Dairy Health Manager : Description fonctionnelle et modalités d'emploi

Philippe Gontier, Nathalie Bareille

Functional description and terms of use

Version 1.2.2 - 11/2023

Philippe Gontier - Nathalie Bareille

INRAE - UMR BIOEPAR - ONIRIS
F-44300 Nantes, France
Phone: +33 2 40 68 76 48
Email: philippe.gontier@inrae.fr

Web site: www.dairyhealthmanager.com
Translation: “Oniris Junior Agroalimentaire Santé”

How to cite: https://commons.datacite.org/doi.org/10.17180/npmc-kh96

Publication level: PUBLIC

Key words: SIMULATOR / HUSBANDRY / DAIRY CATTLE / ECOMAST / HEALTH / PRODUCTION DISEASE / DHM / REPRODUCTION / GENETICS / PERFORMANCE / ECONOMIC IMPACT

Table of contents

1 Introduction

As part of its own research work or in partnership with ONIRIS-INRAE, UMR BIOEPAR used the first-generation "ECOMAST" simulator. This simulator was developed internally and was launched during the thesis on "Ex-ante evaluation of the economic efficiency of programs to control intra-mammary infections in dairy cattle farming" (Hortet, 2000). This simulator, dedicated to dairy herd management and to the technical and economic impacts of mastitis, was designed as a database associated with a simulation engine designed to implement treatments.

Its renewal was decided in 2015 with an immediate focus on a flexible multi-agent system (Gontier, Bareille et Picault, 2022) based on the functional analysis of the previous version , updated, a generic and open conceptual model designed according to an agile methodology inspired from "XP", and the full exploitation of the performance of the latest programming languages and tools.

This simulator was designed to compare management strategies in health disorders and reproduction in a dairy cattle herd, in terms of disease frequency, food consumption, animal performance and dairy cattle technical and economic results.

This document, divided into two main chapters, aims to present the functional analysis intended to describe the technical and biological constraints of livestock management taken into account in the simulations, and the technical procedures for using the simulator.

2 Functional analysis

This document part describes the data and processes related to the functional simulation's requirements. It matches the user or researcher's needs with the simulation's solution set up to respond to it.

Based on recent publications and taking into account expert advice, the simulator aims to take into account all areas of interest involved in the life of the herd and its management. These domains, structured as modules, are each the subject of a chapter.

The "General" section defines the transversal and common aspects of each of these modules. Finally, the last part of this chapter describes the means available to the user to set up its scenarios.

2.1 General

The Dairy Health Manager simulator (DHM) was designed to simulate a dairy cattle herd in a particular farming context. Only dairy production is considered in the simulator with the assumption that the farmer defines the size of his livestock according to its production's objectives and his premises. Developed on a self-centered model basis, it introduces the interest of finely representing the herd by allowing the integration of individuals' diversity and their biological responses' variability.

In this context, the simulator makes it possible to take into account the differences and the genetic variability within and between breeds due to crossing. Furthermore, it enables to consider the interactions between the different decisions based on individual character, such as insemination type choice and culling criteria. The modeling aims to represent the biological processes and the more technical ones related to the farmer's decision-making.

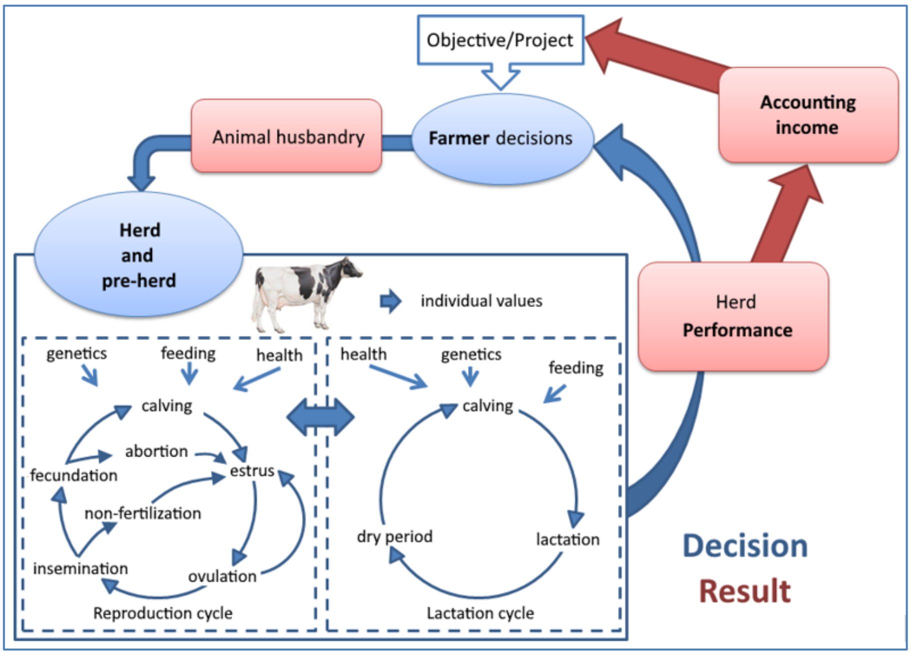


Figure 1 : Biological processes and farmer decisions used in the simulator

Before explaining the data and processes related to the different modules, it is necessary to define their common aspects, which are the simulator's management options and constant data. It is necessary to define their types as well as when they are specific, how to add individuals in the dairy herd and the method to produce data results.

2.1.1 Management options of the simulator

The DHM simulator implements the management options of the time-dependent dynamic simulation, as well as the mechanistic simulation with discrete event modeling and stochastic simulation (Hortet, 2000). It acts on finite horizon.

2.1.1.1 Dynamic simulation with time-related engine

The dynamic simulation is based on modeling the timing of the events that generate change in the attributes' value. In our case, it makes it possible to make actions at a time step defined as 1 day.

2.1.1.2 Mechanistic simulation with discrete event modeling

The elementary simulation unit is an animal at its different stages of life (from birth to sale/death). It is represented by a set of attributes.

The simulation result is constructed by reproducing the stages of the mechanisms involved in individuals' life cycle and, in particular, during discrete event occurrence (for instance, reproduction and health events, or the herd's daily milk production). Thus the evolution of the attributes values depends on the occurrence of the simulated events (for instance, pregnancy onset or the occurrence of an intra-mammary infection) or corresponds to an incrementation (for instance, lactation, pregnancy and drying-off stages).

2.1.1.3 Stochastic simulation

Renewed with the same input parameters, the simulation does not necessarily produce the same results. Indeed, the simulator, based on the probability and variability rules described in the following chapters, will not deliver the same results through several simulations launched successively.

2.1.1.4 Finite horizon simulation

The simulator's point is to compare, both technically and in matters of account the transition phase between the initial and final situations and to not simply compare two static states. This is why the simulation period is defined over a finite space of time.

2.1.2 General constants for simulation

The general constant values include the simulator common data, apart from specialized modules for particular domains (described in paragraph *2.2 Modules on page 12*). By definition, these values can't be modified. Their questioning would require an evolution of the simulator.

Three dairy and three beef breeds are used in the simulator:

Dairy breeds	Montbeliarde
	Normande
	Holstein
Beef breeds	Blanc bleue belge
	Charolaise
	Limousine

Table 1: Breeds involved

Reproduction breeds are only used in the simulator for inseminations, and their products are sold soon after birth.

A cow udder is composed of 4 quarters managed individually.

2.1.3 Initial herd constitution principle

When the simulation starts, a pre-simulation is carried out starting from a situation where the herd does not yet have any cows. They are purchased progressively, at a rate that will then allow a population regulation depending on the renewal setting defined by the user.

This management is described in the population and batch management module (paragraph *2.2.5*)

2.1.4 Produced data principle

Whatever the module concerned, the data is produced regularly (daily, weekly, monthly and annual for the campaign or punctual (recording of actions / events when they occur). They are provided at the simulation's end in the form of "tables" results, available from "csv" files, with ";" as field separator and "," as decimal separator.

These files are located in the folder designated as the one for the results described in paragraph *3.4 Result structure*.

Thus, from this raw data, all the necessary analyses will be possible natively with software like "R" for example.

In addition to the standard data formats used (integer, float, bool, ...), typed formats are used in the parameter files and the results produced, they are determined as follows:

Format's name	Value definitions
Campaign	Expressed in the format `<YYYY starting year>-<year end year in "YYYY" format>`, based on the start date of the simulation. If the exercise is to start in January, the campaign is expressed as `<exercise year in YYYY format>`
Date	Expressed in the format `<YYYY-MM-DD>`
Breed	Possible values: - 0: Montbeliarde, - 1: Normande, - 2: Holstein, - 3: Blanc bleue belge, - 4: Charolaise, - 5: Limousine.
Insemination type	Possible values: - 0: Natural insemination, - 1: Conventional artificial insemination, - 2: Male sexed artificial insemination, - 3: Female sexed artificial insemination.

Table 2: Type data formats

2.2 Modules

The biological and technical / decisional functions are differentiated in the simulator. They are described and programmed in the form of 7 interrelated modules.

These modules are:

- Reproduction,
- Lactation,
- Health,
- Genetics,
- Population and batch management,
- Feeding,
- Accounting.

They interact in the following way:

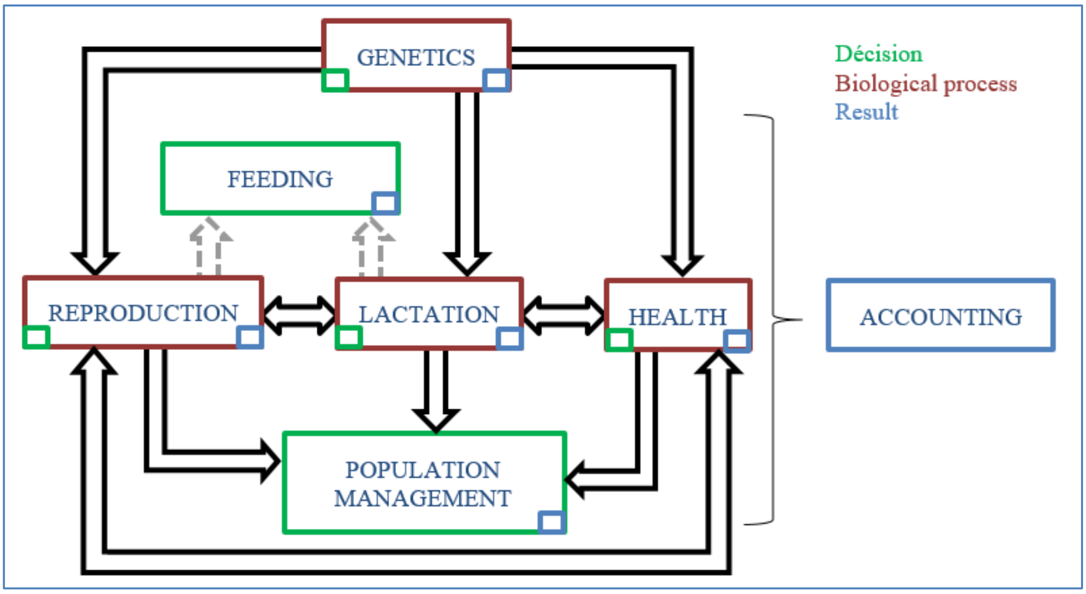


Figure 2: Diagram of the organization in modules and interaction representation

The biological effects of reproduction and lactation on feeding are not simulated in the current state of the software, only the knowledge of the rations to be distributed makes it possible to define the parameters of the cows' diet in relation to the expected production objective. The "Accounting" module provides a summary of all the accounting acts performed during the simulation.

The following chapters describe, for each module, the biological and technical constant values implemented for the domain concerned, the animal's attribute values that can evolve as the simulation proceeds, the management parameters, which can thus make up the desired scenarios, and finally the specific data that will be produced at the end of the simulation.

While most of the data described in the following lines is taken from referenced publications, those with no reference is estimates based on expert opinion, on values already included in the "ECOMAST" simulator (Billon, 2015), and trial and error for the calibration of unobservable phenomena.

These data are in general bases. They are established by the herd effect (phenomena not represented in the simulator) that applies to all cows uniformly, and are weighted by individual events (identified and described) occurring throughout the simulation.

2.2.1 Reproduction

This module integrates all aspects implemented to simulate the animals' ability to reproduce. While these phenomena may depend heavily on biological rules, they are however led by the farmer's decisions.

2.2.1.1 Constant biological and technical values

The constant values that are applied in the simulations' contexts and which affect reproduction deal with ovulation, its detection, insemination, pregnancy and resumption of post-partum ovarian cyclicity.

The simulator differentiates cow reproduction stages in the following way:

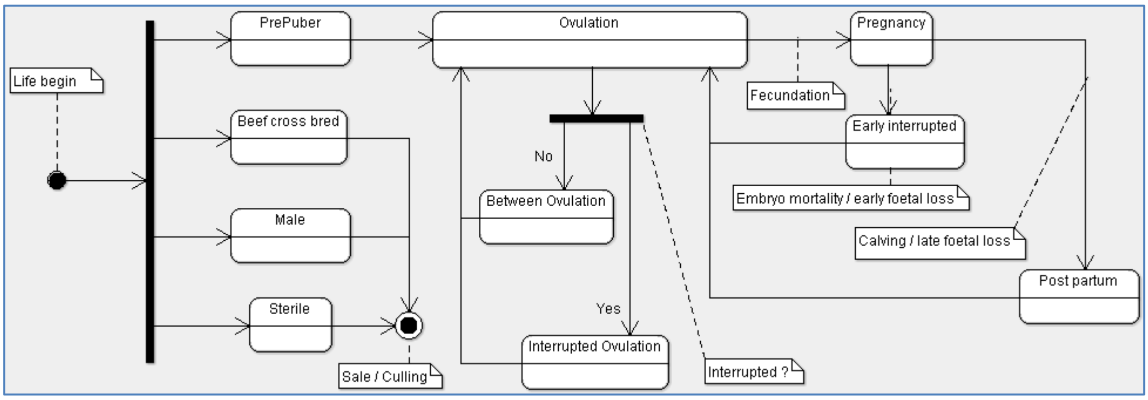


Figure 3: Reproduction stages

Calves crossed with a beef breed, male calves and sterile female calves are not kept in the herd (see paragraph *2.2.5.1.2.1 Assignment*).

2.2.1.1.1 Ovulation occurrence

Ovulation occurs at the age defined as that of puberty. They appear during cycles that can be irregular and result in estrus.

2.2.1.1.1.1 Age at puberty

The age at puberty of dairy females is between 6 and 15 months (i.e., 300 days on average), regardless of their breed (Bareille *et al.*, 2016). The fixed value used is therefore 300 days.

2.2.1.1.1.2 Estrus duration

Since dairy cow estrus lasts between 8 and 23 hours (Kerbrat et Disenhaus, 2004), the value used for the simulation was set at 1 day.

2.2.1.1.1.3 Intervals between ovulations (cyclicity)

This criterion is not breed-related (Bareille *et al.*, 2016). The values used are as follows (Hagen et Gayrard, 2005):

	Average number of days
Heifers	20 days
Cows	21 days

Table 3: Days between ovulations

The standard deviation used is one day.

These values are a base. Various events as described below may change the duration.

2.2.1.1.2 Estrus detection sensitivity

Sensitivity is the ability to detect cows that are currently in estrus (Chanvallon *et al.*, 2011).

