0	51.4
Citrus pulp	0	32.1	0	25.7
Wheat malt	0	24.1	0	21.9
Chemical composition (% of DM)				
OM	93.4	91.1	93.3	91.1
CP	15.8	15	15.5	14.6
Starch	40.3	2.7	37	2.5
NDF	32.2	46.2	34.8	48.4
ADF	15.3	22.9	17.2	24.3
UEB ¹ /kg DM	0.98	0.98	1.02	1.02
NE ¹ (MJ/kg DM)	7.142	6.920	6.773	6.627
NE ¹ (UFV/kg DM)	0.97	0.94	0.92	0.9
MP ¹ (g PDI/kg DM)	91	99	86	95
MP ¹ /NE (g PDI/UFV)	94	105	93	106
EffPDI	0.50	0.47	0.52	0.48

Abbreviations: ADF, acid detergent fibre; EffPDI, efficiency of PDI utilisation; MP, metabolisable protein; NDF, neutral detergent fibre; NE, net energy; OM, organic matter; PDI, protein digestible in the intestine; UEB, fill value for cattle; UFV, feed unit, a net energy value for beef cattle.

¹ according to INRA (2018).

Feeding trial (Trial A) – body composition

The rate of fat deposition was determined once monthly by body condition scores by two trained persons (Agabriel et al., 1986), and three measurements of subcutaneous adipocyte size (Robelin et al., 1986) at the beginning of the trial (on the 19th of November 2011), mid-fattening (on the 5th of April 2012), and at slaughter (between the 21st May and the 25th September 2012). Animals were slaughtered when they reached the target live weight of 700 kg. Actual live weight at slaughter averaged 705 ± 22.5 kg (Table 3) while the measured daily net energy intake differed by an average of 4% across treatments and duration of treatments to reach similar live weights by 17%, at the same intake levels (Fig. 2). At slaughter, body composition was determined according to Robelin (1986). Animals were bled and eviscerated after the removal of their skin. The digestive tract was weighed full and empty, and the different sections (rumen, reticulum, omasum, abomasum, small and large intestines) were separated. The head was removed at the atlas-axis junction, and the members at the tarso-metatarsal and carpo-carpal junctions. The different organs (heart, liver, lungs and spleen) and all separable fats were isolated. All parts were weighed. The carcass was weighed hot and cold after 24 h at 4 °C, and carcass yield was calculated. Carcass composition was estimated from the dissection of the 6th rib (Robelin and Geay 1975).

Feeding trial (Trial A) – behavioural observations

Behaviour was measured in 32 animals only. The four animals from the last pen, which housed one animal per treatment, were excluded. The time budget of the bulls was estimated from 24 h video recordings 5 days before the start, at the middle and end of the fattening period (about 14 and 21 weeks after the beginning of the trial). Video cameras (Sony SPT-M128CE) were fixed above the finishing pens, with one camera covering two pens. From the video recordings, the behaviour of the bulls was encoded on a computer using The Observer® version 5 software. The behaviour of each bull was scanned every 5 min (288 recordings per animal and day). Six behavioural activities mutually exclusive were considered: eating, drinking, social encounters, standing still, moving, and lying (van Dixhoorn et al., 2024). For each bull, we calculated the proportion of time spent in each activity (estimated by the daily percentage of scans with this specific activity), the number of bouts and the mean bout duration for each activity, and the synchronisation of each behaviour (mean number of bulls within a

group performing the same activity at the same time of the focal animal).

Feeding behaviour was estimated from the electronic feeding gate, five times during the fattening period, each time based on 5 consecutive days of recordings. The daily time during which the feeding gate of a bull was open was considered as the daily eating time. The number and mean duration of meals were calculated; for these calculations, we considered that inter-meal intervals lasted at least 4 min (Metz, 1975; Baumont et al., 2006). The intake rate was calculated as the ratio of DM feed intake to eating time (g DMI / min). Data were averaged and expressed on a daily basis.

