Determination of rearing practices combinations increasing the carcase weight according to the heifers slaughter age by the decision tree method

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ABSTRACT
This work aims to identify the rearing practices which increase the carcase weight according to slaughter age. For this purpose, an innovative statistical method, the decision tree method, was used to identify the most influential action levers on the carcase weight, with associated thresholds values and modalities, among the rearing practices applied throughout the animals’ life. The data of 636 heifers carcases were collected from the slaughterhouse and the rearing practices from 45 farms by survey. Firstly, classifications were done to define slaughter-age classes and carcase-weight classes. Three slaughter-age classes (younger, mid-age, older) and 3 carcase-weight classes (lighter, intermediate, heavier) were defined, then these two classifications were crossed. The decision tree method highlighted that the influence on carcase weight of the life periods of the animals (i.e. suckling, growth, and finishing periods) and the related rearing practices were different according to the slaughter age of the heifers. For the younger-slaughtered animals, the most influential rearing practices on the carcase weight were the suckling duration, the concentrate supply during growing, the distributions of compound feed and grass silage in-stall during growing. For the mid-age slaughtered animals, the rearing practices identified as the most influential were the concentrate amount distributed in-stall during finishing, the meal supply in-stall during finishing and the cereals supply at pasture during growing. For the older-slaughtered animals, the compound feed supply at pasture during finishing and the concentrate amount distributed in-stall during growing were the most influential on the carcase weight.

HIGHLIGHTS
- Decision tree: an innovative statistical method to identify action levers on carcase weight among the applied rearing practices throughout the life.
- The influential periods and rearing practices were distinct according to the slaughter-age of the animals.

Introduction
In Europe beef farmers’ income is lower than those of all other farmers despite the support provided by European subsidies and the adaptations of the production systems to make them more economically efficient (Lherm et al. 2018). The improvement of farmer’s income can be achieved by improving the carcases value. The EU’s EUROP beef carcase classification system is based on the assessment of four parameters: animal category (according to sex and age), carcase weight, conformation score, and fat cover score (European Council 2006). Carcase weight is one of the most commonly-used parameters in the world for characterising a carcase and one of the main determinants of its price in Europe (Monteils et al. 2017; Hocquette et al. 2018). A rearing management focussed on increasing carcase weight could improve the beef farmer’s income.

Rearing practices applied on-farm influence carcase properties and could be used as effective levers for increasing the carcase weight (Blanco et al. 2008; Soulat et al. 2016). Numerous studies showed effects of individual rearing practices on carcase weight, for example: weaning age (Shoup et al. 2015), feeding restriction during the suckling or the growth period (Hennessy and Morris 2003; Durunna et al. 2014), finishing duration (Sugimoto et al. 2012), age or weight at the beginning of the finishing period (Reuter and Beck 2013; Ustuner et al. 2016), or slaughter age...
slaughtered. The animals in this study were raised on conditions under which the animals were raised and their effects on the carcass properties (Soulat et al. 2018a; Monteils and Sibra 2019a). The consideration of each period of the whole life (suckling, growth, finishing) was reported as having a significant influence.

The aim of this study was to identify rearing practices combinations that influence heifer carcass weight at different slaughter ages. The results provide knowledges and reflective components which the meat industry stakeholders will be able to use to develop practices in order to better respond to market demand. The hypothesis was that according to the slaughter age the effect of other rearing practices could be different on carcass properties. In order to consider combined rearing practices over the animal’s whole life, we used the decision tree method to process the data. With this method, different splitters are successively identified to separate the population into different and increasingly homogeneous groups. Threshold values or modalities are associated with each splitter, which allows them to be considered as action levers. The decision tree construction allows the inclusion of a large number of explanatory variables, which is perfectly adapted to the study of rearing practices throughout the life of the animals. Its reading is very intuitive with the most important splitters appearing first in the tree, and the path from one branch of the tree to another using the identified thresholds or modalities. Moreover, the splitters identified at the different levels of the decision tree allow to consider combinations of rearing practices over time. This method is easy to interpret and especially appropriate for predicting categorical variables (Yu et al. 2010). Its use is favourable to operational application thereafter. It has been used in the computer and medical fields (Yu et al. 2010; Fan et al. 2011; Song and Lu 2015), and more recently in meat and animal science fields to assess the product quality (Masferrer et al. 2018; Gagaoua et al. 2019; Monteils and Sibra 2019a).