The percentage of detection probability used includes the character that can be related to the cow's expressivity and the detection sensitivity by the farmer (Disenhaus *et al.*, 2010). It varies according to:

- the breed,
- the detection mode
- parity
- the ovulation rank
- the insemination rank (integrating lack of specificity after calving and during insemination return),

The sensitivity of estrus detection can also be influenced by lameness.

There are two categories to differentiate: detection sensitivity for first insemination, and those related to insemination return.

2.2.1.1.2.1 Estrus detection sensitivity for first insemination

The following table makes it possible to estimate estrus detection probability for first insemination.

	Detection mode	Heifers	Primiparous			Multiparous		
		All ovulations	1st ovulation	2nd ovulation	Following ovulations	1st ovulation	2nd ovulation	Following ovulations
Montbeliarde	Embedded sensor	90%	80%	82%	84%	82%	85%	88%
	Farmer	60%	50%	52%	54%	52%	54%	58%
	Robot	80%	70%	72%	74%	72%	75%	78%
	Bull (*)	100%						
Normande	Embedded sensor	90%	80%	82%	84%	82%	85%	88%
	Farmer	60%	50%	52%	54%	52%	54%	58%
	Robot	80%	70%	72%	74%	72%	75%	78%
	Bull (*)	100%						
Holstein	Embedded sensor	85%	75%	77%	79%	77%	79%	81%
	Farmer	55%	45%	47%	49%	47%	49%	51%
	Robot	75%	65%	67%	69%	67%	69%	71%
	Bull (*)	100%						

Table 4: Estrus detecting sensitivity for first insemination

(*) considered to be in the female batch

These values were estimated on the basis of those implemented by the "ECOMAST" simulator.

Note: if the first heat is not observed within 100 days of being (re)bred and in the absence of a veterinary care contract, treatment for undetected heat is given to the cow (see treatment of case "c" in *Table 17: Veterinary treatment plan under the breeding contract*).

2.2.1.1.2.2 Estrus detection sensitivity for following inseminations

Sensitivity may be different depending on insemination rank. The following table establishes the related probabilities:

	Detection mode	Heifers	Primiparous		Multiparous	
		All returns	1st return	2nd return	1st return	2nd return
Montbeliarde	Embedded sensor	90%	84%	84%	88%	88%
	Farmer	60%	64%	59%	68%	63%
	Robot	80%	74%	74%	78%	78%
	Bull (*)	100%				
Normande	Embedded sensor	90%	84%	84%	88%	88%
	Farmer	60%	64%	59%	68%	63%
	Robot	80%	74%	74%	78%	78%
	Bull (*)	100%				
Holstein	Embeddded sensor	85%	79%	79%	81%	81%
	Breede	55%	59%	54%	61%	56%
	Robot	75%	69%	69%	71%	71%
	Bull (*)	100%				

Table 5: Estrus detection sensitivity for following inseminations

(*) considered to be in the female batch

Beyond the insemination ranks in the table above, the probabilities used are those of ovulations in *Table 4: Estrus detecting sensitivity for first insemination.*

These values were estimated on the basis of those implemented by the "ECOMAST" simulator.

2.2.1.1.2.3 Additional criteria affecting estrus detection sensitivity

Detection sensitivity probabilities can be reduced / increased by coefficients taking into account additional criteria related in particular to management and accommodation conditions.

2.2.1.1.2.3.1 Slippery floors

A factor of 0.5 is applied to the detection once obtained (except for bulls). This is a management option described in paragraph *2.2.1.2.3 Slippery floor.*

2.2.1.1.2.3.2 Simultaneous estrus

Concomitant estrus facilitates their detection. The multiplicative values applied in this case are as follows:

2 estrus	+ than 2 estrus
1.3	1.4

Table 6: Multiplicative value increasing sensitivity in the case of concomitant estrus

2.2.1.1.2.3.3 Dairy production

A 50 kg / day milk production has the effect of reducing by 50% the previously estimated estrus detection probability in all signs (Disenhaus *et al.*, 2010).

The multiplicative value v applied to estrus detection probability is calculated as follows:

$$v = 1 - (\frac{\text{DMP}}{100}))$$

$$v \geq 0$$

(DMP = daily milk production)

2.2.1.1.2.3.4 Effect of lameness on estrus detection sensitivity

The sensitivity of heat detection is impaired when the cow is lamed, as described in paragraph *2.2.3.3.1.1.3.1.1 Effect of lameness on estrus detection sensitivity.*

2.2.1.1.3 Estrus detection specificity

A lack of specificity is when the farmer considers cows in estrus when they are not. This applies only to artificial inseminations (AI). Natural inseminations (mating) are not concerned.

The specificity error rates are of two kinds:

- the specificity after calving, when the last estrus day is known,
- the specificity during returns after IA when the last estrus day is unknown.

The percentages set out below reflect the probability of making this mistake when finding estrus.

2.2.1.1.3.1 Lack of specificity after calving (or after reproduction for heifers) and before first artificial insemination

Probabilities of a lack of specificity are applied for the different representative periods.

- *Heifers*

Regarding heifers, these are animals that have never been inseminated since the decision to start reproduction or since their last unsuccessful pregnancy:

Detection mode	1 to 46 days after starting reproduction	47 days and more after starting reproduction
Embedded sensor	1%	2%
Farmer	4%	5%
Robot	2%	3%

Table 7: Probability of a lack of specificity for heifers

- *Cows*

Regarding cows, it's about the ones that have not yet been inseminated since their last calving:

Detection mode	Primiparous			Multiparous		
	40-69 days after pregnancy	70-100 days after pregnancy	More than 100 days after pregnancy	40-69 days after pregnancy	70-100 days after pregnancy	More than 100 days after pregnancy
Embedded sensor	1%	2%	5%	1%	2%	5%
Farmer	4%	5%	13%	4%	5%	13%
Robot	2%	3%	6%	2%	3%	6%

Table 8: Probability of a lack of specificity for cows after calving

2.2.1.1.3.2 Lack of specificity for returns after AI

When an artificial insemination has been performed following an actual ovulation detection, and that it has been successful, a 7% probability of a lack of specifity is simulated, after IA, by a normal law based on the interval between ovulations and a standard deviation of 1.

2.2.1.1.4 Insemination and fertility

Inseminations are considered fertile if they lead to pregnancy. This result may depend on the strategy adopted in terms of inseminations and the animal's fertility.

2.2.1.1.4.1 Insemination choice

Three modes of fertilization are proposed by the simulator:

- natural mating by a bull,
- artificial insemination in conventional semen,
- artificial insemination in sexed semen (male or female).

Bulls used for inseminations are randomly selected from the catalog for this purpose according to the procedures described in paragraph *2.2.4.1.3 Genetic value of bulls for insemination (including natural)*, depending on the breed to be used and the genetic strategy chosen by the experimenter (balanced, with priority over milk quantity or functional traits).

A mating plan is proposed to divide semen types and breed crosses (see paragraph *2.2.1.2.4 Mating plans*).

When artificial insemination occurs due to a specificity lack (see paragraph *2.2.1.1.3 Estrus detection specificity*), it is non-successful because performed "at the wrong time". However, if by chance it is performed on the ovulation day, it would then be considered "at the right time" given the related success rules.

A management parameter is used to stop inseminations under certain conditions (see section *2.2.1.2.8 Individual decision of stop inseminations related to heifer* and cow infertility).

2.2.1.1.4.2 Fertility – basic values

Success (fertility) probabilities related to fertilization methods used are estimated for insemination at the right time (during simulated ovulation). They include non-fertilization and early embryonic mortality. They are based on the results of the FertilIA study conducted between 2004 and 2007 on Holstein cows (Salvetti *et al.*, 2011).

With regard to the Normande and Montbeliarde breed heifers, the FertilIA study results were weighted to take into account the differences reported during the study conducted on sexed semen use in 2014 by the IDELE (Le Mézec, 2015).

Those relating to reproduction are based on expert testimony.

The basic fertility rates of fertilization modes, which do not take into account the harmful effects of certain factors (see paragraph *2.2.1.1.4.4 Fertility modulation*), are as follows:

		Mating	**Conventional artificial insemination**	**Sexed artificial insemination**
Normande	**Heifer**	95%	85%	69%
	Adult	90%	78%	62%
Holstein	**Heifer**	95%	83%	69%
	Adult	90%	74%	62%
Montbeliarde	**Heifer**	95%	85%	73%
	Adult	90%	80%	67%

Table 9: Basic fertility rate (not taking into account the adverse effects of certain factors) according to fertilization modes

One parameter makes it possible to adjust the fertility level of the herd (see paragraph *2.2.1.2.6 Herd-specific fertility factor*).

2.2.1.1.4.3 Grouped calvings

By default, calvings are spread throughout the campaign. However, the simulator makes it possible to group the calvings of the heifers at one time of the year, according to the parameters proposed in the paragraph *2.2.1.2.5 Grouped calvings*, which will also have an influence on the constitution of the initial herd (see paragraph *2.2.5.1.1.1 Gradual herd increase*).

Insemination of heifers is postponed if calving is likely to occur during the prohibited period.

2.2.1.1.4.4 Fertility modulation

Some factors may have a negative or positive influence on cow fertility.

2.2.1.1.4.4.1 Milk production

Milk production impacts fertility. To simulate this effect, a fertility factor linked to milk production that depends on the cow's peak production is applied to influence insemination success, as follows (Meignan, 2018):

Production at peak (in kg, rule of 3 for intermediate values)	**Fertility factor related to milk production**
<= 27.2	1/0.95
= 36.6	1
>= 47.2	1/1.07

Table 10: Calculation of the value of the fertility factor related to milk production at peak

2.2.1.1.4.4.2 Individual potential

Individual potential is determined by the phenotypic trait "Fer", which is set up in paragraph *2.2.4.1.2 Individual genetic value*. The principle is to apply to the success probability of an insemination (even mating) the corrected performance of the phenotypic trait (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*).

2.2.1.1.4.4.3 Ketosis effect on fertility

Fertility can be disturbed when the cow undergoes ketosis, as described in the paragraph *2.2.3.2.1.1.2.1.2 Effect of ketosis on fertility*.

2.2.1.1.4.4.4 Lameness effect on fertility

Fertility can be disturbed when the cow undergoes lameness, as described in the paragraph *2.2.3.3.1.1.3.1.3 Effect of lameness on fertility*.

2.2.1.1.4.4.5 Veterinary surveillance for fertility problems

Fertility may be impaired when the cow suffers from lameness, as described in paragraph *2.2.1.1.5 Veterinary surveillance*.

2.2.1.1.5 Veterinary surveillance

When a veterinary breeding contract is in place (see paragraph *2.2.1.2.9 Breeding contract*), non-pregnant adult cows not intended for culling are examined every 15th of the month to determine the presence of any breeding problems. Three cases are determined:

a) Cows over 60 days old and not seen in heat,

b) Cows with 3 non-fertilising artificial inseminations,

c) Cows with a negative pregnancy diagnosis at 35 days after insemination (with a sensitivity defect for 3.7% of already pregnant cows).

Depending on their classification, cows receive appropriate medical treatment with the following effects:

- The reappearance of heat (cases a, b and c, systematically leading in the latter case to an interruption of gestation in the case of a sensitivity defect), which will inevitably be detected,
- The increase in fertility (case b).

Treatments are set in paragraph *2.2.1.2.9 Breeding contract*. No milk waiting period is necessary regarding these treatments.

Furthermore, as metritis and other uterine diseases were not modelled, it was decided to apply a fertility increase of 3 percentage points (adapted[1] from (Fourichon, Seegers et Malher, 2000)) to cows that were not affected by case a.

2.2.1.1.6 Pregnancy

Pregnancy is when a cow, after having undergone a successful insemination, carries an embryo. It has a basic duration, but can undergo interruptions before term. If nothing disturbs the pregnancy, the cow gives birth to one or two calves.

2.2.1.1.6.1 Late embryonic mortality and abortion

Assuming that the risk of early embryo mortality is taken into account in fertility (see paragraph *2.2.1.1.4 Insemination and fertility*), two critical pregnancy periods remain to be defined in terms of simulation: late embryonic mortality (including fetal mortality) and abortion.

Late embryon mortality occurs between the 16th and 89th pregnancy day. Pregnancy loss probability at this stage was estimated from the results of the FertilIA study on Holstein adult cows (Salvetti *et al.*, 2011). These results' application for Normande and Montbeliarde breeds is the result of cross studies of ovulation return observations by IDELE (Le Mézec, 2015) and of progesteronemia analyzes on a large sample of individuals (Humblot, 2001).

[1] The review by (Fourichon, Seegers et Malher, 2000) indicates that cows with endometritis have a 16 % point reduction in fertility. It is considered that with reproductive monitoring they are diagnosed (1 in 5 cows concerned) and treated.

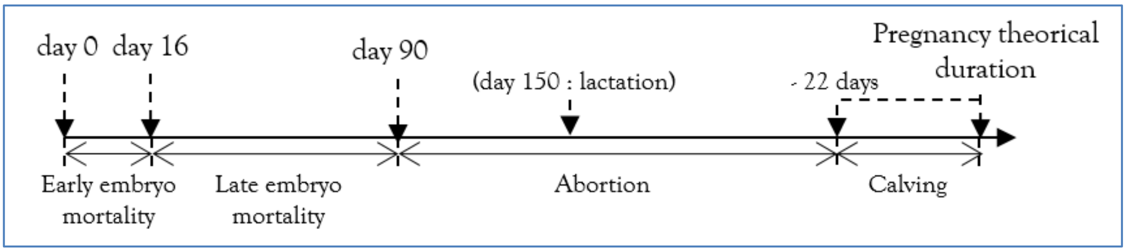


Figure 4: Periods at risk of pregnancy loss

The values used are as follows:

	Late embryonic mortality (*)
Montbeliarde	21%
Normande	23%
Holstein	21%

Table 11: Breed-specific probability of late embryonic mortality

(*) Beta-Pert distribution with 21-day peak

The late abortion period begins on the 90th day and goes until the day from which calving begins to appear according to the established distribution, that is, 22 days less than the breed's average pregnancy (see paragraph *2.2.1.1.6.2 Pregnancy duration*).

The implemented rates are based on the observation of mortality rates in the study conducted by UNCEIA (Humblot, 2001). The values used are as follows:

	Late abortion
Montbeliarde	1.6%
Normande	0.3%
Holstein	2.5%

Table 12: Late abortion probability

Depending on pregnancy stage, a lactation process may be initiated (see paragraph *2.2.2.1 Constant biological and technical values*).

2.2.1.1.6.2 Pregnancy duration

Pregnancy duration depends on the breed, parity, the sex and the number of foetuses (Bareille *et al.*, 2016).

2.2.1.1.6.2.1 Breed and parity

Nominal breed duration is determined for each cow in a stochastic manner with a standard deviation of 5 days that is applied to the following averages (Marceau *et al.*, 2014):

	Heifer average Pregnancy duration	Primiparous and multiparous cow' average pregnancy duration
Montbeliarde	286 days	287 days
Normande	285 days	286 days
Holstein	280 days	282 days

Table 13: Breed and parity-specific average Pregnancy duration

Pregnancy duration is influenced by the breed of the unborn (cross) calf however it is not taken into consideration, as well as the dam performance's repeatability, because of the low heritability of pregnancy duration…

2.2.1.1.6.2.2 *Sex of the unborn calf*

Regarding the unborn calf's sex, the probability of it being a female is 50% for natural insemination, 49% for conventional artificial insemination, and 93% (males) and 90% (female) for sexed artificial inseminations (Le Mézec, 2015).

When the expected calf is a male, Pregnancy duration is reduced by one day.