Balance trial (Trial B) – intake, diet digestibility, N balance

Offered and refused feeds were weighed and sampled daily for DM determination (100 °C, 24 h). Offered and refused feeds were also sampled daily over the 6 days of faeces and urine collection, stored frozen and pooled per animal before chemical analysis for total Kjeldahl N (Association of Official Analytical Chemist; AOAC, 2005), OM (AOAC, 2005), NDF and ADF [Van Soest et al. (1991) using the Ankom 200 Fiber Analyzer (ANKOM Technology Corporation, Macedon, NY, USA)] and starch (Faisant et al., 1995). Intake was calculated by difference between offered and refused.

Total faeces were collected from the faecal collection tray and weighed daily, pooled per animal / period. A subsample was used for DM determination (100 °C, 24 h), a second subsample was stored frozen before chemical analyses on dried (60 °C, 72 h) faeces (OM, NDF, ADF, as above), and a third subsample was used for immediate Kjeldahl N analysis. Urine was collected in flasks containing sulfuric acid (10%) and weighed daily. Daily samples were stored frozen before being pooled per animal and period, and analysed for total Kjeldahl N. Faeces and urine were analysed for their energy contents using an adiabatic bomb calorimeter (Vermorel et al., 1997). Apparent digestibility (DM, OM, N, energy, NDF and ADF) and retained N were calculated as follows, using N as an example:

$$\text{Apparent N digestibility (\%)} = \frac{\text{feed intake of N} - \text{faecal amounts of N}}{\text{feed intake of N}} * 100$$

$$\text{Retained N} = \text{feed intake N} - \text{amount of faecal N} - \text{amount of urinary N}$$

Table 3
Key performance data (average ± SD) of young Charolais bulls fed rations differing in forage [maize (M) vs haylage (G)] and net energy concentration [(High (H), Low (L)).

	MH	GH	ML	GL
Feeding trial (Trial A)				
Daily DM intake (kg/d)	9.10 ± 1.08	9.2 ± 1.3	8.3 ± 0.4	8.9 ± 0.9
Daily NE intake (MJ/d)	65.07 ± 8.40	63.25 ± 8.34	56.50 ± 3.05	58.98 ± 0.90
Daily PDI intake (g/d)	830 ± 103	911 ± 60	714 ± 133	846 ± 91
Fattening duration (d)	202 ± 33	235 ± 31	213 ± 22	251 ± 28
Cumulated DM intake (kg)	1 839 ± 220	2 160 ± 306	1 766 ± 87	2 238 ± 248
Cumulated NE intake (MJ)	13 145 ± 1 697	14 864 ± 1 961	12 035 ± 654	14 805 ± 1 651
Cumulated PDI Intake (kg)	167.7 ± 20.9	214 ± 8.2	214.0 ± 28.4	216.8 ± 23.0
Initial liveweight (kg)	369 ± 43	362 ± 37	357 ± 34	368 ± 20
Final liveweight (kg)	701 ± 27	701 ± 15	687 ± 26	707 ± 16
ADG (kg/d)	1.716 ± 0.242	1.492 ± 0.146	1.589 ± 0.163	1.387 ± 0.139
Cold carcass weight (kg)	416 ± 13.9	404 ± 11.6	411 ± 8.4	416 ± 16.7
Total body adipose tissues/cold carcass weight (%)	22 ± 1.6	18.4 ± 5.9	19.9 ± 1.8	18.8 ± 3.2
Balance trial (Trial B)				
DM digestibility (%)	74 ± 2	73 ± 2	72 ± 3	72 ± 1
OM digestibility (%)	75 ± 2	76 ± 2	74 ± 3	74 ± 1
N Digestibility (%)	67 ± 4	60 ± 2	64 ± 4	58 ± 1
CH ₄ emission/Gross energy intake (%/d)	6.2 ± 1.5	7 ± 1.0	6.5 ± 1.2	7.4 ± 1.2

Abbreviations: ADG, average daily gain; NE: net energy; OM, organic matter; PDI: protein digestible in the intestine.