**Material and methods**

The method used in this study did not change the conditions under which the animals were raised and slaughtered. The animals in this study were raised on private farms according to the production itineraries decided by the farmers in compliance with the French cattle breeding standards in force at the time of the study. All animals were slaughtered in the private slaughterhouse ‘Abattoir du Gévaudan’ (Antrenas, France) which has the approval of the ‘Génisse Fleur d’Aubrac’ PGI and which respected the French legislation in force at the time of the study for the slaughter of cattle.

**Dataset**

Rearing practices were collected by survey from 45 breeders-fatteners, all members of the ‘Génisse Fleur d’Aubrac’ PGI. The main specifications for this PGI are: heifers are cross-bred Aubrac × Charolais; weaning cannot occur before 6 mo and artificial suckling is prohibited; animals graze for at least 4 months per year in an extensive system (stocking rate less than 1.4 LU/ha of main fodder area); maize is excluded in all its forms after the age of 18 months; animals are slaughtered between 24 and 42 months age (Légifrance 2008). Information was collected in a single survey based on a questionnaire containing open and closed questions. Surveys addressed the suckling, growing and finishing periods mainly through stall and grazing feeding practices (composition and quantity), duration of these three periods and their match to animals’ age. Birth season, suckling method (accompanied i.e. the farmer led the calves to her mother twice a day for suckling; free i.e. the calves stayed always with her mother and suckled ad libitum, or both) and prophylactic treatments (vaccination, antiparasitics) were also studied. Livestock management was described using quantitative and qualitative variables to characterise suckling period (3 and 9 variables, respectively), growing period (17 and 7 variables, respectively) and finishing period (19 and 6 variables, respectively). All the 61 variables characterising rearing practices are presented in Tables 1 and 2 for quantitative and qualitative variables respectively.

The study dataset counted 636 carcases of heifers slaughtered in the same slaughterhouse (Gévaudan slaughterhouse, Antrenas, France). Average slaughter age was 30.5 months (from 24.5 to 42.5 months). Average carcass properties were a cold weight of 402 kg (from 310 to 566 kg), a EUROP classification grid fat cover score of 2.99 (from 2 to 3) on a scale of 1–5, and a EUROP classification grid conformation score between E+ and R= (with 3 sub-classes for each conformation level: ‘+’ for high, ‘=’ for mean, ‘−’ for low).
**Table 1. Rearing practices data collected during the farm surveys by life periods (quantitative variables).**