2.2.1.1.6.2.3 *Twin pregnancy*

Twin pregnancy probability is as follows:

Nulliparous	1%
Primiparous	6%
Multiparous	7%

Table 14: Twin pregnancy probability

These values are based on the 2004 observation of Holstein herds in the United States (Germain, 2009). While in reality, the cattle's twining rate depends on the breed; this factor is not integrated into the simulator.

If the calves to be born were of opposite sexes, the female would be sterile.

The simulator does not take into account the increased risk of twin pregnancies.

In reality, in case of multiple pregnancies, births occur 5 to 8.5 days in advance (Germain, 2009). Since the simulator only manages twin pregnancies, pregnancy will be reduced by 5 days.

2.2.1.1.7 Cyclicity resumption after pregnancy loss and calving

The post-parturm cyclicity recovery depends on the end of the last pregnancy: loss case or calving. It can also be affected by ketosis or lameness.

2.2.1.1.7.1 *Pregnancy loss case*

For cases of pregnancy loss (late embryonic mortality and abortion), the time until estrus return is proportional to the actual pregnancy duration, increasing until the 150th day of pregnancy until reaching 60 days, to gradually resume a normal cycle until the day from which calving is considered normal:

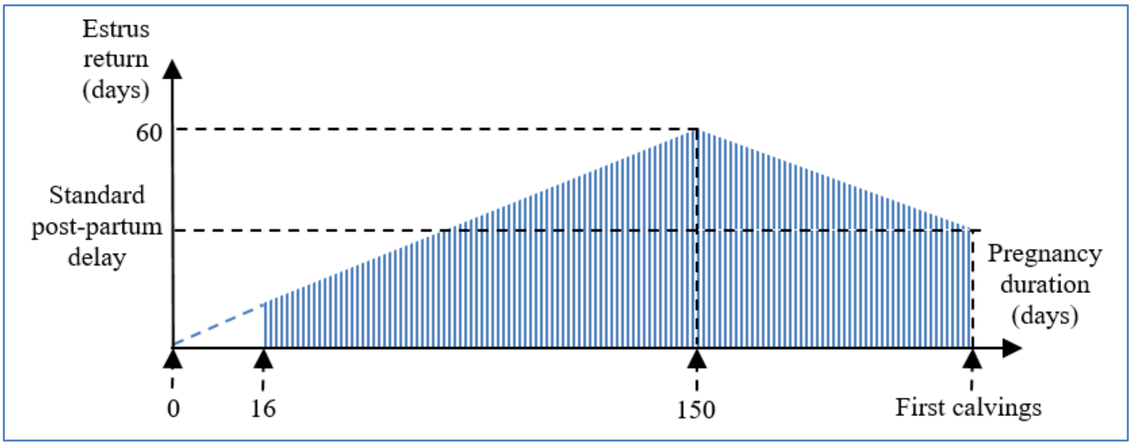


Figure 5: Delay of cyclicity resumption time after embryo or fetal mortality

The farmer chooses when to start reproduction again after a pregnancy loss (see paragraph *2.2.1.2.7 Minimum post-partum delay before breeding (waiting period)*). If a new lactation begins after pregnancy loss (pregnancy stage of at least 150 days), the delay until reproduction is the same as for calving. Otherwise, there is no latency delay.

2.2.1.1.7.2 *Calving case*

The recovery time of a post-calving cow cycle and the probability of a cyclical interruption are breed and parity dependent (Disenhaus *et al.*, 2008). Probability distribution is as follows:

		1st standard cycle (10 to 50 days)		1st delayed cycle (51 to 100 days)		1st cycle after 100 days (INO)
		Normal cycle	Interrupted cycle	Normal cycle	Interrupted cycle	
Montbeliarde(*)	**Primiparous**	84%	4%	11%	1%	0%
	Multiparous	87%	11%	1.4%	0.6%	0%
Normande	**Primiparous**	78%	6%	15%	1%	0%
	Multiparous	83%	15%	1.4%	0.6%	0%
Holstein	**Primiparous**	51%	19%	17%	1%	12%
	Multiparous	56%	30%	5.4%	2.6%	6%

Table 15: Post-partum cyclicity resumption by breed and parity

(*) The study used does not show the details of first-calf heifers and multiparous' cyclicity returns for the Montbeliarde breed. The values were chosen by trial and error to obtain a delay variation in setting the reproduction of Montbeliarde cows 4 days before Normande cows (Reproscope data).

The postpartum delay of ovulation of the standard and delayed cycles is distributed evenly over the period in question. When a cycle is interrupted, the second ovulation occurs until 35 days after the first one.

For the first cycle after 100 days (INO), the determined D-day of return follows this distribution:

$$D = 101 * (1 + n^2)$$

With n = uniform distribution from 0 to 1

These data are a global result. They include the distribution of the effects of the prevalence of ketosis cases as defined in the paragraph *2.2.3.2.1.1.2.1.3 Effect of ketosis on the recovery of ovarian activity* and lameness case as defined in paragraph *2.2.3.3.1.1.3.1.2 Effect of lameness on the recovery of ovarian activity*.

2.2.1.1.7.3 *Treatment in case of cyclicality recovery problems*

Treatment by the veterinarian can solve problems of cyclicity recovery. This is the subject of paragraph *2.2.1.1.5 Veterinary surveillance*.

2.2.1.2 Parameters for reproductive management

This paragraph describes the decision-making parameters of the farmer for aspects related to reproduction. Several options are offered to the user. Combined, they simulate different managements.

2.2.1.2.1 Breeding age

This parameter makes it possible to define the age in days at which the heifers are put to reproduction by the farmer. This results in estrus monitoring in preparation for first insemination.

The default value is 500 days.

2.2.1.2.2 Estrus detection modes

The detection mode used in the herd is configurable. The possible values are:

- embedded sensor,
- robot, with milk progesterone dosage, paid option (see table *Table 113: Default rates for miscellaneous accounting transactions)*
- farmer,
- bull, when mating.

This option will have an impact on estrus sensitivity rates (see paragraph *2.2.1.1.2 Estrus detection sensitivity*) and on lack of specificity (see paragraph *2.2.1.1.3 Estrus detection specificity*).

The default mode is detection by the embedded sensor.

2.2.1.2.3 Slippery floor

Simulation may involve accommodation conditions that could reduce estrus expression, such as a slippery floor which is a Boolean option (true or false) that will affect estrus detection rates (see paragraph *2.2.1.1.2.3.1 Slippery floors*).

By default, the option is not selected (false).

2.2.1.2.4 Mating plans

It is possible to set the choice of insemination type and breed according to AI rank and cow parity, as well as the proportion to be applied, by implementing a Bernoulli law. The complement of this proportion causes a conventional artificial insemination (not sexed) of the designated breed of the herd (see paragraph *2.2.5.2.1.1 Initial cow breed*).

The default values are:

	First insemination		**2 and 3 insemination**		**4 and more insemination**	
	Insemination type	**Breed**	**Insemination type**	**Breed**	**Insemination type**	**Breed**
Heifers	100% Female sexed artificial	100% Holstein	100% Conventional artificial	100% Holstein	100% Conventional artificial	100% Limousine
Primiparous and multiparous	100% Conventional artificial	100% Holstein	10% Conventional artificial	100% Holstein	100% Conventional artificial	100% Charolaise

Table 16: Default values for mating plans

2.2.1.2.5 Grouped calvings

The grouping of heifer calvings is possible by excluding a period from the campaign. The setting consists of indicating the first month of the exclusion of calvings as well as the last. The calvings will be spread over the remaining period of the campaign. By default, no calving period is excluded for heifers.

This setting also determines the way in which the herd is built up, see paragraph *2.2.5.1.1.1 Gradual herd increase.*

2.2.1.2.6 Herd-specific fertility factor

A multiplicative value can improve fertility (value greater than 1.0) or reduce it (value less than 1.0). This option will affect the success rates of inseminations (see paragraph *2.2.1.1.4 Insemination and fertility*). Reproduction factors that influence fertility which are not explicitly represented are therefore taken into consideration.

The default value is 1.0.

2.2.1.2.7 Minimum post-partum delay before breeding (waiting period)

This parameter makes it possible to define the delay to be respected before post-calving reproduction (pregnancy end having led to a lactation).

Besides, this parameter makes it possible to apply a strategy to extend lactations.

The default value is 55 days.

2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility

The time limits described in this paragraph make it possible to determine whether, under certain conditions, it is no longer considered necessary to carry out inseminations. When an animal fulfils these conditions, it is considered infertile and therefore generally culled (see paragraph *2.2.5.1.1.2.2 Heifer sales and adult cow*).

The evaluated period's beginning is the date of the reproduction decision for both heifers and cows.

Estrus detection absence

This parameter is used to define the delay after which the first insemination will no longer be attempted because no estrus has been detected since breeding start. The default values are 150 days for heifers and 190 days for cows.

Lack of fertility

This parameter makes it possible to define the delay after which the inseminations will be stopped because none has been successful since the cow has been set (back) to breeding. The default values are 200 days for heifers and 260 days for cows.

2.2.1.2.9 Breeding contract

A management option allows the reproduction aspects to be contracted with a veterinarian (see *Table 118: Keys and formats for farm management parameters*). This fee-based option is invoiced at the beginning of the campaign at the herd level, and is calculated by multiplying the accounting cost for one animal with the average number of cows present (see paragraph *2.2.7.1.1 Reproduction*).

This contract makes it possible to reduce the costs linked to reproduction and to carry out treatments according to the reproduction problems encountered (see § *2.2.1.1.5 Veterinary surveillance*). These treatments can be configured, and are defined by default in the following way:

Case	**Calved cow not seen in heat** (see paragraph 2.2.1.1.5 a)	**Artificial inseminations without fertilisation** (see paragraph 2.2.1.1.5 b)	**Negative pregnancy diagnosis** (see paragraph 2.2.1.1.5 c)
Type	ENZAPROST® T	RECEPTAL® (2 ml)	ENZAPROST® T
Obtained effect	Return in heat (100%)	New estrus (100%) and specific 6 percent points increase in fertility on the AI	Return in heat with embryo loose on sensibility defect (100%)
Time to effect	3 days	Immediate (at insemination)	3 days
Referency	RCP*	(Besbaci *et al.*, 2020) and (Morgan et Lean, 1993)	RCP*

Table 17: Veterinary treatment plan under the breeding contract

* Summary of Product Characteristics (RCP): http://www.ircp.anmv.anses.fr/rcp.aspx?NomMedicament=ENZAPROST+T

The cost of these treatment is set in paragraph *2.2.7.1.1 Reproduction*.

2.2.1.3 Data produced

Data are produced based on calving data, insemination data and technical reproduction data.

2.2.1.3.1 Calving-based reproductive performance

By convention, a calving is considered to be the birth of one or two calves born at term. Cases of embryonic mortality or abortion (see paragraph *2.2.1.1.6.1 Late embryonic mortality and abortion*) are therefore not considered calving.

2.2.1.3.1.1 *Primiparous*

Production type: one-off

Information level: cow

Result file name: « PrimipareReproductionResultsBasedOnCalving.csv »

This data is produced during a primiparous cow calving.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Successful_calving_date	Date (*)	Successful calving date
First_insemination_age	integer	Age at the first insemination
Successful_insemination_age	integer	Age at the first successful insemination
Calving_age	integer	Age at the caving
First_insemination_date	Date (*)	First insemination date
First_insemination_type	Insemination type (*)	First insemination type
First_insemination_bull_breed	Breed (*)	First insemination bull breed
Insemination_quantity	integer	Number of inseminations performed
Successful_insemination_date	Date (*)	Successful insemination date
Successful_Insemination_quantity	integer	Successful insemination number
Successful_insemination_type	Insemination type (*)	Successful insemination type
Successful_insemination_bull_breed	Breed (*)	Successful insemination bull breed
First_insemination_successful_insemination_interval	integer	Number of days between the first and the successful insemination
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 18: Structure of calving-based reproductive performance data for primiparous cows

(*) See *Table 2: Type data formats* page 12.

2.2.1.3.1.2 *Multiparous*

Production type: one-off

Information level: cow

Result file name: « MultipareReproductionResultsBasedOnCalving.csv »

This data is produced during a multiparous cow calving

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Successful_calving_date	Date (*)	Successful calving date
Previous_calving_date	Date (*)	Previous calving dates
Previous_successful_calving_interval	integer	Number of days between the successful calving and the previous one
Previous_calving_rank	integer	Rank of the previous calving
First_insemination_date	Date (*)	First insemination date
First_insemination_type	Insemination type (*)	First insemination type
First_insemination_bull_breed	Breed (*)	First insemination bull breed
Previous_calving_first_insemination_interval	integer	Number of days between the previous calving and the first insemination
Insemination_quantity	integer	Number of inseminations performed
Successful_insemination_date	Date (*)	Successful insemination date
Successful_Insemination_quantity	integer	Successful insemination number
Successful_insemination_type	Insemination type (*)	Successful insemination type
Successful_insemination_bull_breed	Breed (*)	Successful insemination bull breed
Previous_calving_successful_insemination_interval	integer	Number of days between the previous calving and the first insemination
First_insemination_successful_insemination_interval	integer	Number of days between the first and the successful insemination
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 19: Structure of calving-based reproductive performance data for multiparous cows

(*) See *Table 2: Type data formats* page 12.

2.2.1.3.2 Insemination-based reproductive performance

2.2.1.3.2.1 Nulliparous

Production type: one-off

Information level: cow.

Result file name: « NullipareReproductionResultsBasedOnInsemination.csv »

This data is produced when a heifer calves.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
First_insemination_age	integer	Age at the first insemination
First_insemination_date	Date (*)	First insemination date
Insemination_date	Date (*)	Insemination date
Insemination_type	Insemination type (*)	Insemination type
Insemination_bull_breed	Breed (*)	Insemination bull breed
Insemination_number	integer	Number of inseminations performed
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 20: Structure of insemination-based reproductive performance data for nulliparous cows

(*) See *Table 2: Type data formats* page 12.

2.2.1.3.2.2 Primiparous and multiparous

Production type: one-off

Information level: cow

Result file name: « PrimiMultipareReproductionResultsBasedOnInsemination.csv »

This data is produced during a primiparous or a multiparous cow insemination.

The available fields are:

Field name	Format	Value
Id	integer	Identity of the cow involved
Previous_calving_date	Date (*)	Previous calving date
Previous_calving_rank	integer	Previous calving rank
First_insemination_date	Date (*)	First insemination date
Insemination_date	Date (*)	Insemination date
Insemination_type	Insemination type (*)	Insemination type
Insemination_bull_breed	Breed (*)	Insemination bull breed
Previous_calving_first_insemination_interval	integer	Number of days between the previous calving and the first insemination
Insemination_number	integer	Number of inseminations performed
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 21: Structure of insemination-based reproductive performance data for primiparous and multiparous cows

(*) See *Table 2: Type data formats* page *12*.

2.2.1.3.3 Technical reproduction data

Type of production: annual.

Information level: Herd.

Result file name: these results are included in the structure of technical results described in paragraph *3.4 Result structure*.

This data represents the annual technical balance sheet related to breeding activities.

