Modelling of the lactation curve in French dairy sheep

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Abstract

In France, as in many areas of production of sheep milk, dairy sheep lactation is based on 2 phases, a suckling or suckling plus milking period of 3 to 5 weeks, followed, after weaning of the lambs, by a period of exclusive milking until the end of the lactation. Milk recording occurs therefore after weaning. Until recently, the exclusive milking period concerned only the decreasing part of the lactation curve, the peak of lactation occurring at the end of the suckling period. The modelling of the lactation curve to predict the production, whether at the flock scale or at a dairy plant scale was based on a decreasing exponential depending on the initial production and the lactation stage. As a result of a combination of the important genetic gain on milk yield and the evolution of the production system, the lactation curve during the milking period, observed with the collected milk yield, shows that the lactation peak has been progressively replaced by a plateau phase whose duration extends over several weeks. Hence, within the RESPOL project whose general topic was to assess the consequence of redesigning the reproduction system in dairy sheep (decrease hormonal synchronisation used in the AI protocol) on milk and lamb production at single/multi flock scale, we set up a study aiming at updating the model of prediction of the lactation to better estimate the production of the ewes. The first objective was to account for the plateau phase by exploring new models, according to different factors (breed, parity, season of lambing). The second objective was to model the curve of the fat and protein yields by valorising at the best the routine data issued from a very simplified, yet efficient on a genetic point of view, design of sampling based on test-day only available in the mid-lactation period in French dairy sheep programs.

The model was based on a modified Brain-Cousens model taking as parameters the initial yield (milk, fat, protein) and stage (either at the start of the milking period or at the first test-day) and 8 parameters varying according to the breed, the parity (1 vs 2 and more), the lambing period of the flocks (early lambing, mid-season lambing, late lambing) and the average initial yield level of the flock (low, medium, high).

For milk yield, the model calibration used 6,868,860 test-day recorded between 2017 and 2021 (553,595 ewes representing the 5 French breeds) between the lactation stages 30 and 200 days after lambing. The validation used 1,383,645 test-day recorded in the year 2022 (290,352 ewes representing the 5 French breeds). The validation consisted in comparing the predicted and observed curves and checking that they coincide. The difference between predicted yield and observed yield was also calculated at each period to check the percentage of over- or underprediction, and to verify that the model's prediction is correct at each stage. For fat and protein yield, the model calibration used 2,031,643 test-day recorded between 2015 and 2021 (474,740 ewes representing the 5 French breeds). The validation was done on 330,121 test-day recorded in the year 2022 (122,978 ewes representing the 5 French breeds), by the same methods as for milk yield. The main outcome of the model was to predict the lactation production of a flock or a milk plant, based on the mating system (permitting

to predict lambing period, hence lactation period) and the starting level of milk, fat and protein yield. This allowed a second phase of validation by comparing the predicted and observed production at a large production area scale, gathering several dairy plants.

Keywords: dairy sheep, modelling lactation curve, milk yield prediction, fat and protein prediction.

Introduction

Dairy sheep production in France is based on a high rate of animal insemination (AI) varying (according to the breed) from 20 to 50% when including the whole population and from 50 to 85% when considering the flocks in the breeding programmes. The protocol for AI is based on the synchronisation of the heats, thanks to hormonal treatments. The societal expectations pushed the dairy sheep farmers (within their technical and interprofessional organisations) to assess the impact of a decrease in hormonal treatments in the future. This was the scope of the RESPOL project (2022-2025). Assessing the consequences of a reduction in hormonal treatments on milk production and its repartition along the year implies to be able to predict the daily lactation of the ewes (milk yield but also fat and protein yield).

In France, as in many areas of production of sheep milk, dairy sheep lactation is based on 2 phases, a suckling or suckling plus milking period of 3 to 5 weeks, followed, after weaning of the lambs, by a period of exclusive milking until the end of the lactation. Milk recording occurs therefore after weaning. Until recently, the exclusive milking period concerned only the decreasing part of the lactation curve, the peak of lactation occurring at the end of the suckling period. The modelling of the lactation curve to predict the production, whether at the flock scale or at a dairy plant scale was based on a decreasing exponential depending on the initial production and the lactation stage (Lagriffoul *et al*., 2003). As a result of a combination of the important genetic gain on milk yield and the evolution of the production system, the lactation curve during the milking period, observed with the collected milk yield, shows that the lactation peak has been progressively replaced by a plateau phase whose duration extends over several weeks. Hence it became relevant to update the model to predict the lactation (milk, fat and protein yield) accounting for the evolution described above (plateau phase, different factors such as breed, parity, season of lambing). For reaching this objective, we valorised at the best the routine data from the national genetic database “SIEOL”.