| Description                                      | Unit | Mean ± SEM          |
|--------------------------------------------------|------|---------------------|
| **Suckling period**                              |      |                     |
| Number of days between the birth and the weaning, days | | 249.7 ± 1.4        |
| Number of days spent on pasture during the suckling period, days | | 163.0 ± 1.4        |
| Proportion of time spent on pasture during the suckling period, % | | 65.1 ± 0.6         |
| **Growth period**                                |      |                     |
| Number of days between the weaning and the beginning of the finishing, days | | 476.0 ± 5.1        |
| Number of days spent on pasture during the growth period, days | | 229.5 ± 2.7        |
| Proportion of time spent on pasture during the growth period, % | | 49.1 ± 0.4         |
| Amount of straw cereals distributed in stall per heifer during the growth, wet kg | | 141.8 ± 10.8       |
| Amount of meals distributed in stall per heifer during the growth, wet kg | | 207.7 ± 1.9        |
| Amount of by-products distributed in stall per heifer during the growth, wet kg | | 112.5 ± 7.2        |
| Total amount of concentrate distributed in stall per heifer during the growth, wet kg | | 293.2 ± 12.6       |
| Amount of concentrate distributed in stall per heifer and per day during the growth, wet kg | | 0.57 ± 0.02        |
| Amount of straw cereals distributed on pasture per heifer during the growth, wet kg | | 215.5 ± 3.5        |
| Amount of meals distributed on pasture per heifer during the growth, wet kg | | 1.00 ± 0.2         |
| Amount of by-products distributed on pasture per heifer during the growth, wet kg | | 0.51 ± 0.13        |
| Amount of compound feed distributed on pasture per heifer during the growth, wet kg | | 53.6 ± 6.0         |
| Amount of mash distributed on pasture per heifer during the growth, wet kg | | 1.9 ± 0.5          |
| Amount of concentrate distributed on pasture per heifer during the growth, wet kg | | 78.4 ± 8.4         |
| Total amount of concentrate distributed on pasture per heifer and per day during the growth, wet kg | | 0.13 ± 0.01        |
| **Finishing period**                             |      |                     |
| Number of days between the beginning of the finishing and the slaughter, days | | 187.7 ± 2.3        |
| Age of the heifers at the beginning of the finishing period, days | | 727.5 ± 4.9        |
| Number of days spent on pasture during the finishing period, days | | 38.6 ± 2.4         |
| Proportion of time spent on pasture during the finishing period, % | | 21.5 ± 1.4         |
| Amount of straw cereals distributed in stall per heifer during the finishing, wet kg | | 317.6 ± 14.5       |
| Amount of meals distributed in stall per heifer during the finishing, wet kg | | 132.4 ± 8.1        |
| Amount of by-products distributed in stall per heifer during the finishing, wet kg | | 11.2 ± 2.0         |
| Amount of compound feed distributed in stall per heifer during the finishing, wet kg | | 346.0 ± 17.4       |
| Total amount of concentrate distributed in stall per heifer during the finishing, wet kg | | 812.9 ± 19.8       |
| Amount of concentrate distributed in stall per heifer and per day during the finishing, wet kg | | 4.51 ± 0.1         |
| Amount of straw cereals distributed on pasture per heifer during the finishing, wet kg | | 185.5 ± 3.5        |
| Amount of meals distributed on pasture per heifer during the finishing, wet kg | | 7.4 ± 1.4          |
| Amount of by-products distributed on pasture per heifer during the finishing, wet kg | | 0.12 ± 0.04        |
| Amount of compound feed distributed on pasture per heifer during the finishing, wet kg | | 153.2 ± 12.5       |
| Amount of mash distributed on pasture per heifer during the finishing, wet kg | | 4.2 ± 1.3          |
| Amount of concentrate distributed on pasture per heifer during the finishing, wet kg | | 183.4 ± 13.2       |
| Amount of concentrate distributed on pasture per heifer and per day, wet kg.d^{-1} | | 1.04 ± 0.07        |
| Total amount of concentrate distributed in stall and at pasture per heifer during the finishing, wet kg | | 996.4 ± 15.2       |
| Age of the heifers at the slaughter, months | | 30.5 ± 0.1         |

The mean, standard deviation, minimum and maximum values of all these variables are reported in Monteils and Sibra (2019a).

**Statistical analysis**

The approach was i/to classify heifer carcases by slaughter age and by carcase weight and ii/to develop decision trees to identify influential rearing practices on the carcase weight for a given slaughter age. Statistical analysis was performed with XLSTAT 2020.3.1 (Addinsoft, Paris, France).

**Carcase classifications**

Two independent carcase classifications were carried out: the first based on slaughter age, and the second based on carcase weight. Hierarchical clustering analysis (HCA), K-means and univariate partitioning methods were performed and were compared in order to find classifications that most clearly discriminate between classes. The choice of the most discriminant classification method for each classification was based on number of in-class objects, intra-class variance, minimum, maximum and average distances at the barycentre, and distances between the classes’ barycentres. Then the two classifications were crossed to determine carcase weight classes within slaughter-age classes.

The properties of these slaughter age and carcase weight classes were analysed by ANOVA followed by a t-test on significant differences. The threshold for significance was set at 0.05. To facilitate statistical analysis of the conformation scores, we ran a numerical conversion of the EUROP grid conformation classes (5 levels × 3 subclasses) from 1 for class P- to 15 for class E+.

**Decision trees**

The decision tree method was used to find relationships between carcase weight classes at a given
Table 2. Rearing practices data collected during the farm surveys by life periods (qualitative variables).