The available fields are the following:

Field name	Format	Value
IV_IA1	real	Herd average of calving-1st AI intervals
TRIA1	real	Herd average of percentage of successful 1st AI
IVIAF	real	Herd average of calving-fertile AI intervals
IVV	real	Herd average of calving intervals
First_calving_age	real	Age average at first calving
IA1_count	integer	Number of first AIs
IA_count	integer	Number of AIs
Reproduction_treatment_count	integer	Number of vet treatments for reproductive problems
Reproduction_treatment_per_100_cows	real	Number of vet treatments for reproductive problems per 100 cows in the herd
Reproduction_culling_per_100_cows	real	Number of culls for reproductive problems per 100 cows in the herd

Table 22: Structure of the data on technical results related to reproduction

2.2.2 Lactation

The lactation module integrates all the aspects implemented to simulate female milk production. While this phenomenon is strongly dependent on biological constraints, it is however led by the farmer.

2.2.2.1 Constant biological and technical values

The internal parameters used for lactation simulations relate to milk production in terms of duration, quantity and composition, depending on different biological and technical factors.

The simulator differentiates cows' lactation stages as follows:

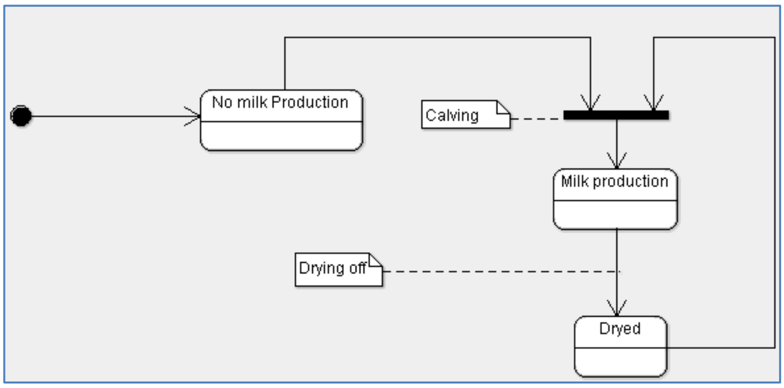


Figure 6: Lactation initiation and end steps

By convention, a lactation is considered as such when the female gives birth at the end of a pregnancy of at least 150 days, whatever the viability of new-born calf (calves).

Regarding the liter representation of milk production expressed in kg, the following coefficient is applied (Bareille *et al.*, 2017):

1 liter = 1.033 kg

Lactation duration is decided by the farmer who schedules the drying-off date. Like the quantity produced and the composition, the duration of the lactation can vary.

2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination

The quantity of milk produced and its composition varies according to the breed, as the daily production depends on the lactation stage (Bareille *et al.*, 2017). Lactation duration is set up by the farmer.

2.2.2.1.1.1 Breed impact on cumulated milk production

Milk quantity and composition depends on the cow's breed, and to a lesser extent on its genetic make-up (discussed in paragraph *2.2.4.1.1 Genetic values associated with phenotypic traits*, describing the basic performances of the gross production).

2.2.2.1.1.2 Daily production by lactation stage

Daily dairy production (DDP) is not constant over time, it depends on the lactations stage. Moreover, unlike milk quality, which is represented firstly by the fat content (FC) and secondly by the protein content (PC), the produced quantity is also linked to the parity of the cow (1st lactation, 2nd lactation and following lactations). The shape of the curves does not depend on breed, but on parity. This was demonstrated in a retrospective observational study conducted on French dairy herd data enrolled in the official Milk Recording Scheme covering the period January 2008 to December 2015. The shape of the lactation curves of non-pregnant Prim'holstein cows observed in these data for the different parities allowed modelling up to day 800 of lactation. However, production levels are differentiated by breed as modelled in paragraph *2.2.4.1.1.2 Criteria of genetic values associated with breed-dependent phenotypic traits* and modulated as described in paragraph *2.2.2.1.2 Milk production modulation*.

Thus, for each breed and to take account of parity, five curves are applied to distribute the DDP on a daily basis throughout a 305-day reference lactation. The curves obtained for DDP are as follows:

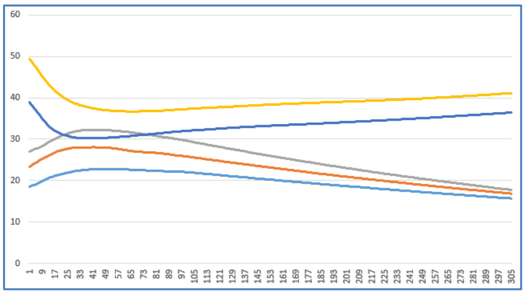


Figure 7: Daily dairy production curve for the Montbeliarde breed

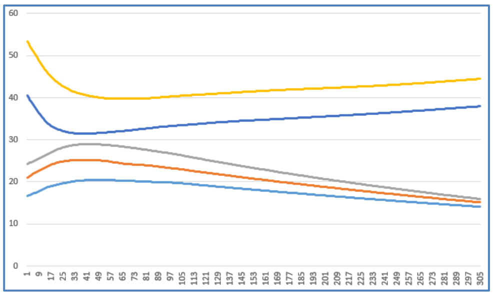


Figure 8: Daily dairy production curve for the Normande breed

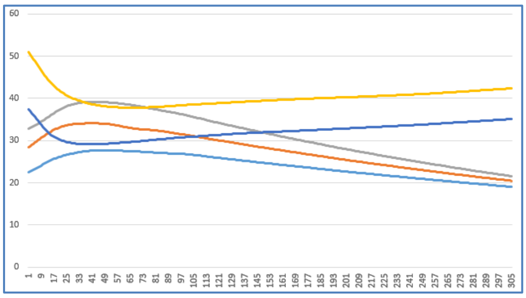
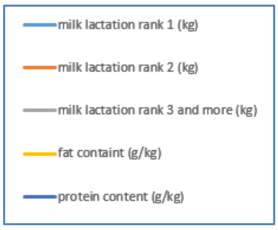


Figure 9: Daily dairy production curve for the Holstein breed



The non-pregnant effect is described in paragraph *2.2.2.1.2.3 Pregnancy*.

2.2.2.1.1.3 Milk somatic cell count in absence of infection

The level of milk somatic cell in absence of infection is dependent on the rank and stage of lactation, but not on the breed of the cow. It is accepted that the shape of the curve representing the variation due to the stage of lactation is that observed for the first lactation of non-pregnant Prim'holstein cows taken from the same data as those used for the milk curves (see previous paragraph), only the levels differ according to the lactation rank as follows:

Parity	1	2	3 and +
Mean level (1000 cell / ml)	43.3	67.7	84.7

Table 23: Basis levels of somatic milk cell count in mammary infection absence depending on the parity

Thus, the Somatic Cell count (SCC) of the milk in the absence of infection, expressed in number of 1000 cells / ml of milk, will respect the following curves:

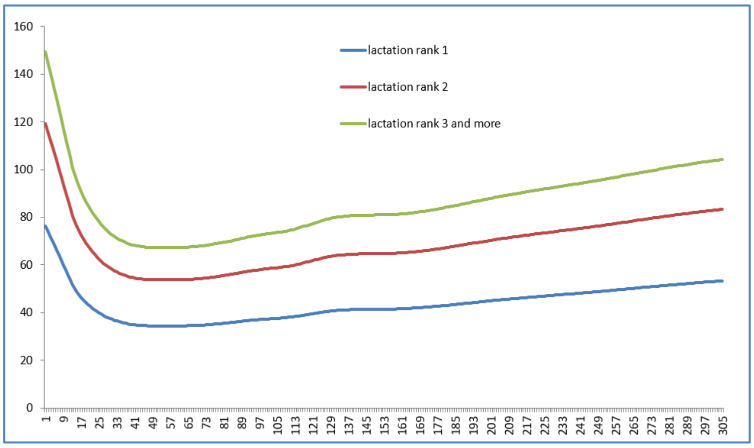


Figure 10: SCC wood curves of the udder in mammary infection absence

The inter-day-to-day variability of SCC (excluding mastitis) is defined by hazard in paragraph *2.2.2.1.2.14 Daily hazard*.

2.2.2.1.1.4 Basic lactation duration – drying-off programming

The theoretical lactation duration is decided by the farmer (drying-off). This allows him to consider the dry period he wants as part of his farm management. This duration is configurable (see paragraph *2.2.2.2.1 Drying-off*).

For this purpose, if a lactation is to be in progress, the drying-off date is programmed as soon as an insemination has been determined as successful and therefore a pregnancy begins. Calculation is done as follows:

$$Tp = Ir + Pg - Ps$$

with

Tp = planned day for drying-off

Ir = day of the successful insemination

Pg = expected duration according to the pregnancy's breed and parity

Ps = duration set up for the Dry Period.

The "farmer" estimate of Pregnancy duration is based on the average pregnancy duration based on breed and parity (see paragraph *2.2.1.1.6.2.1 Breed and parity*). It does not take into account other biological factors.

Drying-off is deprogrammed in case of embryonic mortality or abortion.

When a drying-off date has been programmed, the milk production is stopped on the planned day. In the opposite case (e.g. if the cow is destined for culling and therefore has not been bred), the production is automatically stopped as soon as the milk product level is lower than the one set (see paragraph *2.2.2.2.1 Drying-off*).

2.2.2.1.1.5 Milk destination

The production of the first days of lactation is not considered consumable (marketable) because it is colostrum (Bareille *et al.*, 2017). It will not be delivered to the dairy, but is considered as discarded milk. The simulator is used to set the time length during which this milk will be discarded by the farmer (see paragraph *2.2.2.2.3 Minimum lactation stage for delivered milk*).

The milk to be delivered produced daily is stored in the tank and is collected every three calendar days. This milk is analysed at the cooperative three times a month to determine the average SCC. The dates of these controls are not known by the farmers, the simulator carries them out on the 5th, 15th and 25th of the month, and the results are communicated the next day. Depending on the measured SCC (i.e. from the first test) and the SCC ceiling that he decides not to exceed, the farmer discards the milk that penalises him the most, i.e. the milk from the quarter of the cow with the highest SCC since the last two milk tests (thus assuming that the milk test is not a simulation option, but a systematic subscriber).

Depending on the average SCC of the three milk checks carried out during the month, penalties are applied to the price paid for the milk delivered by the farmer, by instalments:

- above 250 (000/ml)
- above 300 (000/ml)
- above 450 (000/ml)

The amount of the penalties can be configured, see chapter *2.2.7.1.2 Production*.

2.2.2.1.2 Milk production modulation

"Real" milk production is a modulation of the theoretical production due to the circumstances described below.

2.2.2.1.2.1 Parity

Milk production MP increases with parity (Bareille *et al.*, 2017). For this purpose, the simulator uses a divisor factor of MP at adult stage, the values of which are established as follows (Institut de l'élevage, 2021b):

Parity	Value of the divisor
1	1.3
2	1.12
3	1.03
4+ (adult)	1.0

Table 24: Divisor value of the milk quantity produced during adulthood according to parity

Durations remain the same, but a very slight decrease in PC with age (-0.2g / kg between the 1st and 4th lactation) is taken into account.

2.2.2.1.2.2 Drying-off

The dry period starts from the drying day (milking's end) and ends when the next lactation begins. Its reference duration is a decision of the farmer, but it can be modulated according to unpredictable biological events (abortions, variability of the pregnancy duration, ...).

The duration of the dry season influences the coming production. Indeed, the elimination of drying-off has the effect of reducing the quantity of milk produced by 15%, and a dry period of 30 days by 7%.

The principle adopted to simulate this effect is the application of a multiplicative value whose calculation is based on a proportionality implementing the actual dry period's duration (taking into account biological events) and the foreseeable decrease in quantity:

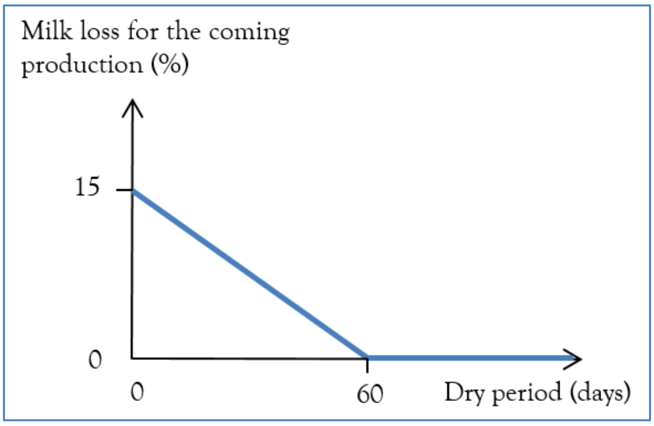


Figure 11: Effect of the decreased milk production due to reduced dry period at the next lactation

Thus the proportional multiplicative value v is calculated using the formula:

$$v = 1 - \frac{\mathrm{dp} * \left(\frac{-15}{60}\right) + 15}{100}$$

$$with \quad 0.85 \leq v \leq 1$$

dp = actual duration of the dry period.

Regarding FC and PC, according to the Breton Survey (Kerouanton et al., 1995, Designé 1966), the benefits obtained due to the omission of the previous lactation's dry period are as follows (Rémond, Kérouanton et Brocard, 1997):

Lactation	FC gain (g/kg)	PC gain (g/kg)
2nd	2.9	3.0
3rd and more	0.4	1.1

Table 25: Gain in FC and PC due to the omission of the drying up of the previous lactation

According to the same scheme as for milk production, the proportionate additive value v is calculated for FC and PC using the following formula:

$$v = g \; x \; \frac{60 - dp}{60}$$

$$with \quad v \geq 0$$

g = basic gain

dp = actual duration of the dry period

The lactation curve's shape is little or no modified by the absence of dryness (Rémond, Kérouanton et Brocard, 1997), it is not modified in the simulation.

2.2.2.1.2.3 Pregnancy

The theoretical production curves (see paragraph *2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination*) are based on the assumption that cows are not pregnant. In case of pregnancy, the following values are minored from the quantity produced (Billon, 2015):

Lactation stage	Minored value
From 242 days	1 kg
From 272 days	2 kg
From 303 days	2,5 kg

Table 26: Minored value of milk production of a cow that is pregnant according to its lactation stage

FC and PC are not changed.

2.2.2.1.2.4 Individual potential

Individual potential in adult stage (lactation 4) depends on the genetic value of the individual. It is determined in the simulation for the following phenotypic traits:

- MILK : Quantity milk (in kg)
- FC : fact content (in g/kg)
- PC : protein content (in g/kg)

These values' determination is explained in the genetic module (see paragraph *2.2.4 Genetics*).

2.2.2.1.2.5 Estrus

Milk production decreases the day the cow is in estrus from 5 to 10% (Bareille *et al.*, 2017). Therefore, the simulator uses a multiplicative value of 0.925, which affects the quantity of milk produced and corresponds to a 7.5% drop.

FC and PC do not undergo any Movements during estrus.