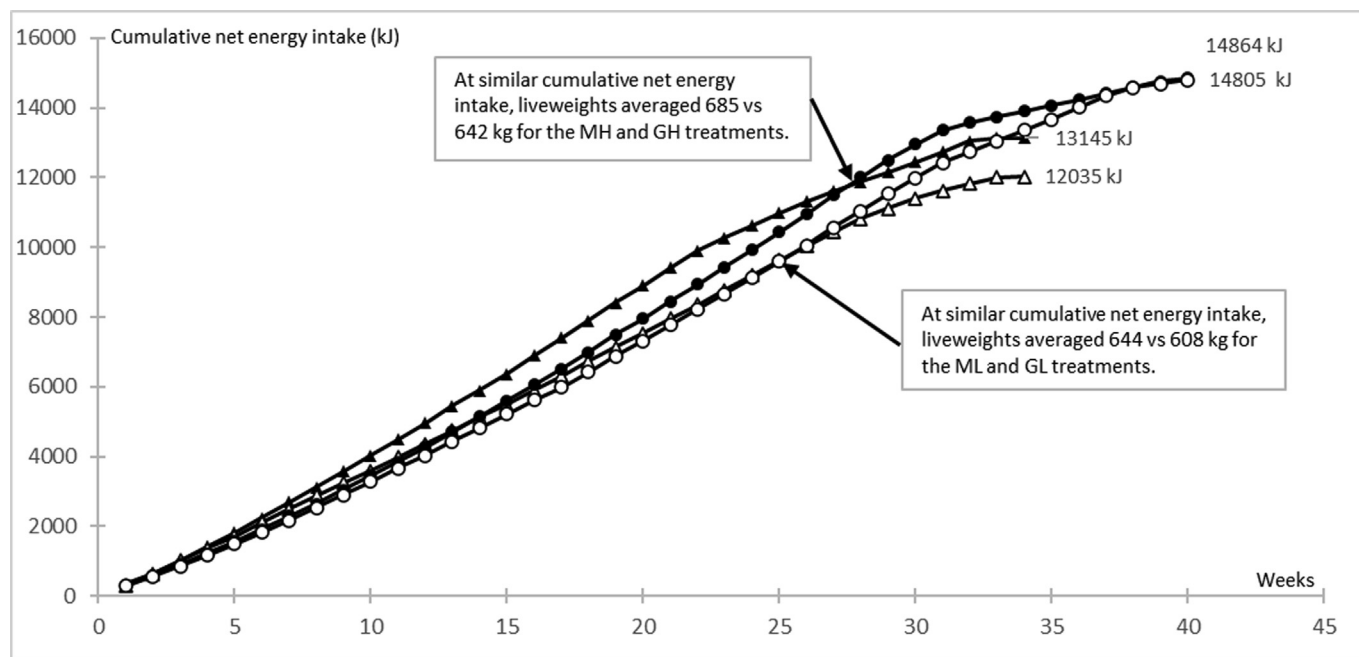


Fig. 2. Cumulative net energy intake, based on weekly averages for the four treatment groups of young Charolais bulls fed diets differing in forage [maize (M) vs haylage (G)] and net energy concentration (High (H), Low (L)). MH (▲), ML (△), GH (●), GL (○). Week 1 corresponds to the first week of fattening.

Animals were weighed (single weighing) before the morning meal, before and after each treatment period.