| Qualitative variables description and modalities | Number (%) |
|-------------------------------------------------|------------|
| **Suckling period**                              |            |
| Heifers submitted to dehorning                   |            |
| Yes                                             | 259 (40.7) |
| No                                              | 377 (59.3) |
| Birth season of the heifers                      |            |
| Autumn                                          | 63 (9.9)   |
| Winter                                          | 510 (80.2) |
| Spring                                          | 63 (9.9)   |
| Suckling method used\(^1\)                       |            |
| Accompanied                                      | 220 (34.6) |
| Free                                            | 252 (39.6) |
| Both                                            | 164 (25.8) |
| Distribution of compound feed in stall during the suckling |        |
| Yes                                             | 372 (58.5) |
| No                                              | 264 (41.5) |
| Distribution of mash in stall during the suckling |            |
| Yes                                             | 12 (1.9)   |
| No                                              | 624 (98.1) |
| Distribution of concentrate in stall during the suckling |        |
| Yes                                             | 402 (63.2) |
| No                                              | 234 (36.8) |
| Distribution of straw cereals on pasture during the suckling |        |
| Yes                                             | 69 (10.8)  |
| No                                              | 567 (89.2) |
| Distribution of compound feed on pasture during the suckling |        |
| Yes                                             | 85 (13.4)  |
| No                                              | 551 (86.6) |
| Distribution of concentrate on pasture during the suckling |        |
| Yes                                             | 112 (17.6) |
| No                                              | 524 (82.4) |
| **Growth period**                                |            |
| Distribution of hay in stall during the growth   |            |
| ad libitum                                       | 84 (13.2)  |
| Rationed                                         | 537 (84.4) |
| No                                               | 15 (2.4)   |
| Distribution of wrapped grass in stall during the growth |        |
| ad libitum                                       | 35 (5.5)   |
| Rationed                                         | 158 (24.8) |
| No                                               | 443 (69.7) |
| Distribution of grass silage in stall during the growth |        |
| ad libitum                                       | 12 (1.9)   |
| Rationed                                         | 321 (50.5) |
| No                                               | 546 (85.8) |
| Distribution of maize silage in stall during the growth |        |
| Rationed                                         | 90 (14.2)  |
| No                                               | 463 (74.8) |
| Distribution of hay on pasture during the growth  |            |
| ad libitum                                       | 44 (6.9)   |
| Rationed                                         | 121 (19.0) |
| No                                               | 471 (74.1) |
| Distribution of wrapped grass on pasture during the growth |        |
| ad libitum                                       | 20 (3.1)   |
| Rationed                                         | 53 (8.3)   |
| No                                               | 563 (88.6) |
| Distribution of stored grass (hay or grass silage or wrapped grass) on pasture during the growth |        |
| Yes                                             | 173 (27.2) |
| No                                              | 463 (72.8) |
| **Finishing period**                             |            |
| Distribution of hay in stall during the finishing |            |
| ad libitum                                       | 145 (22.8) |
| Rationed                                         | 428 (67.3) |
| No                                               | 63 (9.9)   |
| Distribution of wrapped grass in stall during the finishing |        |
| ad libitum                                       | 60 (9.4)   |
| Rationed                                         | 151 (23.7) |
| No                                               | 425 (66.9) |
| Distribution of grass silage in stall during the finishing |        |
| ad libitum                                       | 19 (3.0)   |
| Rationed                                         | 184 (28.9) |
| No                                               | 433 (68.1) |

(continued)
slaughter age and rearing practices applied throughout the animal’s life. In order to identify the rearing practices with the most influence on carcase weight for each slaughter-age class, all the 61 quantitative and qualitative variables characterising rearing practices (Tables 1 and 2) were tested for integration into the decision tree. Various methods, as proposed by Song and Lu (2015), were tested to select the one that led to the strongest predictive performance: the CHAID method associated with likelihood or Person measures, the C&RT method associated with Gini measures, information gain or Twoing, and the Quest method. For each method tested, the threshold for significance was set at 0.05 and the minimum number of individuals in a terminal group was set at 10. The predictive quality of the decision trees was assessed based on the percentages of correctly-classified carcasses and the sensitivity and specificity of predictions calculated using the method described by Baratloo et al. (2015). The highest-weight carcase class was used as a reference class in the calculations as it was considered the target class.

Results

Carcase classifications

The most discriminant of the three classification methods tested in terms of slaughter age was hierarchical clustering which led to three classes. The slaughter ages of these three classes were significantly different ($p < .0001$). These classes were called Age 1 class for younger animals (i.e. 27.6 months), Age 2 class for mid-age animals (i.e. 30.8 months), and Age 3 class for older animals (i.e. 35.0 months). The Age 1 class had the highest number of heifers (49.2% of total sample) and the Age 2 class had the lowest number (21.2% of total sample). Analysis of carcase properties associated with these three age classes showed significant increases in carcase weight ($p < .0001$) and conformation score ($p < .0001$) with increasing age at slaughter (Supplementary material, Table S1).