2.2.2.1.2.6 Photoperiod

The photoperiod (associated with the season) has a specific effect on the daily milk production of the cow (Coulon, Chilliard et Rémond, 1991). This additive effect is represented by the following curve (Bareille *et al.*, 2017):

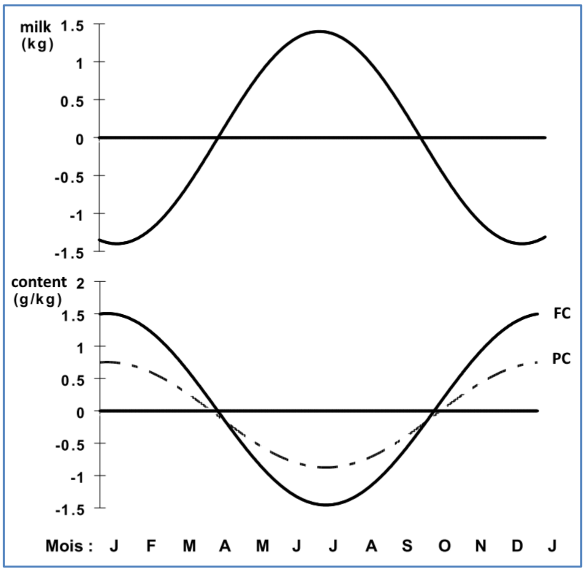


Figure 12: Specific effect of the month on the dairy production of the cow

Thus, the equation used to determine the multiplicative value v of the performance p to add to the milk production of the day (PLJ) is as follows:

$$v = p * \cos\left(\frac{2\pi *< day\ of\ the\ year >}{< number\ of\ days\ in\ the\ year >}\right)$$

With as criterion value p:

p Value	Factor
Dairy production (kg)	-1.5
FC (g/kg)	1.5
PC (g/kg)	0.75

Table 27: Performance-specific seasonal multiplier factor

The photoperiod effect thus calculated is applicable to a herd located at the average latitude of metropolitan France.

2.2.2.1.2.7 Milking frequency

Milking frequency is usually set at twice a day. Reducing this frequency to one time leads to a 25% drop in production, with a 2.7g / kg increase in FC and a 2.2g / kg increase in PC (Rémond, Pomiès et Pradel, 2005). However, a milking carried out 3 to 4 times a day results in an increase of approximately 15%, without impacting the rates (Bareille *et al.*, 2017) nor of the SCC.

Milking frequency can be parameterized (see paragraph *2.2.2.2.2 Milking frequency*).

2.2.2.1.2.8 Somatic cell count

Beyond 50,000 cells / ml of milk, SCC causes a decrease in milk production depending on parity and lactation stage. This effect following the presence of mastitis is taken into account by the simulator by applying the following equations (Hortet *et al.*, 1999):

$$RMY(X) = (a * DIM^2 + b * DIM + c) * \text{logn}\left(\frac{X}{50}\right)$$

With

RMY = decrease in the milk production (kg)

X = SCC value studied (1000 cells/ml)

DIM = lactation stage

and for each parity:

Parity	a	b	c
1	0	0	0.44
2	0.00002	-0.0019	0.5006
3+	0.00001	0.0015	0.3341

Table 28: Parameters specific to each parity for the equation of milk quantity reduction related to milk SCC

2.2.2.1.2.9 Mastitis effect on dairy production

Mastitis can occur from the beginning of the first lactation until the culling (or death) of the cow. Depending on its severity, this disease can modify milk production, both in quantity and in composition. These situations are described in paragraph *2.2.3.1.1.1.3 IMI consequences*.

2.2.2.1.2.10 Ketosis effect on dairy production

When ketosis occurs, it alters milk production, both in quantity and composition. This situation is described in the paragraph *2.2.3.2.1.1.2.2 Impact of ketosis on milk production performance*.

2.2.2.1.2.11 Lameness effect on dairy production

When ketosis occurs, it alters milk production, both in quantity and composition. This situation is described in the paragraph *2.2.3.3.1.1.3.2 Impact of lameness on milk production performance*.

2.2.2.1.2.12 Quarter loss

When one quarter of the udder is dry (for example following a severe case of mastitis, see paragraph *2.2.3.1.1.1.3.2 Important decrease in milk production*), the udder production is reduced by 20% (ECOMAST), which amounts to slightly increase the theoretical quantity of milk produced by each of the healthy quarters of the udder, according a *F* factor defined as following:

$$F = 1 + \frac{\left(\frac{1}{4} - 0.2\right)}{3} \cong +1.0167$$

2.2.2.1.2.13 Feeding

In this chapter milk production is calculated on the basis that the cow is fed in a balanced way. During production peak, it may be necessary to give some concentrate in addition. This method is detailed in paragraph *2.2.6.2.2 Production concentrate diets*.

2.2.2.1.2.14 Daily hazard

A hazard is applied to the daily milk production. This hazard meets the following character:

Criterion	Distribution
Quantity	Uniform (+ or – 2kg)
FC	N (0 ; 1.25)
PC	N (0 ; 0.5)
SCC	N (0 ; 0.1)

Table 29: Daily hazard on milk performance

2.2.2.2 Parameters for lactating farmer management

Different parameters allow the user to define the management rules related to lactation.

2.2.2.2.1 Drying-off

The simulator offers to the user to decide the drying period duration (see paragraph *2.2.2.1.1.4 Basic lactation duration – drying-off programming*). By default, this duration is set to 60 days.

2.2.2.2.2 Milking frequency

The simulator offers different daily milking frequencies:

- once a day,
- twice a day (default value),
- above twice a day,

This option may affect the amount of milk produced (see paragraph *2.2.2.1.2.7 Milking frequency*).

2.2.2.2.3 Minimum lactation stage for delivered milk

A legal lactation stage must be respected before the milk is considered marketable (see paragraph *2.2.2.1.1.5 Milk destination*). The default value applied by the simulator is a six-day delay. However, the experimenter has the possibility to set this value to decide on a different number.

2.2.2.2.4 Herd production level

The simulator makes it possible to vary the production level of the herd with respect to the average of the herds of the same breed. For each milk characteristic (quantity, TB and TP), a value expressed in kg for quantity and in g/kg for TB and TP will be added to the animal's production according to the desired adjustment of the production level of the simulated herd. The default value is 0.

2.2.2.3 Data produced

The data produced concern milk deliveries, side locks, monthly test-day results and technical production data.

2.2.2.3.1 Milk delivery to a dairy

Production type: monthly.

Information level: Herd.

Result file name: « DeliveredMilk.csv »

This data represents the monthly assessment of milk production (sum of the daily dairy production) for the herd. This production is reduced by calves' milk consumption, if this option is to be chosen (see paragraph *2.2.6.2.1.1 Unweaned calf* feeding).

The available fields are:

Field name	Format	Value
Date	Date (*)	Monthly test-day date
Liter_quantity	real	Monthly delivered milk quantity (liters)
Liter_TB	real	Monthly average FC in milk (g/l)
Liter_TP	real	Monthly average PC in milk (g/l)
SCC (**)	real	Monthly average SCC in milk (1000/ml)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 30: Data structure of monthly results of delivered milk

(*) See *Table 2: Type data formats* page *12*.

(**) Obtaining the SCC value is detailed in paragraph *2.2.3.1.1.1.3.1 Increase in somatic cell count.*

2.2.2.3.2 Spread and discarded milk

Production type: monthly.

Information level: Herd.

Result file name: « DiscardedMilk.csv »

This data represents the monthly assessment of discarded milk (sum of the daily quantities of milk actually discarded) for the herd. This result takes into account the possible consumption of discarded milk by calves, if this option is to be chosen (see paragraph *2.2.6.2.1.1 Unweaned calf feeding*).

The available fields are:

Field name	Format	Value
Date	Date (*)	Monthly-test day date
Liter_quantity	real	Quantity of milk discarded in the month (liters)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 31: Data structure of monthly results of discarded milk

(*) See *Table 2: Type data formats* page *12*.

2.2.2.3.3 Performance estimation by monthly test-day

Production type: monthly.

Production level: Simulation (merging of the result of all protocols and runs)

Information level: Herd.

Result file name: « MilkControlResults.csv »

This data represents the result of the milk controls, which is not an option but is systematically implemented by the simulator on the 15th of each month. Although considered present in the herd, cows that have not reached the minimum stage of lactation for the milk delivered are not considered to be lactating and therefore their milk is not checked (see paragraph *2.2.2.2.3 Minimum lactation stage for delivered milk*).

The available fields are:

Field name	Format	Value
< Simulation framework>	*Table 116: Structure of the fields defining the simulation framework*	
Date	Date (***)	Monthly test-day date
Herd_cow_count	integer	Number of cows in the herd
Milking_cow_count	integer	Number of milking cows in the herd
Average_milk_quantity_cow	real	Average milk quantity per milking cows (checked) the monthly test-day (kg)
Average_lactation_stage	integer	Average lactation stage of the cows that aren't dried up (days)
Average_FC	real	Average milk FC of the day (g/kg)
Average_PC	real	Average milk PC of the day (g/kg)
Average_SCC (*)	real	Average SCC of the day (1000 cellules/ml)
SCC_300_prevalence	real	Ratio of milking cows whose SCC exceeds 300 000 c / ml on the monthly test-day
SCC_300_incidence	real	Incidence ratio for SCC threshold at 300 000 c / ml (**)
Detected_infectious_lameness_percent	real	Percentage of controlled cows with infectious lameness detected
Infectious_G1_lameness_percent	real	Percentage of controlled cows with G1 infectious lameness
Infectious_G2_lameness_percent	real	Percentage of controlled cows with G2 infectious lameness
Detected_non_infectious_lameness_percent	real	Percentage of controlled cows with non-infectious lameness detected
Non_infectious_G1_lameness_percent	real	Percentage of controlled cows with G1 non-infectious lameness
Non_infectious_G2_lameness_percent	real	Percentage of controlled cows with G2 non-infectious lameness

Table 32: Data structure of monthly test-day results

(*) SCC represents milk aspect. This concept is detailed in paragraph *2.2.3.1.1.1.3.1 Increase in somatic cell count*.

(**) The incidence ratio is obtained by calculation BH / (BB + BH), with BH the number of milking cows whose milk SCC produced the previous month was less than 300 000 c / ml and whose SCC exceeded 300 000 c / ml on the monthly test-day, and BB that of milking cows whose milk SCC produced the previous month was less than 300 000 c / ml and who remained with an SCC less than 300 000 c / ml on the monthly test-day.

(***) See *Table 2: Type data formats* page *12*.

2.2.2.3.4 Technical production data

Production type: annual.

Information level: Herd.

Result file name: these results are included in the structure of technical results described in paragraph *3.4 Result structure*.

This data represents the annual technical balance sheet related to production activities.

The available fields are:

Field name	Format	Value
Delivered_milk_liter_quantity	real	Total quantity of milk delivered during the campaign (litres)
Delivered_milk_liter_quantity_by_cow	real	Total quantity of milk delivered during the campaign / Average number of cows present (litres)
Produced_milk_liter_quantity_by_cow	real	Total quantity of milk produced during the campaign / Average number of cows present (litres)
SCC	real	Average tank milk cell count over the campaign (1000 cells/ml)
TB_liter	real	Tank milk TB level over the campaign (g/litre)
TP_liter	real	Tank milk TP level over the campaign (g/litre)

Table 33: Structure of data on technical production results

2.2.3 Health

This module deals with production diseases that can have an economic impact, both in terms of production loss and in terms of health costs related to their treatment.

The diseases that are implemented by the simulator and described in this chapter are mastitis (i.e. intra-mammary Infections), ketosis and lameness.

A management option can be used to simulate adherence to a veterinary care contract (see *Table 118: Keys and formats for farm management parameters*) and to define the invoicing method, which can be based on the number of cows, calvings and kiloliters produced, each obtained during the previous financial year. It is invoiced at the beginning of the season for the whole herd.

The effects of the veterinary care contract on the diseases modelled, in terms of prevention, detection, response time and cure, are all described in the "Effects [...] of the veterinary care contract" section for each of the diseases concerned. This contract also entails planned preventive visits, two per month in the first year of the contract, then one per month in subsequent years. The number of these visits is shown in the results produced (see paragraph *2.2.3.4 General health produced data*).

In addition, the veterinary care contract also helps to reduce mortality that may be due to diseases that are not modelled (see paragraph *2.2.5.1.1.3 Mortality*).

Technically, the implementation of the veterinary care contract begins when the simulation produces results (i.e. after the simulator warm-up period).

The health contract is not selected by default.

2.2.3.1 Intramammary infection (IMI)

In the lactation phase, somatic cells are naturally present in the milk produced, at a limited concentration even if there is no infection. IMIs are infections caused by the proliferation of different types of bacterium. They impact the immune defence system of the cow, so significantly increasing the concentration of these somatic cells in the milk. They can appear in the four quarters of the udder. These IMIs have consequences on the quantity and the quality of the produced milk cows and on their reproduction. These consequences can go as far as cullinging the cow. Depending on their severity, IMIs may require treatment for recovery.

2.2.3.1.1 Constant biological and technical values for IMI

2.2.3.1.1.1 IMI description

The chapter's purpose is to describe the different types of mastitis, their severity level, their relation to the lactation stage, and their impact on milk production and animal health.

2.2.3.1.1.1.1 IMI types

The IMIs implemented by the simulator are of five different types, which makes it possible to take into account the diversity of the current epidemiological-clinical entities:

Bacterium name	Short name
Staphylococcus aureus	StaphA
Streptococcus uberis	StreptU
Gram Negative bacterium	G-
Coagulase Negative Staphylococcus	CNS
Corynebacterium bovis	CB

Table 34: Bacterium responsible for IMI

2.2.3.1.1.1.2 IMI severity levels

When it occurs, each IMI can begin as subclinical or clinical mastitis, varying in different severity levels, and with various frequencies.

2.2.3.1.1.1.2.1 Definition of IMI severity levels

Severity levels were defined as follows:

Name	Definition
G0	Subclinal IMI
G1	IMI with slight milk modification (clinical)
G2	Local IMI (clinical)
G3	Systemic IMI (clinical)

Table 35: IMI severity levels

2.2.3.1.1.1.2.2 Severity levels by IMI type and by lactation stage/cow pregnancy stage at infection time

Three degrees of severity can be differentiated according to the stage and lactation number of the cow (Robert-Briand, 2006). In the simulator, they are distributed as follows:

Lactation stage (*)	**Lactation number**		
	Primiparous	2 lactations	3 lactations et +
Peri-partum and early lactation	increased	increased	increased
Lactation	basic	basic	increased
Dry period	decreased	increased	increased

Table 36: Modulation in IMI severity by lactation stage and rank

(*) the duration of the periods is defined in paragraph 2.2.3.1.1.2.1 Periods at risk page 43.

Thus, when the cow is infected, the IMI initial severity (possibly increased or decreased) of the IMI is evaluated as follows (Ecomast):

IMI type	**Risk level** (%) **basic (decreased- increased)**			
	G0	G1	G2	G3
StaphA	85 (87 – 86)	9 (7 – 3)	5 (4 – 7)	1 (2 – 4)
StreptU	45 (45 – 25)	25 (30 – 13)	23 (23 – 49)	7 (1 – 13)
G-	15 (10 – 15)	33 (38 – 20.5)	36 (41 – 23.5)	16 (6 – 41)
CNS	90 (90 – 90)	5 (7 – 4)	5 (3 – 5.5)	0 (0 – 0.5)
CB	98 (98 – 98)	1.5 (1.8 – 1.3)	0.3 (0.2 – 0.4)	0.2 (0 – 0.3)

Table 37: Risk levels according to IMI type and severity

2.2.3.1.1.1.3 IMI consequences

Depending on their type, IMI can have consequences on the production as well as on the cow's health condition.

2.2.3.1.1.1.3.1 Increase in somatic cell count

IMI occurrence increases the concentration of somatic cells, so the SCC evolves in the following way (ECOMAST):

IMI type	Severity	Decreased SCC (1000/ml)	Increased SCC (1000/ml)
StaphA	G0	1320	3800
	G1	1000	27000
	G2	7700	47500
	G3	27000	55000
StreptU	G0	2760	6160
	G1	2000	26000
	G2	7500	47500
	G3	26000	55000
G-	G0	2430	6700
	G1	2500	26000
	G2	7500	47500
	G3	26000	55000
CNS	G0	530	2080
	G1	700	27000
	G2	7500	47500
	G3	27000	55000
CB	G0	310	1980
	G1	500	20000
	G2	6000	34000
	G3	20000	40000

Table 38: IMI occurrence impact on quarter SCC

This variability is implemented by the daily application of a Beta-pert law delimited by the lowest and highest values thus determined and shifted to the left, possibly cumulative if several mastitis (thus of different bacterium) simultaneously were to occur in the same quarter.