Balance trial (Trial B) – enteric methane emission

Methane emission was determined using the sulphur hexafluoride (SF₆) tracer method (Johnson et al., 1994; Martin et al., 2008) over 4 consecutive days in the second week of treatment, i.e. before the faecal and urine collection periods, as previously described by Doreau et al. (2011). Brass permeation tubes (12.5 mm × 40 mm i.d.) weighing about 32 g were loaded with about 700 mg of SF₆ at liquid nitrogen temperature (−196 °C) and calibrated by regular weighing (twice a week) for an 8-week period. Tubes were kept immersed in a water bath at 39 °C. Permeation rate of SF₆ from the tubes was 1.528 ± 0.052 mg/d. A calibrated permeation tube was dosed per os into the rumen of each bull 10 days before sampling gas in period 1. Representative breath samples from each animal were sampled in pre-evacuated (−83 kPa) yoke-shaped polyvinylchloride collection devices (~2.5 L) by means of capillary and Teflon tubing fitted to a halter. The end of the sampling tube was maintained close to the nostrils. The collection devices were changed every 24 h before the morning feeding. The devices containing the samples were immediately transported to the laboratory and over-pressured with N₂ gas to about +83 kPa prior to SF₆ and CH₄ analyses. Background concentrations of these gases were also measured in ambient air samples collected every day in the shed during the same 4-day sampling period.

Concentrations of SF₆ and CH₄ in breath and ambient air samples were determined by gas chromatography. A gas chromatograph (Varian-Chrompack, CP-9003, Les Ulis, France) fitted with an electron capture detector and a gas chromatograph (Perkin Elmer instruments; Autosystem XL, Courtaboeuf, France) fitted with a flame ionisation detector were used to determine the concentrations of SF₆ and CH₄, respectively. The samples were run on chromatographs equipped either with a Molecular Sieve 0.5 nm column (3 m × 3.2 mm i.d.) maintained at 50 °C for the SF₆ analysis or with a Porapak N 80–100 mesh column (3 m × 3.2 mm i.d.) maintained at 40 °C for the CH₄ analysis.

The flow rate of the carrier gases was 30 mL/min of N₂ for the SF₆ analysis and 40 mL/min of He for the CH₄ analysis. Chromatographic analyses were performed after calibration with standard gases (Air Liquide, Mitry-Mory, France) for SF₆ (202 ppt) and CH₄ (99.9 ppm).

Daily CH₄ production by each animal was calculated using the known permeation rate of SF₆ for each animal and the concentrations (above the background) of SF₆ and CH₄ in the breath samples:

$$\text{CH}_4 \text{ (g/d)} = \text{SF}_6 \text{ permeation rate (g/d)} \times [\text{CH}_4]/[\text{SF}_6],$$

where gas concentrations are expressed in µg/m³.

Peer Review Summary

Peer Review Summary for this article (<https://doi.org/10.1016/j.anopes.2026.100128>) can be found at the foot of the online page, in Appendix A.

Ethics approval

The experiments were conducted in 2011–2012 in compliance with national legislation on animal care (Certificate of Authorisation to Experiment on Living Animals, No. 004495, Ministry of Agriculture, France).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

Sepchat B.: <https://orcid.org/0000-0002-9751-351X>.
 Ortigues-Marty I.: <https://orcid.org/0000-0002-0399-013X>.
 Martin C.: <https://orcid.org/0000-0002-2265-2048>.
 Mialon M.M.: <https://orcid.org/0000-0002-2356-4365>.
 Agabriel J.: no Orcid.

Author contributions

Sepchat B.: Conceptualisation, Investigation, Methodology, Resources, Formal analysis, Data curation, Visualisation, Validation, Project administration, Writing – original draft, Writing – review & editing.

Ortigues-Marty I.: Conceptualisation, Investigation, Funding acquisition, Supervision, Validation, Writing – original draft, Writing – review & editing.

Martin C.: Resources, Formal analysis, Data curation, Visualisation, Validation, Writing – review & editing.

Mialon M.M.: Resources, Formal analysis, Data curation, Visualisation, Validation, Writing – review & editing.

Agabriel J.: Conceptualisation, Investigation, Software, Project administration, Funding acquisition, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors warmly thank staff of the Herbipôle facility in Theix for running the animal experiments, and staff from the UMR1213 Herbivores, V. Largeau and Y. Huo (MSc student) for the N balance data, Y. Rochette for methane emission data as well as A.S. Bage, I. Constant, S. Faure and A. Thomas for the sampling.