The most discriminant method in terms of classifying carcases according to their cold weight was K-means clustering which led to three classes. The slaughter weights of these three classes were significantly different ($p < .0001$). These classes were called $W-$ class for the class containing light carcases (i.e. 365 kg), $W=$ class for the class containing intermediate-weight carcases (i.e. 406 kg) and $W+$ class for the class containing heavy carcases (i.e. 452 kg). The $W=$ class had the highest number of carcases (45.9% of total sample) and the $W+$ class had the lowest number (21.1% of total sample). Analysis of carcase properties associated with these three weight classes showed significant increases in slaughter age ($p < .0001$) and conformation score ($p < .0001$) with increasing carcase weight (Supplementary material, Table S2).

In both classifications, there were no significant between-class differences in fat cover score.

Cross-analysis of the two classifications (slaughter age × carcase weight) led to 9 carcase classes (Age 1_W=, Age 1_W+, Age 2_W=, Age 2_W+, Age 2_W+, Age 3_W=, Age 3_W+, Age 3_W+). All weight classes were represented in all slaughter-age classes. Class W− carcases were predominantly represented in the Age 1 class (46.0% of class size), while W+ class carcases were predominantly in the Age 3 class (39.9% of class size). Conversely, there were few W+ class carcases in the Age 1 class (less of 10% of class size) and few W− class carcases in the Age 3 class (18.1% of class size). W= class carcases accounted for a substantial proportion of each of the 3 slaughter-age classes, particularly the Age 2 class (44.4%, 54.8% and 42.0% in Age 1, 2 and 3 classes, respectively). Only in the Age 1 class a significant increase of slaughter age was observed with an

Table 2. Continued.

| Qualitative variables description and modalities | Number (%) |
|-----------------------------------------------|------------|
| Distribution of straw in stall during the finishing |            |
| ad libitum | 17 (2.7) |
| Rationed | 21 (3.3) |
| No | 598 (94.0) |
| Distribution of stored grass (hay or grass silage or wrapped grass) on pasture during the finishing |            |
| Yes | 74 (11.6) |
| No | 562 (88.4) |
| Slaughter season of the heifers |            |
| Autumn | 152 (23.9) |
| Winter | 43 (6.8) |
| Spring | 274 (43.1) |
| Summer | 167 (26.3) |

1 accompanied = the farmer led the calves to her mother twice a day for suckling; free = the calves stayed always with her mother and suckled ad libitum; both = the both methods were used.
increase of carcase weight ($p < .0001$). The Age 2 class was the only class which presented a significant difference of fat cover score between the W – and W = class carcases ($p < .05$). For the three age classes the conformation score increased significantly with an increase of carcase weight ($p < .0001$). Table S3 in Supplementary material reports the carcase properties for each class.

Identification of rearing practices influencing carcase weight classes according to slaughter-age classes by decision tree method

All the 61 variables (quantitative and qualitative) characterising rearing practices were used to determine the decision trees for the three age classes (Tables 1 and 2). The means and SEM of all these variables are detailed for each age-class in Supplementary material (Tables S4 and S5).

Among the different methods tested to produce the decision trees, the CHAID method with Person measures gave the highest predictive accuracy and was retained. In the three decision trees the terminal groups had at least 40% carcases associated with a weight class. Among all the studied rearing practices, only 10 practices emerged as splitters in decision trees, between 2 and 4 per tree (Table 3). Each practice appeared only once, i.e. in a single tree and at a single level.

Identification of rearing practices influencing carcase weight classes for the early-slaughtered class (age 1 class)

In the decision tree of the Age 1 class, the mean percentage of correctly-classified carcases based on weight was 52.4% (Table 4). The proportion of correctly-classified carcases was 87.5% for the W – class, 23.7% for the W = class and 16.7% for the W + class.