According to the SCC resulting from the IMI, the quarter milk can be dismissed by the farmer. The strategy implemented under these circumstances is detailed in paragraph *2.2.2.1.1.5 Milk destination*.

2.2.3.1.1.1.3.2 Important decrease in milk production

The quantity of milk produced naturally reduces with the increase in somatic cell count (see paragraph *2.2.2.1.2.8 Somatic cell count*). With regard to clinical mastitis, milk production loss during the severe phase is specifically modified in the following way (Robert-Briand, 2006):

IMI type	Severity	Milk loss in the quarter		
		Highest loss (%)	Lowest duration (j)	Highest duration (j)
StaphA	G1	20	8	10
	G2	40		
	G3	75		
StreptU	G1	25	5	10
	G2	40		
	G3	75		
G-	G1	1	5	15
	G2	4		
	G3	110 [(1)]		
CNS	G1	0	2	10
	G2	40		
	G3	60		
CB	G1	20	2	10
	G2	40		
	G3	60		

Table 39: Consequences of IMI clinical cases on quarter milk production

The variability of a mastitis duration is implemented by the application of a uniform law delimited by the decreased and increased values thus determined. This is also the case for the variability of the percentage of milk loss associated with it. If the quarter has multiple infections (i.e. different bacterium), the highest percentage of milk loss will be applied.

In extreme cases of G3 severity mastitis, a permanent loss of the quarter may be possible. It is represented the following probabilities:

IMI type	Probability of quarter permanent loss (%)
StaphA	2
StreptU	6
G-	2
CNS	2
CB	1

Table 40: Probability of quarter loss in G3 mastitis

This eventual loss occurs at the expected end of the infection period and has an effect on milk production in the neighbouring quarters (see paragraph *2.2.2.1.2.12 Quarter loss*).

2.2.3.1.1.1.3.3 Impact on feeding

Because of the reduction in the quantity of milk produced in the event of mastitis, feed consumption is reduced as follows: a reduction of 8 kg of milk leads to a reduction in consumption of 1 kg (divided proportionally between forage and concentrate), except for cases of quarter loss for which this effect is divided by 2.

2.2.3.1.1.1.3.4 Impact of mastitis on susceptibility to other diseases

Mastitis has an effect on susceptibility to other diseases. The diseases concerned in DHM are ketosis (see paragraph *2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes*) and lameness (see paragraph *2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases*).

2.2.3.1.1.1.3.5 Mortality and culling risk related to G3 severity

G3 severity IMI can have an impact on the animal's fate according to the following probabilities (Robert-Briand, 2006):

[1] The loss is total for the quarter, and impacts 10% of the neighbouring quarter

IMI type	Probability (%)	
	Mortality	Culling
StaphA	2	2
StreptU	1	1
G-	5	8
CNS	0	0
CB	0	0

Table 41: Mortality and culling risk related to G3 severity

2.2.3.1.1.2 IMI incidence

The occurrence or not of an IMI on a quarter of a given cow depends on the combination of a risk specific to the cow, its environment and the effectiveness of the prevention methods. Thus, the basic probability of IMI onset depends on the incidence of mastitis on the udder per lactation cycle, corresponding to the use of basic means of prevention.

The udder of a cow (or of a heifer at the approach of the first calving) is likely to contract an IMI according to the following epidemiological model:

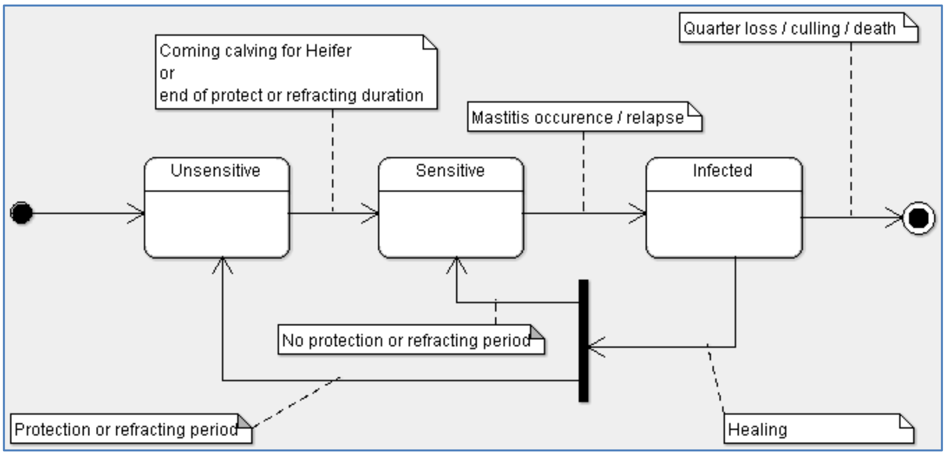


Figure 13: IMI epidemiological model

This model presented here is simplified. The dynamics of infection evolution applied for each quarter and for each type of bacterium is detailed in paragraph *2.2.3.1.1.4 Evolution and cure*. Not all bacteria are equivalent in terms of impact. The share of incidence that each one is led to take is configurable, this is the subject of the paragraph *2.2.3.1.2.3 Share of bacterial type in incidence*.

A quarter is likely to contract multiple IMIs simultaneously if they were to be caused by different bacterium. For each quarter, a refractory period of 7 days follows the occurrence of an IMI, preventing the appearance of a new infection. At the end of this period, the quarter is again exposed to IMI. Only one mastitis case can occur on a given day in neighbouring quarters. However, in case of several mastitis cases (for different bacterium) the least common disorder is considered. The ranking order is as follows (from least to most frequent):

- Gram Negative
- Streptococcus Uberis
- Staphylococcus Aureus
- Coagulase Negative Staphylococcus
- Corynebacterium Bovis

The udder is considered infected by a bacterium when one of its quarters is in the infected state for this bacterium.

2.2.3.1.1.2.1 Periods at risk

The risk of onset of the disease depends especially on biological periods and production activities, particularly those related to lactation (Robert-Briand, 2006). It therefore depends on the cow's (re) productive periods, whose sequence and reference duration are defined as follows:

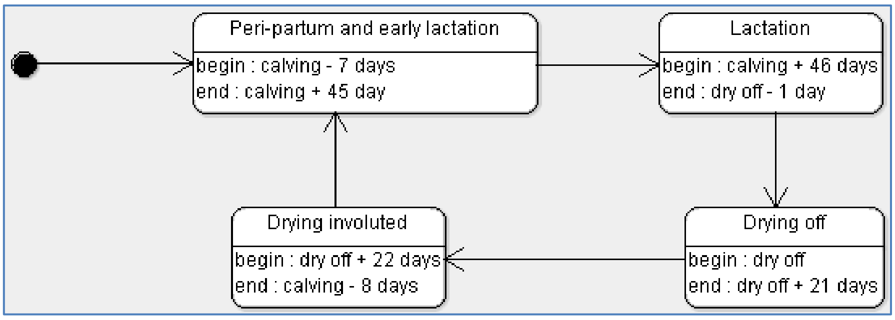


Figure 14: Sequence and duration of (re)productive periods at IMI risks

Note : The peripartum period is also triggered at the time of an abortion if it has resulted in lactation (see paragraph *2.2.1.1.6.1 Late embryonic mortality and abortion*).

According to the cow's pregnancy/lactation stage, based on lactation after 305 days and a dry period of 60 days (so for a cycle of 365 days), each IMI type occurrence's basic distribution is the following (ECOMAST):

IMI type	**Periods**			
	Peri-partum and lactation beginning	Lactation	Drying-off	Drying involuted
StaphA	0.42	0.31	0.2	0.07
StreptU	0.51	0.22	0.2	0.07
G-	0.615	0.235	0.1	0.05
CNS	0.825	0.025	0.1	0.05
CB	0.3	0.55	0.08	0.07

Table 42: Distribution of each IMI type occurrence according to pregnancy and lactation stage over a year

Thus, relying on two Beta-Pert distributions with respectively a peak on the calving day and a lambda value of 10 for one, and a peak 5 days after drying-off and a lambda value of 4 for the other, the probabilities of IMI occurrences are distributed as follows:

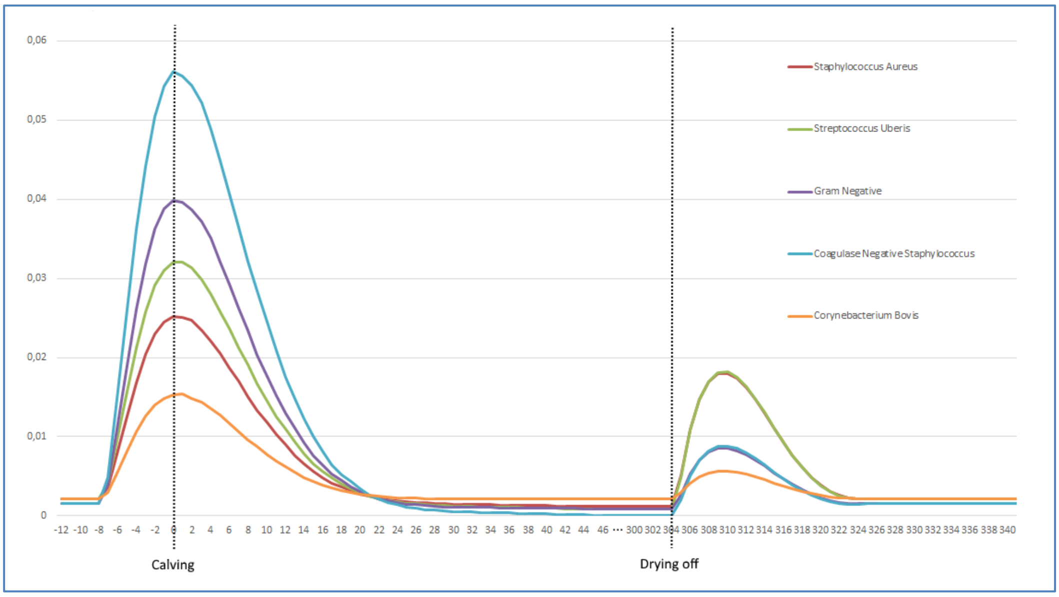


Figure 15: Distribution of each IMI type occurrence according to pregnancy-lactation stage over a year

2.2.3.1.1.2.2 *Incidence risk modulation*

The risk of mastitis incidence can be modulated according to individual situations and husbandry conditions.

2.2.3.1.1.2.2.1 Individual modulation of incidence risk

The risk of developing basic mastitis cases can be weighted by particular conditions. Indeed, certain driving practices, and in particular those implemented in the context of prevention, can modulate this risk, which is simulated by taking into account a global factor of individual prevention, which can be parameterised according to the methods defined in the paragraph *2.2.3.1.2.5 Prevention factor for mastitis at the individual level*. For the others, they are defined in the following paragraphs.

2.2.3.1.1.2.2.1.1 Dairy production

IMI incidence may change according to the amount of milk produced during a lactation. If milk quantity decreases, the risk is attenuated (Billon, 2015). On the contrary, during peak production, the risk increases:

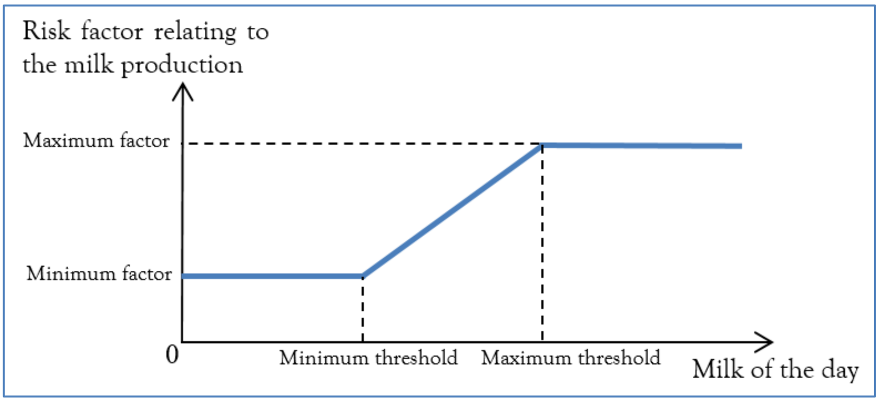


Figure 16: Risk factor for mastitis incidence according to milk production

The threshold values of the udder production and of the afferent risk, depending on the bacterium studied, are defined in the following way (ECOMAST):

IMI type	Decreased risk		Increased risk	
	Production threshold (kg)	Risk factor	Production threshold (kg)	Risk factor
StaphA	25	0.50	50	1.5
StreptU	25	0.45	50	2.0
G-	25	0.45	50	1.8
CNS	25	0.50	50	1.5
CB	25	0.50	50	1.5

Table 43: Risk factor values for mastitis incidence according to udder milk production and bacterium presence

2.2.3.1.1.2.2.1.2 Lactation rank

IMI incidence may be different depending on parity, it tends to increase throughout its productive life (Billon, 2015). In order to take this effect into account in the simulator, a risk factor related to this lactation rank is applied. Without distinction of bacterium type, this risk is determined in the following way (ECOMAST):

Number of lactations	Risk factor
1	0.75
2	1
3	1
4 et +	1.5

Table 44: IMI risk depending on lactation rank

2.2.3.1.1.2.2.1.3 Potential milk

The milk potential influences IMI incidence during lactation phases. The more milk the cow is able to produce, the higher the risk of developing mastitis is (Billon, 2015). Therefore, the simulator applies a risk factor based on the following values, without distinction of bacterium type (ECOMAST):

	Decreased risk	Increased risk
Potential milk	4000 kg	12000 kg
Associated risk	0.8	1.5

Table 45: IMI risk related to potential milk

The milk potential implemented here is the individual's corrected milk performance P, based on the corrected lactation production (cumulative over 305 days and adult level) of the breed, described in paragraph *2.2.4.1.1 Genetic values associated with phenotypic traits.*

2.2.3.1.1.2.2.1.4 *Individual character*

Individual susceptibility to mastitis is determined by the phenotypic trait "MACL", described in paragraph *2.2.4.1.2 Individual genetic value*. The principle adopted for its consideration at the simulation level is to apply to the risk the factor represented by the corrected performance of this phenotypic trait (see paragraph *2.2.4.1.2.2 Individual potential in adult stage*).