Overview of the RESPOL project

The RESPOL project aimed at accompanying the French dairy sheep farmers in case they would have to redesign their production system by decreasing the use of hormonal treatments facilitating animal insemination (AI). For 5 decades, hormonal treatments to induce heat and ovulation in sheep in the AI protocol has been widely used, for many reasons among them selection improvement programmes and grouping of lambings, including out-of-season lambings. In the breeding flocks, included in the selection scheme, the AI rate reaches 85% in the Lacaune (LAC) breed and 50% in the other French breeds (Manech tête rousse – MTR, Manech tête noire -MTN, Basco-Béarnaise – BB, Corse breed – COR). Societal expectations are demanding a more reasoned use of hormonal treatment, especially for animal welfare reasons. As the potential drop in the utilisation of hormones for reproduction might have a major impact on breeding systems and organisation of the supply-chain of cheese and lambs, the purpose of RESPOL is to assess the magnitude of this impact.

The main tasks of the RESPOL project were:

- Task 1: the tracking, description and valorisation of innovative reproduction system relevant enough to be proposed to the breeders, especially those in the selection programmes to decrease the hormonal treatments,
- Task 2: the experiment of a protocol of AI that would not use PMSG, based of FGA sponge and male effect,
- Task 3: the delivery of new models for predicting the lambing kinetics and the production (milk yield, milk components, lambs). Such models are intended to be used at various levels: the dairy plant, the flock (to assess the impact of different reproduction systems). In addition, gestation scan is intended to be valorised to precise the mating data with extra information for improving the prediction of production,
- Task 4: the assessment of an evolution of the reproduction systems at a global scale: milk and lamb production in each production area, availability and production of rams genetically improved for the diffusion of genetics from breeding flocks towards commercial flocks.

Modelling the lactation curve of milk, fat and protein yield in French dairy sheep breeds

The task 3 mentioned above implied to be able to predict the lactation curve with enough accuracy, in order to predict, given the lambing date of each animal and the starting production level (milk and components), the milk and components produced each day during the whole lactation. Hence, a study was set up to update the model of prediction of the lactation to better estimate the production of the ewes. The first objective was to account for the plateau phase by exploring new models, according to different factors (breed, parity, season of lambing). The second objective was to model the curve of the fat and protein yields by valorising at the best the routine data issued from a very simplified, yet efficient on a genetic point of view, design of sampling based on test-day only available in the mid-lactation period in French dairy sheep programs (Astruc and Barillet, 2004).

The chosen model was based on a mathematical translation of the Brain-Cousens' hormesis model (Brain and Cousens, 1989), which is a modified log-logistic model, taking as parameters the initial yield (milk, fat, protein) and lactation stage (either at the start of the milking period or at the first test-day) and 8 parameters varying according to the breed, the parity (1 vs 2 and more), the lambing period of the flocks (early lambing, mid-season lambing, late lambing) and the average initial yield level of the flock (low, medium, high).

The equation of the model can be written as follows:

$$\text{Yield(t)} = c + \frac{\text{Yield}_{\text{ref}} \times (d - c + ft)}{1 + \exp\left(b\left(\log(t) - \log(e)\right)\right)} + \left(\text{Yield}_{\text{init}} - (m \times \text{stage}_{\text{init}} + h)\right)$$

With:

- t is the lactation stage in days.
- Yield(t) is the milk, fat or protein yield at the lactation stage t.

- $Yiel_{dref}$ is a milk, fat or protein yield of reference, for different levels of production. Within a given breed, we can have a single Yieldref or several Yieldref. The results are better when we fit the Yieldref with the production level of the flocks.
- $Yield_{init}$ and stageinit are the milk, fat or protein initial yield at the initial lactation stage t (it can be the first day of milk delivery after weaning or the first test-day). These values must be produced by the user.
- b, c, d, e, f, m, h are parameters to be estimated from a calibration dataset. Each one might have an interpretation (decreasing part of the curve, point of inflexion, inferior and superior asymptote of the curve, settings parameters).