In the decision tree three levels of splitters appeared with at the 1st level a rearing practice related to suckling duration and at the 2nd and 3rd levels 3 rearing practices related to concentrate and grass silage distributions during growing (Figure 1). If suckling duration was inferior to 251 days, the carcases were predominantly light (49.3% of W – class, terminal group 1). A suckling duration superior to 251 days led to the three weight classes. In this case if no compound feed was distributed in-stall during growing, a concentrate distribution in-stall and at pasture during growing less than to 238 kg led to light carcases (45.3% of W – class, terminal group 2) compared to a distribution greater than to 238 kg which led to increase the carcase weight to W = class (70.4% of W = class, terminal group 3). If a compound feed was distributed in-stall during growing with a quantity lower than 205 kg, the lack of distribution of grass silage in-stall during growing led to predominantly light carcases (88.2% of W – class, terminal group 4) whereas a rationed distribution of grass silage led to increased carcase weight in W = class (51.8% of W = class, terminal group 5). The heavier carcases were observed when the distribution of compound feed in-stall during growing was greater than 205 kg (45.5% of W + class, terminal group 6).

Identification of rearing practices influencing carcase weight classes for the mid-age slaughtered class (age 2 class)

In this decision tree, the mean percentage of correctly-classified carcases based on weight was 60.7%
The proportion of correctly-classified carcases was 12.5% for the W- class, 81.1% for the W= class and 62.1% for the W+ class.

Four levels of splitters appeared with a single splitter at each level (Figure 2). The rearing practices selected as splitter were related to all life periods: the amount of concentrate distributed in stall during finishing, the distribution of compound feed on pasture during the suckling, the amount of meals distributed in stall during finishing, then the amount of straw cereals distributed on pasture during the growing for the four successive levels respectively. For the Age 2 class the amount of concentrate distributed in-stall during finishing less than 5.47 kg per day led to carcases mostly associated to W= class (58.0% of W= class, terminal group 1). If the distribution of this concentrate was greater than 5.47 kg per day the three weight classes could be reached. In this case without distribution of compound feed and with a distribution of meals in-stall during finishing less than 191 kg and without straw-based cereals distributed at pasture during growing, all the carcases were associated to W= class (100%, terminal group 2). If straw-based cereals were distributed at pasture during growing, the carcase weight increased to the W+ class (50.0% of W+ class, terminal group 3). With a quantity of meals in-stall during finishing greater than 191 kg the carcase weights were mostly high (61.9% of W+ class, terminal group 4). Finally a distribution of compound feed at pasture during suckling led to 40.0% of carcases associated to W – class (terminal group 5).

Table 4. Prediction quality of carcase weights according to the slaughter-age classes, obtained by decision trees with CHAID method with Person’s measure.

|                     | Age 1 class<sup>1</sup> | Age 2 class<sup>2</sup> | Age 3 class<sup>3</sup> |
|---------------------|------------------------|------------------------|------------------------|
| Classifications, n  | 144                    | 139                    | 30                     |
| Decision tree, n    | 248                    | 54                     | 11                     |
| Correctly-classified carcases, % | 52.4                  | 87.5                   | 16.7                   |
| Classifications, n  | 32                     | 74                     | 29                     |
| Decision tree, n    | 10                     | 94                     | 31                     |
| Correctly-classified carcases, % | 12.5                  | 81.1                   | 62.1                   |
| Classifications, n  | 34                     | 79                     | 75                     |
| Decision tree, n    | 0                      | 151                    | 37                     |
| Correctly-classified carcases, % | 0                     | 96.2                   | 42.7                   |

Global (all classes) 52.4 60.7 57.4
W- class<sup>4</sup> 144 248 87.5 32 10 12.5 34 0 0
W= class<sup>5</sup> 139 54 23.7 74 94 81.1 79 151 96.2
W+ class<sup>6</sup> 30 11 16.7 29 31 62.1 75 37 42.7
Sensitivity, % 16.7 62.1 42.7
Specificity, % 97.9 87.7 95.6

<sup>1</sup>Age 1 class: early-slaughtered heifers clas, i.e. 27.6 months; 2Age 2 class: mid-age-slaughtered heifers class, i.e., 30.8 months; 3 Age 3 class: older-slaughtered heifers class, i.e. 35.0 months; 4 W- class: light carcases class, i.e. 365 kg; 5 W= class: intermediate-weight carcases class, i.e. 406 kg; 6 W+ class: heavy carcases class, i.e. 452 kg.

Figure 1. Decision tree for the prediction of carcase weight classes according to rearing practices applied during the whole life of early-slaughtered heifers (Age 1 class), obtained by the CHAID method with Person’s measure.