2.2.3.1.1.2.2.1.5 *IMI risk related to pre-existing SCC level*

Pre-existing high SCC in the udder may have a beneficial effect on the incidence of IMI during lactation. Conversely, a low level may favour its appearance (Billon, 2015). The simulator produces these effects by applying a risk factor based on the following values (ECOMAST):

IMI type	**Risk factor**		
	SCC < 75 (1000/ml)	SCC ≥ 75 (1000/ml) and SCC ≤ 750 (1000/ml)	SCC > 750 (1000/ml)
StaphA	1	1	0.8
StreptU	1	1	0.8
G-	1.1	1	0.8
CNS	1	1	0.8
CB	1	1	0.8

Table 46: Risk factor values for mastitis incidence according to the pre-existing level of SCC

2.2.3.1.1.2.2.1.6 *Quarter interdependence*

The risk of mastitis occurring in one area is increased by the presence of mastitis of the same type (same bacterium) on another area of the udder. These complementary risk factors are defined in the following way (ECOMAST):

IMI type	**Risk factor**
StaphA	3.2
StreptU	3.2
G-	3.2
CNS	3.2
CB	3.2

Table 47: IMI risk related to quarter interdependence

2.2.3.1.1.2.2.1.7 *Modulation of mastitis incidence due to competition from other disease episodes*

The presence of certain diseases may increase the risk of developing mastitis. Mastitis susceptibility refers to all types of IMI, which are clinically severe (G1, G2 and G3). The following relative risks are associated:

Disease	Relativ risk	Risk duration	References
Ketosis	1,61	Concomitant with the disease	G1 : (Raboisson, Mounié et Maigné, 2014) Other severities: Extrapolation of risk from expert opinion
Lameness	1,44	Concomitant with the disease	(Peeler, Otte et Esslemont, 1994)

Table 48: Relative risk of mastitis occurrence due to competition with other disease episodes

2.2.3.1.1.2.2.2 Modulation of the incidence risk related to herd management

The risk of basic mastitis cases may also be modulated by certain circumstances or management practices, particularly those implemented in the context of herd prevention. The seasonal risk and the risk of contagion of the batch are simulated precisely in the following paragraphs. For other effects, an overall prevention factor for the population is used, which can be parameterised according to the methods defined in paragraph *2.2.3.1.2.6 Prevention factor for mastitis at* herd level.

2.2.3.1.1.2.2.2.1 Seasonal risk (housing effect)

Depending on the season, mastitis incidence increases (or even decreases). The simulator reproduces this effect by taking into account a factor that modulates the probability of mastitis occurrence depending on the simulation month and the bacterium studied. This configurable factor is described in paragraph *2.2.3.1.2.2 Seasonal impact on IMI incidence*.

2.2.3.1.1.2.2.2.2 Batch contagion

Mastitis presence in a batch can have a contagion effect to the whole batch. Therefore, the simulator makes it possible to define, by bacterium, the relation between the number of cases encountered over the last seven days, at the scale of a quarter, and the incidence of the simulated day, by taking into account a factor f used as follows:

f = 1 + *<contagion effect>* * *<prevalence of the previous week>*

The effect per bacterium is defined as such (Billon, 2015):

Bacterium	Contagion effect
StaphA	0.15
StreptU	0.08
G-	0.05
CNS	0.10
CB	0.15

Table 49: IMI contagion effect in the batch

2.2.3.1.1.3 IMI detection

The clinical IMI of G2 severity to G3 is systematically detected, however it is not necessarily the case of G1 severity IMI. The sensibility of mastitis detection for those levels can be modified, it is described in paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis.*

2.2.3.1.1.4 Evolution and cure

The evolution dynamics of a quarter's infection by a bacterium type is defined according to the following model:

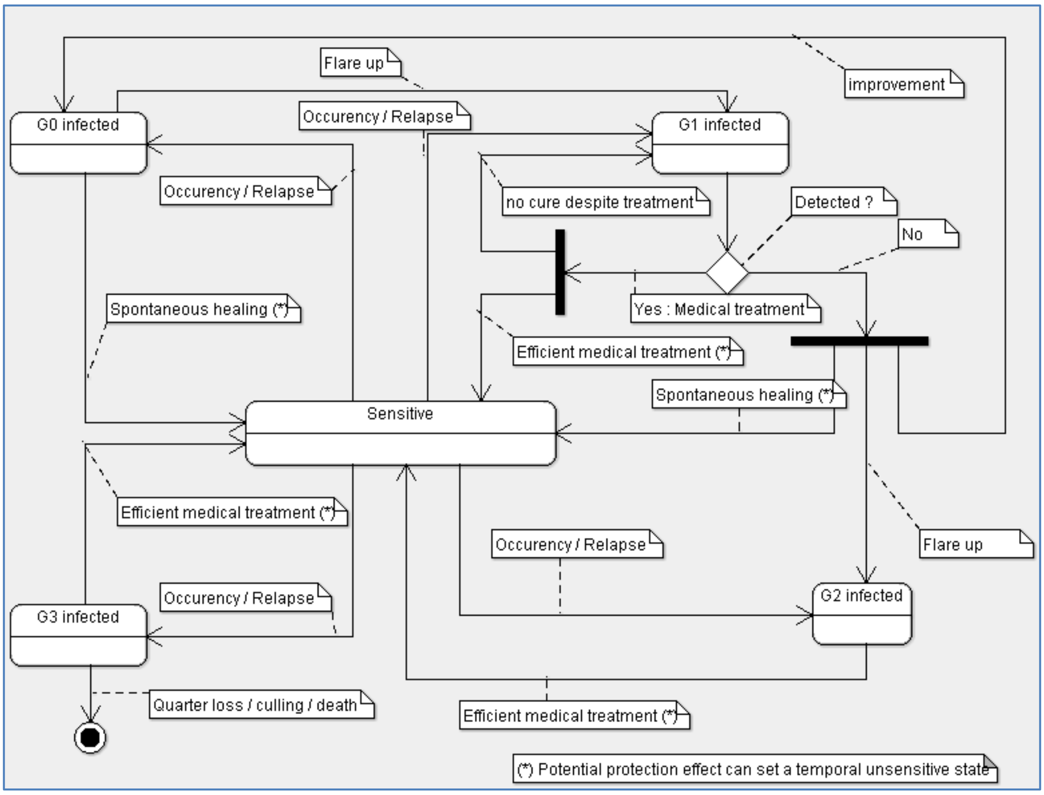


Figure 17: IMI evolution dynamics

2.2.3.1.1.4.1 *Spontaneous healing*

While healing usually requires treatment, it can be spontaneous (Billon, 2015).

2.2.3.1.1.4.1.1 Basic spontaneous healing

Subclinical G0 IMIs, if they do not turn into clinical mastitis (see paragraph *2.2.3.1.1.4.2.1 Clinical recurrence of persistent subclinical infection*), can heal spontaneously after 50 days, and if not, their duration is extended to 200 days. A G1 severity IMI, if it has not been detected, will not benefit from the appropriate medical treatments, it can nevertheless heal spontaneously or regress to G0. The conditions for spontaneous recovery from undetected G0 and G1 severity mastitis are as follows:

IMI type	During lactation (from peri-partum until drying-off)	At drying-off	Dry period
StaphA	0.2	0.35	0.2
StreptU	0.3	0.45	0.3
G-	0.9	0.9	0.9
CNS	0.2	0.7	0.65
CB	0.2	0.6	0.5

Table 50: Baseline rate of spontaneous cure of a G1 seriousness IMI not detected according to the pathogen

2.2.3.1.1.4.1.2 Cure induced by the cure of a new infection in the quarter

Mastitis cure (caused by a bacterium) that occurs after a mastitis already on the quarter (so due to another bacterium) can trigger the cure of the latter. The survival probability of pre-existing mastitis in this case is determined under the following conditions (ECOMAST):

Current healed IMI	Pre-existing IMI in the quarter				
	StaphA	StreptU	G-	CNS	CB
StaphA		1.0	0.5	0.5	0.5
StreptU	1.0		0.5	0.1	0.3
G-	1.0	1.0		0.1	0.3
CNS	1.0	1.0	0.5		0.7
CB	1.0	1.0	0.5	0.7	

Table 51: Probability of pre-existing mastitis during the cure of a previous mastitis

For G3 severity mastitis, they will heal according to this modality only if it was expected that they heal. This excludes those for which a quarter loss, a culling or a mortality was foreseen (see paragraph *2.2.3.1.1.1.3.2 Important decrease in milk production* and paragraph *2.2.3.1.1.1.3.5 Mortality and culling risk related to G3 severity*).

2.2.3.1.1.4.2 *Mastitis worsening*

Under certain conditions, mastitis may worsen. This may be the case of a persistent subclinical mastitis or an undetected G1 severity mastitis.

2.2.3.1.1.4.2.1 Clinical recurrence of persistent subclinical infection

Persistent subclinical infections are at risk of clinical recurrence, the probability of which is defined as follows (ECOMAST):

IMI type	Probability (%)
StaphA	30
StreptU	60
G-	90
CNS	10
CB	0

Table 52: Clinical recurrence of persistent subclinical infection depending on bacterium type

Thus, at the end of the period initially defined for each G0 severity mastitis, a random draw is carried out, making it possible to determine whether the mastitis has worsened (thus becoming G1 severity) or if it has been the subject of spontaneous cure.

2.2.3.1.1.4.2.2 Worsening of undetected clinical mastitis

When a G1 severity mastitis is undetected (see paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis*), it evolves in 10% of the cases and after 2 days in a G2 severity, and if it does not heal spontaneously (see paragraph *2.2.3.1.1.4.1.1 Basic spontaneous*), it evolves to G0 severity mastitis after 5 days.

2.2.3.1.1.4.3 *Healing following treatments*

When an IMI is detected, it is systematically and immediately subjected to a medical treatment provided by the farmer or a veterinary. The effectiveness of this treatment will be different according to the mastitis treatment plan that will be implemented and the individual's character. This treatment is carried out over a given period of time and its effects may require a certain delay. This may lead to not marketing the milk of the infected udder, during treatment but also beyond. Other mastitis (including subclinical) present in the quarter also benefit from the treatment caused by the detection of clinical mastitis, under the same conditions as those set in the treatment plan.

Under certain conditions, this treatment may have a protective effect against the occurrence of new mastitis, regardless of the bacterium. This eventual effect is applied as soon as the treatment is taken.

The criteria for defining treatments are configurable according to the procedures described in paragraph *2.2.3.1.2.4 Treatment plans*.

2.2.3.1.1.4.4 *Relapses*

The probability of a clinical relapse of persistent (unhealed) mastitis is defined, depending on the pathogen, as follows (Robert-Briand, 2006):

Pathogen	Relapse probability (%)
StaphA	50
StreptU	50
G-	10
CNS	10
CB	10

Table 53: Pathogen-related relapse probability

This probability corresponds to the potential risk of clinical relapse in the 245 days following the start of an untreated IMI (G0 and G1 severity not detected) but healed spontaneously. It is simulated according to a beta law shifted to the left ($\alpha = 2$, $\beta = 4$) so that the probability of relapse is maximal within 60 days post IMI. This relapse is effective only if the affected area is susceptible to this mastitis at the scheduled time.

2.2.3.1.2 Parameters for IMI management

Various parameters enable the user to change breeding's sanitary conditions, according to the simulation's needs.

2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis

The experimenter has the possibility of setting the probability of detection by the farmer of G1 clinical mastitis. The default value is 50%.

On the other hand, if the veterinary care contract is taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), G1 mastitis detection sensitivity can be increased to 100% from 6 months after its implementation, whatever the value of the G1 mastitis detection sensitivity parameter defined at the start of the simulation (Beaugrand, personal data).

2.2.3.1.2.2 Seasonal impact on IMI incidence

The experimenter can define the seasonal impact on IMI incidence. It assigns a factor that decrease or increase the basic value (neutral value equal to 1) for each bacterium and each month of the year.

In order to highlight the increase in IMI incidence in summer and winter for certain bacterium, the default values proposed by the simulator were defined as follows (ECOMAST):

IMI type	Worsening factor		
	Summer (from july to august)	Winter (indoor period, from december to february)	Rest of the year
StaphA	1	1	1
StreptU	1.2	1.2	1
G-	1.5	1.5	1
CNS	1	1	1
CB	1	1	1

Table 54: Defaults values for IMI incident change factors by seasons

2.2.3.1.2.3 Share of bacterial type in incidence

The experimenter can adjust the importance of the type of bacteria in the incidence. The standardised default values are as follows (ECOMAST):

IMI type	Incidence part
StaphA	0.283
StreptU	0.351
G-	0.027
CNS	0.226
CB	0.113

Table 55: Share of bacterial types in mastitis incidence

2.2.3.1.2.4 Treatment plans

During the lactation, when a mastitis is detected by the farmer (clinical mastitis), it is treated with a treatment set up for that period. The curative treatment of mastitis causes unplanned activity on the part of the farmer, which is reinforced by the unplanned arrival of the vet in the case of G3 severity for a cow care (see *Table 87: Structure of data on technical production results*). When the cow is dry, if she is pregnant and if her cell count measured at the last milk control exceeds 200,000 c/ml, she will undergo a systematic preventive treatment set for this period, farmer's scheduled activity (see *Table 87: Structure of data on technical production results*). The default values are as follows (Billon, 2015):

	Lactation period (peri-partum until drying-off)			**Drying-off and dry period**		
Name	Default Mastitis wide range treatment			Default Mastitis AB BP treatment		
Delay before effect (d)	2			1		
Waiting time milk (d)	4			14		
Bacterium	**Cure probability**	**Relative risk of protective effect**	**Protection duration (d)**	**Cure probability**	**Relative risk of protective effect**	**Protection duration (d)**
StaphA	0.45	0.00	0	0.65	0.589	72
StreptU	0.70	0.00	0	0.92	0.586	72
G-	0.95	0.00	0	1.00	0.895	72
CNS	0.85	0.00	0	0.95	0.943	72
CB	0.90	0.00	0	1.00	0.781	72

Table 56: Default values of mastitis treatment plan according to the period and the bacterium

The veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) can improve the success rate of mastitis treatments by 5% during the lactation period.

Treatment costs are set in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.1.2.5 Prevention factor for mastitis at the individual level

A multiplicative value makes it possible to improve the prevention of mastitis (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it makes it possible to include the individual effect of farm management factors which have an influence on the incidence but are not explicitly represented (see paragraph *2.2.3.1.1.2.2.1 Individual modulation of incidence risk*). By default, the value is 1.0.

Note: Where a veterinary care contract is in place, a flat-rate annual cost for mastitis prevention on one cow is added at the end of the financial year based on the average number of adult cows present (see *Table 110: Default rates for health-related accounting transactions* and *Table 115: Structure of the economic balance sheet data expressed in euros*).

2.2.3.1.2.6 Prevention factor for mastitis at herd level

A multiplicative value makes it possible to improve the prevention of mastitis (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it makes it possible to include the herd effect of husbandry factors which have an influence on the incidence but are not explicitly represented (see paragraph *2.2.3.1.1.2.2.2 Modulation of the incidence risk related to herd management*). By default, the value is 1.0.

The effects of this parameter can be modulated according to the terms of the veterinary care contract. Indeed, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), the veterinary care contract makes it possible to improve herd mastitis prevention over time. This level of prevention is then modulated to improve by 25% after 24 months, and by a further 25% after 42 months. This modulation achieves the following progression in terms of clinical incidence (Beaugrand, personal data):

Number of effective months of veterinary care contract	Clinical incidence obtained depending on the prevention parameters value (see paragraphs *2.2.3.1.2.5* and *2.2.3.1.2.6*)		
	0.4	**1.0**	**1.7**
0	76.5%	35%	22.7%
24	61%	26.4%	13.6%
42	46%	21%	11.3%

Table 57: Clinical incidence of mastitis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract

For intermediate values of parameterised prevention, progress is weighted. For marginal values, the closest modelled level of progress is used.

2.2.3.1.2.7 Veterinary care contract option

A parameter allows to simulate a veterinary care contract whose effects are felt on mastitis (and also on the other diseases modelled), in terms of prevention, detection, intervention time and cure. This contract also entails preventive visits scheduled twice a month in the first year of the contract, then once a month in subsequent years (this visit also involves a planned activity for the farmer). The number of visits carried out is shown in the results produced (see § *2.2.3.4 General health produced data*).