Financial support statement

The research was supported by internal funding from the INRAE-UMR Herbivores Unit devoted to the interdisciplinary research programme on Dietary Recommendations for Fattening Beef Cattle.

References

- Agabriel, J., Giraud, J.M., Petit, M., 1986. Détermination et utilisation de la note d'état d'engraissement en élevage allaitant. *Bulletin Technique CRZV Theix-INRA* 66, 43–50.
- Association of Official Analytical Chemists (AOAC), 2005. *Official Methods of Analysis*. AOAC, Arlington, VA, USA.
- Baumont, R., Doreau, M., Ingrand, S., Veissier, I., 2006. Feeding and mastication behaviour in ruminants. In: Bels, V. (Ed.), *Feeding in Domestic Vertebrates*. CABI Publishing, Wallingford, UK, pp. 241–262.
- Doreau, M., van der Werf, H.M.G., Micol, D., Dubroeuq, H., Agabriel, J., Rochette, Y., Martin, C., 2011. Enteric methane production and greenhouse gases balance of diets differing in concentrate in the fattening phase of a beef production system. *Journal of Animal Science* 89, 2518–2528.
- Faisant, N., Planchot, V., Kozłowski, F., Pacouret, M.P., Colonna, P., Champ, M., 1995. Resistant starch determination adapted to products containing high level of resistant starch. *Science Des Aliments* 15, 83–89.
- INRA, 2018. *Alimentation des ruminants*, Editions Quae, Versailles, France.
- Johnson, K.A., Huylar, M., Westberg, H., Lamb, B., Zimmerman, P., 1994. Measurement of methane emissions from ruminant livestock using a SF₆ tracer technique. *Environmental Science & Technology Journal* 28, 359–362.
- Martin, C., Rouel, J., Jouany, J.P., Doreau, M., Chilliard, Y., 2008. Methane output and diet digestibility in response to feeding dairy cows with crude linseed, extruded linseed or linseed oil. *Journal of Animal Science* 86, 2642–2650.
- Metz, J.H.M., 1975. Time patterns of feeding and rumination in domestic cattle. *Medelingen Landbouwhogeschool Wageningen Nederland* 75, 1–66.
- Robelin, J., 1986. *Composition corporelle des bovins : évolution au cours du développement et différences entre races*. Thèse d'Etat, Université Clermont-Ferrand-2, 390p.
- Robelin, J., Geay, Y., 1975. Estimation de la composition de la carcasse des taurillons à partir de la composition de la 6^{ème} côte. *Bulletin Technique CRZV Theix-INRA* 22, 41–44.
- Robelin, J., Agabriel, J., Barboiron, C., Jailler, R., Raynal-Rongere, C., 1986. Estimation de l'état d'engraissement des bovins vivants à partir de la taille des cellules adipeuses. *Bulletin Technique CRZV Theix, INRA* 66, 37–41.
- Sepchat, B., Ortigues-Marty, I., Mialon, M.M., Faure, P., Agabriel, J., 2013. Croissance et nature des dépôts de jeunes bovins charolais recevant en engraissement des rations à base d'enrubannage ou d'ensilage de maïs. *Rencontres Recherches Ruminants* 20, 169–172.
- Van Dixhoorn, I., Aubé, L., Van Zyl, C., De Mol, R., Van der Werf, J., Lardy, R., Mialon, M.-M., Van Reenen, K., Veissier, I., 2024. From data on gross activity to the characterization of animal behaviour: which metrics for which purposes? *Peer Community Journal* 4. <https://doi.org/10.24072/pcjournal.489>.
- Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583–3597.
- Vermorel, M., Martin-Rosset, W., Vernet, J., 1997. Energy utilization of twelve forages or mixed diets for maintenance by sport horses. *Livestock Production Science* 47, 157–167. [https://doi.org/10.1016/S0301-6226\(96\)01402-9](https://doi.org/10.1016/S0301-6226(96)01402-9).