Caption: S-Duration: number of days between birth and weaning (day); G-CompFeed-Stall: amount of compound feed distributed in-stall during growing (wet kg/heifer); G-Conc-Total: total amount of concentrate distributed in-stall and at pasture per heifer during growing (wet kg); G-GrassS-Stall: distribution of grass silage in-stall during growing (ad libitum/rationed/no).
Identification of rearing practices influencing carcass weight classes for the older-slaughtered class (age 3 class)

In this decision tree, the mean percentage of correctly-classified carcasses based on weight was 57.4% (Table 4). No carcase was correctly-classified for the $W-$ class. The proportion of correctly-classified carcasses was 96.2% for the $W=$ class and 42.7% for the $W+$ class.

Two levels of splitters appeared with a single splitter at each level related to the amount of compound feed. Figure 2. Decision tree for the prediction of the carcass weight classes according to rearing practices applied during the whole life of mid-age slaughtered heifers (Age 2 class), obtained by the CHAID method with Person’s measure.

Caption: F-Conc-Stall-Day: amount of concentrate distributed in-stall per heifer and per day during finishing (wet kg); S-CompFeed-Past: distribution of compound feed at pasture during suckling (yes/no); F-Meals-Stall: amount of meals distributed in-stall per heifer during finishing (wet kg); G-Cereals-Past: amount of straw-based cereals distributed at pasture per heifer during growing (wet kg).

Figure 3. Decision tree for the prediction of carcass weight classes according to rearing practices applied during the whole life of older-slaughtered heifers (Age 3 class), obtained by the CHAID method with Person’s measure.

Caption: F-CompFeed-Past: amount of compound feed distributed at pasture per heifer during finishing (wet kg); G-Conc-Stall-Day: amount of concentrate distributed in-stall per heifer and per day during growing (wet kg).
feed distributed on pasture during finishing and the daily amount of concentrate distributed in stall during growing for the 1st and 2nd levels respectively (Figure 3). For the Age 3 class, if no compound feed was distributed at pasture during finishing the carcases were mostly associated to \( W = \) (46.1\% of \( W = \) class, terminal group 1). If compound feed was distributed at pasture during finishing with a quantity less than 840 kg the carcases were \( W = \) or \( W + \). Additionally an amount of concentrate distributed in-stall during growing less than 0.5 kg per day led to \( W + \) class (79.2\% of \( W + \) class, terminal group 2). An increase of amount of concentrate distributed in-stall during growing (superior to 0.5 kg per day) did not increase the carcase weight (54.8\% \( W = \) class, terminal group 3). A compound feed at pasture during finishing distributed between 840 and 900 kg led to \( W = \) class (68.7\% of \( W = \) class, terminal group 4) whereas a distribution was superior to 900 kg led to heavier carcases (100\% of \( W + \) class, terminal group 5).

**Discussion**

The rearing practices selected in these decision trees influencing the carcase weight linked back to the three animal life-periods (suckling, growing, finishing). These results confirmed previous findings by Soulat et al. (2018a) and Monteils and Sibra (2019b) which showed effects of rearing practices applied during the animal’s whole life on carcase properties such as pasture duration during suckling and growing periods, concentrate supplies at each life period and slaughter age. The most important results in this study were i/ that the rearing practices influencing the carcase weight of heifers were different for the three classes of slaughter-age considered and ii/the identification of combinations of rearing practices specific to each slaughter-age class. Therefore the rearing practices used as action levers to increase carcase weight should be determined in relation to the targeted slaughter age.

In this study the suckling duration was identified as the most influential rearing practice on the carcase weight for early-slaughtered heifers. This is in agreement with Schoonmaker et al. (2004) and Sexten et al. (2012) who observed heavier carcases when weaning age increased whereas Blanco et al. (2008) and Shoup et al. (2015) observed the opposite with earlier weaning ages. This study showed for early-slaughtered heifers that i/when the suckling duration was short the other associated rearing practices had no significant influence on carcase weight, and ii/an increase of suckling duration alone was not sufficient to increase the carcase weight. Other studies found no effect of weaning age on carcase weight if post-weaning feed management was appropriate (Vaz et al. 2011; Moriel et al. 2014). Our results reinforced those of Pordomingo et al. (2012) and Brito et al. (2014) who observed an increase of carcase weight with increasing concentrate content in growing diet. For early-slaughtered heifers, dietary management during growing was also influential on the carcase weight. This result confirmed the results reported by Keady et al. (2013) that grass-silage associated with a high concentrate amount led to heavier carcases than maize silage associated with a lower concentrate amount. However heavier carcases were observed when grass-silage was distributed with maize-silage or wheat-silage rather than alone (Keady et al. 2007). This study highlighted, for early-slaughtered heifers, that the most important periods to influence carcase weight were firstly the suckling period and after the growing period. For early-slaughtered heifers to take advantage of the suckling duration increase, it has to be combined with minimal amounts of total concentrate distributed in stall and at pasture, or compound feed distributed in stall during growing.