The model was fitted with a calibration dataset including 6,868,860 test-day recorded between 2017 and 2021 (milk yield) and 2,031,643 test-day recorded between 2015 and 2021 (fat and protein yield). The model was tested against a validation dataset including 1,383,645 test-day recorded in the year 2022 (milk yield) and 330,121 test-day recorded in the year 2022 (fat and protein yield). The tables 1 and 2 detail the different datasets (summing all the breeds) used for calibration and the validation of the model of prediction of milk, fat and protein yield. The validation consisted in comparing the predicted and observed curves and checking that they coincide. The difference between predicted yield and observed yield was also calculated at each period to check the percentage of over- or underprediction, and to verify that the model's prediction is correct at each stage.

The figure 1 displays the comparison between actual average curves and predicted curves in the Manech tête rousse and Basco-Béarnaise breeds, for primiparous and multiparous ewes. Such plots were provided for each breed and each category (primiparous vs multiparous, lambing period of the flocks in the case of the Lacaune breed).

In a same pattern, the figure 2 displays the comparison between actual average curves and predicted curves for fat and protein yield in the Lacaune breed. Such plots were provided for each breed and each category (primiparous vs multiparous, lambing period of the flocks in the case of the Lacaune breed).

The adapted Brain-Cousens model allowed a good accuracy of the prediction at the scale of a quite homogeneous group of flocks (e.g. flocks in the breeding program) or at the scale of a production area averaging a high number of flocks. Hence it allowed to test different levels of decreasing hormonal treatment utilisation, with a good accuracy of prediction, to assess the impact at the production area scale. However, the dependence of the parameters to the yield of reference (average level of production of the animals) is a limit to the utilisation at the flock level and jeopardize the utilisation at the animal level. New modelling might fix such limits by using a more dynamic parametrisation instead of fixed parameters.

Conclusion and perspectives

The main outcome of the model was to predict the lactation production of a flock or a milk plant, based on the mating system (permitting to predict lambing period, hence lactation period) and the starting level of milk, fat and protein yield. This allowed a second phase of validation by comparing the predicted and observed production at a large production area scale, gathering several dairy plants. This comparison showed good results and permitted to build scenarios with lower AI rate and therefore assess the impact of such scenarios on milk and lamb production in a production area, and on the variation of the kinetic of milk and lamb production around the year.

Table 1. Data used for the calibration of the model of prediction of milk, fat and protein yield. Figures are given for each bread (LAC=Lacaune, MTN=Manech tête noire, MTR=Manech tête rousse, BB=Basco-Béarnaise, COR=Corse)

	Data used for calibration										
		Number of ewes					Number of test-days				
Breed	**Year of production**	**LAC**	**MTN**	**MTR**	**BB**	**COR**	**LAC**	**MTN**	**MTR**	**BB**	**COR**
Milk yield	2017-21	343,452	13,659	127,144	40,480	28,860	4,299,334	156,703	1,498,268	477,533	437,022
Total				**553,595**					**6,868,860**		
Fat and protein yield	2015-21	330,139	9,438	98,531	25,303	11,329	1,585,813	29,038	306,490	76,604	33,698
Total				**474,740**					**2,031,643**		

Table 2. Data used for the validation of the model of prediction of milk, fat and protein yield. Figures are given for each bread (LAC=Lacaune, MTN=Manech tête noire, MTR=Manech tête rousse, BB=Basco-Béarnaise, COR=Corse)

	Data used for validation										
		Number of ewes					Number of test-days				
Breed	**Year of production**	**LAC**	**MTN**	**MTR**	**BB**	**COR**	**LAC**	**MTN**	**MTR**	**BB**	**COR**
Milk yield	2022	176,717	7,528	66,181	24,790	15,136	847,282	34,507	306,715	116,258	78,883
Total				**290,352**					**1,383,645**		
Fat and protein yield	2022	96,098	1,692	16,776	5,447	2,965	254,966	4,580	47,821	14,689	8,065
Total				**122,978**					**330,121**		

Figure 1. Comparison between actual average curves (in black) and estimated curves from the model (in red for primiparous (L1) and blue for multiparous (L2+) for milk yield in the Manech tête rousse (left) and Basco-Béarnaise (right) breeds.

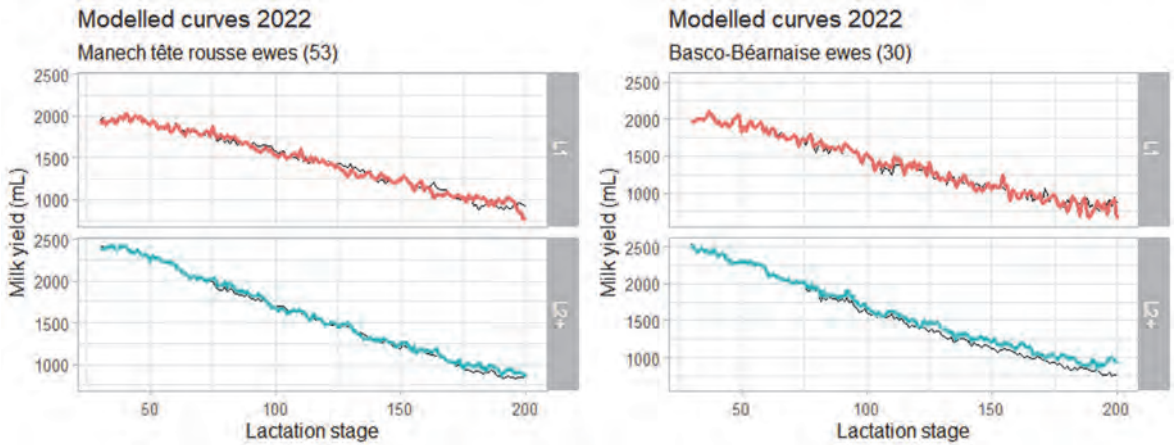
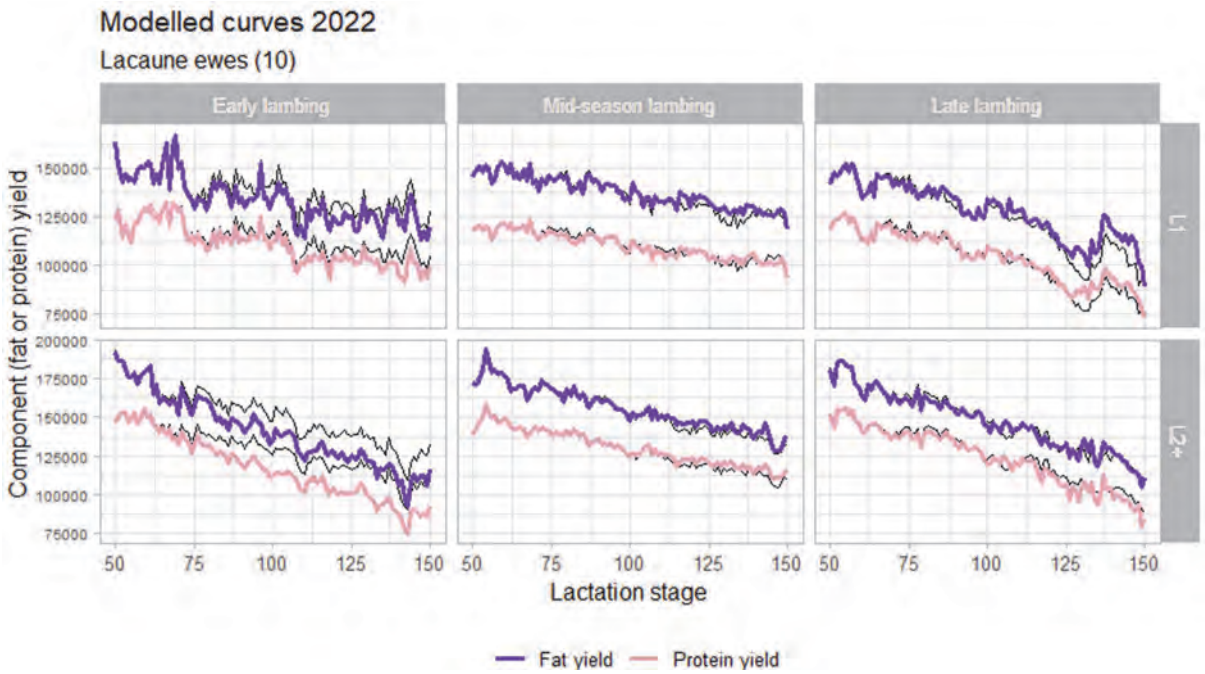


Figure 2. Comparison between actual average curves (in black) and estimated curves from the model (in purple for fat yield and pink for protein yield) of fat and protein yield in the Lacaune breed. Comparison is given for primiparous (L1) and multiparous (L2+) and for the lambing period of the flocks.

Figure 2. Comparison between actual average curves (in black) and estimated curves from the model (in purple for fat yield and pink for protein yield) of fat and protein yield in the Lacaune breed. Comparison is given for primiparous (L1) and multiparous (L2+) and for the lambing period of the flocks.



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