In our study, for mid-age and older slaughtered heifers, another influential rearing practice on carcase weight was related to high-energy distribution during finishing. This result confirmed that an increase of concentrate content in the finishing diet led to an increase of carcase weight as previously observed (Roberts et al. 2009; Keady et al. 2013). Moreover Serrano et al. (2018) showed an increase of carcase weight with *ad libitum* concentrate supply during finishing. However several studies did not show an effect of an increase of concentrate amount in finishing diet (French et al. 2000; Keady et al. 2007; Sugimoto et al. 2012). In our study for mid-age slaughtered heifers, the practices applied during suckling, growing and finishing had an impact on carcase weight whereas for older-slaughtered animals only the growing and finishing practices were considered. Then the concentrate supplies during finishing had to be considered in a combined way with rearing practices applied during other life periods, specially with concentrate supplies during growing. However our study showed, for these slaughter ages, that concentrate supplies later than suckling were more efficient to increase carcase weight.

In this work, the rearing practices applied throughout the life of the animals were collected by a farmers’ survey. This allowed us to be as close as possible to the real rearing management of private farms.
However a limitation of this method is the accuracy of the answers obtained, especially for the oldest data. To mitigate this possible problem, a large number of farmers were included in the study. Moreover, the data collected are either qualitative or quantitative depending on the rearing practices and the accuracy level possible to achieve. The practices identified as influencing carcase weight for the different slaughter age classes were practices encountered in our dataset, in accordance with the specifications of the ‘Génisse Fleur d’Aubrac’ PGI, mostly related to diet and based on available data from private farms. To improve the accuracy of the results and to establish more generic decision trees, our database would need to be extended to more diverse rearing practices with other than grass-based mountain systems (e.g., maize silage and concentrate-based diets), and with other animals categories and breeds which would imply more diverse slaughter ages. This will allow the identification of other rearing practices that can be used as action levers to manage carcase weight and the associated thresholds. Moreover these results need to be validated on an external dataset.

In terms of operational application, the results of this work provide guidance to the farmers to increase the carcase weight of the heifers. The action levers identified could be implemented directly or require adaptation according to the specific characteristics of the different situations. The results of this work should be included in a broader approach that considers the constraints of rearing systems and market demand. Some of the action levers reported in this study induce additional production costs with mostly an increase of concentrate amount in diet to increase carcase weight. To be beneficial to the farmers’ income the carcases produced with these managements have to be higher value. Our results should be considered in association with the economic balance taking into account both the feed dependency of the farm (ability to produce its own feed or the commercial value of the cake feed) and the carcase payment. To really address this issue, an economic analysis should be carried out in addition to this work considering cost of rearing management and added-value to the carcase.

Conclusion
This study showed that the carcase weight could be managed by rearing practices applied throughout the animals’ life. However this result depended strongly on the slaughter age of animals. While rearing practices during all life periods (suckling, growing and finishing) were taken into account for mid-age slaughtered heifers, only practices related to the suckling duration and feeding during growing were considered for early-slaughtered heifers. For the older-slaughtered heifers, feeding during growing and finishing were considered. The innovative analysis with decision tree method allowed to identify combinations of rearing practices applied throughout the whole life of animals with threshold values or modalities related with each action lever.

The dataset used to establish these decision trees was based on practices allowed by the ‘Génisse Fleur d’Aubrac’ PGI specifications. Consideration of a broader range of rearing practices with other systems, animal categories and breeds could improve the accuracy of the results and establish more generic decision trees. Moreover an economic analysis should be carried out in addition to this work considering cost of rearing management and added-value to the carcase to be able to provide advice.

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Data availability statement
The data that support the findings of this study are available from the corresponding author, [VM], upon reasonable request.

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