In addition, the veterinary care contract also helps to reduce mortality from diseases that are not modelled (see paragraph *2.2.5.1.1.3 Mortality*).

Three modalities are available:

- based on the average number of cows present during the previous campaign,

- according to the average number of calving in the previous campaign,

- according to the quantity of milk delivered during the previous campaign (per 1000 liters).

Technically, the implementation of the veterinary care contract begins when the simulation produces results (i.e. after the simulator warm-up period), and is not retained by default.

2.2.3.1.3 IMI produced data

IMI produced data are the estimation of teat health.

Production type: annual.

Information level: Herd.

Result file name: « AnnualMastitisResults.csv »

This data makes it possible to know the mammary health of the herd, on the basis of the observation of clinical mastitis detected and the average of the present cows.

The available fields are:

Field name	Format	Value
Herd_cow_average	integer	Average of the number of cows in the herd (*)
Clinical_mastitis_per_100_cows	integer	Number of clinical cases occurring for 100 cows present (**)
First_clinical_mastitis_per_100_cows	integer	Number of first clinical cases for a cow lactation occurring for 100 present cows
Herd_SCC	integer	SCC average (1000 cells / ml) (***)
Under_300_SCC_per_100_controls	integer	Percentage of SCC controls not exceeding 300 000 cells / ml (****)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 58: Structure of annual outcome data for clinical mastitis

(*) Average of the number of cows present at the monthly dairy checks.

(**) Severity G1 (theoretically clinical) mastitis that has not been detected is not counted here.

(***) Average SCC measured during monthly dairy checks.

(****) Records at monthly dairy checks.

2.2.3.2 Ketosis (or acetonaemia)

Ketosis is a metabolic disease that reflects an energy deficiency. It is accompanied by acetonaemia, which is the increase in the blood concentration of ketone bodies (Vincent, 2019). Cases of ketosis affect different aspects of the cow's life and production. These effects can go as far as culling or even the death of the animal. Different options allow for increased detection, which offers the opportunity to improve health awareness.

2.2.3.2.1 Biological and technical constant values for ketosis

The purpose of this chapter is to describe ketosis, its incidence, the detection of cases and their evolution.

2.2.3.2.1.1 Description of ketosis

The occurrence of ketosis in cows results in the appearance of specific physiological phenomena that can be observed under certain conditions. It is also the cause of zootechnical consequences.

2.2.3.2.1.1.1 Ketosis severity levels

In addition to the external manifestation of its effects in its clinical form, ketosis, from its subclinical form, causes in cows an increase in the level of Beta-HydroxyButyrate (BHB) and acetone in their milk, which can be interpreted by expert systems as soon as they are implemented.

The blood BHB threshold generally used to detect a dairy cow suffering from subclinical ketosis corresponds to a concentration higher than 1.2 mmol/L (Benedet *et al.*, 2019).

There are three levels of severity with regard to the disease:

Severity	Definition
G0	Healthy subclinical ketosis status
G1	Cow with subclinical ketosis
G2	Cow with clinical ketosis

Table 59: Ketosis Severity Levels

2.2.3.2.1.1.2 Zootechnical consequences of ketosis

Cases of ketosis affect reproduction, production and susceptibility to other diseases, and then on culling decisions and mortality. The accounting effect of the change in feeding behaviour induced by the occurrence of ketosis is not significant and is therefore not simulated.

2.2.3.2.1.1.2.1 Effect of ketosis on reproductive performance

The occurrence of ketosis disrupts the reproductive cycle, affecting the resumption of ovarian activity, the sensitivity of heat detection and fertility and ultimately fertility. As information, robust data from the literature gives us the following impacts on fertility:

Effect	Severity	Impact	Reference
Lengthening of the IA 1 – IA f interval (days)	Untreated G1	+ 11	Adapted regarding (Fourichon, Seegers et Malher, 2000) and (Raboisson *et al.*, 2015)
	Treated G2	+ 5,5	
Lengthening of the calving-calving interval (days)	Untreated G1	+ 21	(Raboisson *et al.*, 2015)
	Treated G2	+ 8	Adapted regarding (Fourichon, Seegers et Malher, 2000)

Table 60: Impacts of ketosis on fertility

Only the impacts on the resumption of ovarian activity, on the sensitivity of heat detection and on fertility are represented and simulated.

2.2.3.2.1.1.2.1.1 *Effect of ketosis on estrus detection sensitivity*

The impact of ketosis on the detection of heat is linked to a lower expression of the behaviour associated with estrus by the cow (Rutherford, Oikonomou et Smith, 2016). It is neglected in the model because it is estimated to be insignificant on the overall effect of ketosis on reproduction.

2.2.3.2.1.1.2.1.2 *Effect of ketosis on fertility*

Fertility is disturbed when the cow has undergone ketosis (see paragraph *2.2.1.1.4.4.3 Ketosis effect on fertility*). The relative risk of insemination failure is 1.66 when the cow has had subclinical ketosis (Raboisson, Mounié et Maigné, 2014) during lactation. However, if the cow has had less than 30 days of ketosis in early lactation and a subclinical ketosis treatment has been given and has been effective, the relative risk of failure is reduced to 1.3.

In order to remain within the general scope of the *Table 9*: *Basic fertility rate (not taking into account the adverse effects of certain factors) according to fertilization modes* of the paragraph *2.2.1.1.4.2 Fertility – basic values*, a risk weighting is carried out for cows affected by a case of ketosis during insemination as well as for cows that are not.

As a result, ketosis during lactation will mechanically result in a longer calving - fertilizing insemination interval (IVIAF).

2.2.3.2.1.1.2.1.3 *Effect of ketosis on the recovery of ovarian activity*

The resumption of ovarian activity may be altered if the cow suffers from postpartum ketosis (see paragraph *2.2.1.1.7.2 Calving case*). First oestrus is delayed by 9 days when the cow has had at least one episode of subclinical ketosis since calving (Rutherford, Oikonomou et Smith, 2016). It is recognised that this also applies to cases of clinical ketosis. In simulation, this translates for the first postpartum oestrus into a weighted distribution of extra days due to ketosis cases and fewer days due to the absence of ketosis to obtain proportionally and globally the following results in the *Table 15*: *Post-partum cyclicity resumption by breed and parity* in the paragraph *2.2.1.1.7.2 Calving case*.

Furthermore, in case of ketosis during the last lactation, it can be considered that there are interruptions of cyclicity after the 1st cycle, the associated risk is 0.67 (Shin *et al.*, 2015). To take this into account in the simulator, the risk of cycle interruption between the post-partum ovulation of the standard cycle and the next ovulation is increased when the cow is affected by ketosis since calving. Conversely, a proportionate decrease in this risk is calculated when the cow has not experienced ketosis. Consequently, ketosis during lactation may result in a longer calving to first insemination interval (IVIA1).

2.2.3.2.1.1.2.2 Impact of ketosis on milk production performance

Ketosis has an effect on milk production (see paragraph *2.2.2.1.2.10 Ketosis effect on dairy production*) that depends on the cow's production level and the ketosis severity. The effects are simulated as follows:

Severity	Impacted feature	Effect on milk production		Reference
		Difference	Impact duration	
G1	Quantity	1.12%	55 days	Adapted regarding (Raboisson, Mounié et Maigné, 2014) and (Bareille *et al.*, 2003)
	TB	+1‰	during disease	(Vanholder *et al.*, 2015)
	TP	-1‰		
G2	Quantity	2.01%	55 days	Adapted regarding (Raboisson, Mounié et Maigné, 2014) and (Bareille *et al.*, 2003)
	TB	+3.1‰	during disease	(Vanholder *et al.*, 2015)
	TP	-2.2‰		

Table 61: Effect on milk production as a function of ketosis severity level compared to healthy cows (G0)

(*) the effect on production continues, even if the ketosis has been cured.

As far as the distribution of the daily loss of milk quantity is concerned, it follows a sinusoidal curve (angle $\pi/2$). The following example graph shows the daily loss at D0 of G1 and G2 ketosis for a cow producing 10000 kg of milk per lactation on 305 days:

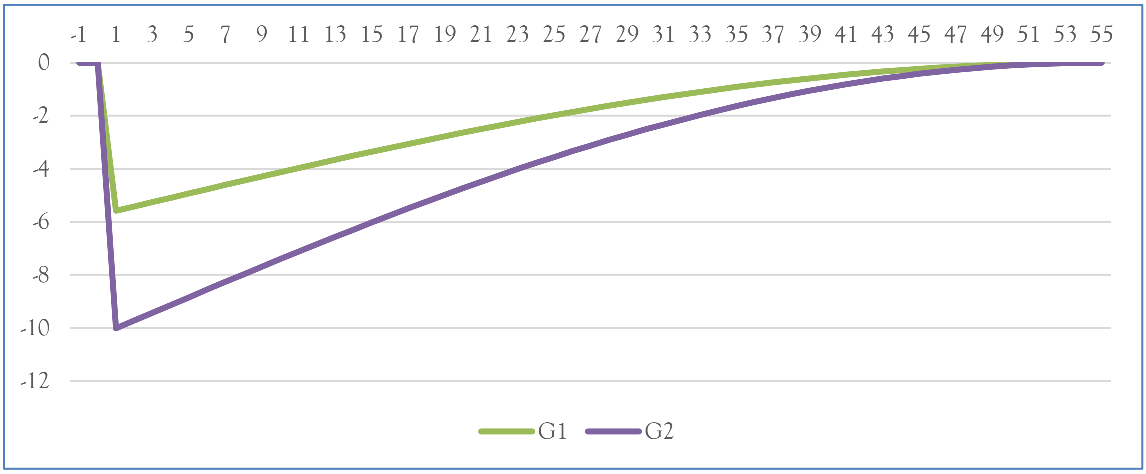


Figure 18: Distribution of the loss of milk quantity (Kg) over 55 days for a cow producing 10000 kg of milk during a lactation period of 305 days

2.2.3.2.1.1.2.3 Feeding impact

Because of the reduction in the amount of milk produced in ketosis, feed consumption is reduced as follows: a reduction of 2 kg of milk results in a reduction of 1 kg of feed consumption (divided proportionally between forage and concentrate).

2.2.3.2.1.1.2.4 Effect of ketosis on susceptibility to other diseases

Ketosis has an effect on susceptibility to other diseases. The diseases considered in DHM are mastitis (see paragraph *2.2.3.1.1.2.2.1.7 Modulation of mastitis incidence due to competition from other disease episodes*) and lameness (see paragraph *2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases*). As the movements of the abomasum are not simulated, their ketosis effect is not taken into account.Ketosis culling and mortality

When a cow develops ketosis, she is at direct and indirect risk of mortality and culling.

For the risk of culling, the causes directly related to ketosis are negligible compared to the frequency of indirect causes for poor reproductive performance or for lameness. As the simulator already takes into account culling related to these health disorders, only the risk of lethality is represented here:

		Lactation rank				**Reference**
		1	**2**	**3**	**≥4**	
Lethality percent	**G1**	0%	0,63%			Used regarding (McArt, Nydam et Overton, 2015) and (McArt, Nydam et Oetzel, 2012b) ; (Roberts *et al.*, 2012)
	G2	0%	0,7%	1,7%	2,5%	Used by (Mostert *et al.*, 2017) ; Used regarding (Bar *et al.*, 2008)

Table 62: Percentage lethality for an episode of ketosis based on severity and lactation rank of the affected cow

This risk is taken into account through a weighting of the basic risk identified in the *Table 97: Mortality risk among the herd* of the paragraph *2.2.5.1.1.3 Mortality.*

2.2.3.2.1.2 Incidence

There are two dimensions to the incidence: the basic incidence based on a standard management and feeding causing only spontaneous cases, and modulation to incorporate additional elements and management conditions that may encourage the occurrence of additional cases (or possibly reduce the basic incidence).

2.2.3.2.1.2.1 Basic incidence

The basic incidence is to be determined for standard feeding and nominal prevention methods. It therefore only reflects the spontaneous occurrence of the disease in the herd. Given the lack of epidemiological evidence for clinical ketosis in the literature, it will be described as an aggravation of subclinical ketosis (see paragraph *2.2.3.2.1.4 Evolution and healing of ketosis*). Thus, only the basic incidence of subclinical ketosis is described here.

Ketosis is mainly observed during the first two months of lactation (Duffield, 2000).

Most studies describe the prevalence of subclinical ketosis during the first two weeks of lactation or during the first month of lactation. A prevalence of around 20% during the first two weeks of lactation has been described in a large number of herds in North America (Duffield *et al.*, 2009), as well as in Europe (Suthar *et al.*, 2013). The same 20% prevalence level has been described, this time during the first month of lactation, in Canada (Santschi *et al.*, 2016), (Tatone *et al.*, 2017). From the second month of lactation onwards, the prevalence of ketosis drops below 10% according to (van der Drift *et al.*, 2012).

Prevalence takes into account both the duration of ketosis evolution and ketosis recurrence for the same lactation. However, no study clearly estimates the recurrence rate of ketosis.

Incidence, defined as the percentage of lactations affected for the first time in a given time interval, is poorly described in the literature because it requires repeated measurements over time on the same sample of cows. The study of (McArt, Nydam et Oetzel, 2012b) shows a lactational incidence of 43.2% between 3 and 16 days postpartum in 4 large American herds. (Kaufman *et al.*, 2016) finds a similar incidence (44%) in 4 Canadian herds.

Thus, for a lactation, the baseline incidence of subclinical ketosis by breed is as follows:

	Baseline incidence
Montbeliarde	35%
Normande	25%
Prim'Holstein	45%

Table 63: Baseline incidence of subclinical ketosis by breed

The incidence curve of subclinical ketosis as a function of the stage of lactation implemented by the simulator is as follows:

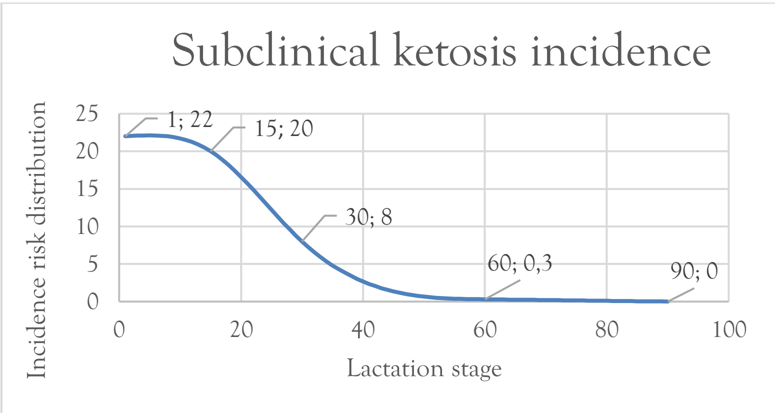


Figure 19: Incidence curve of subclinical ketosis as depending on lactation stage

2.2.3.2.1.2.2 *Incidence risk modulation*

The risk of ketosis incidence can be modulated according to individual situations and farming conditions.

2.2.3.2.1.2.2.1 Modulation of the ketosis incidence depending on genetics

Several authors describe the BHB level in milk or blood as heritable traits.

The genetic parameters of the 'BHBlait' trait are therefore taken into account in the simulator to represent the modulation of the incidence of G1 ketosis.

The 'BHBlait' index approximates the genetic risk of subclinical ketosis for a cow going through the risk period of the defined disease.

This trait is quantitative but for modelling purposes will be implemented as a qualitative risk trait for G1 in chapter *2.2.4 Genetics*.

2.2.3.2.1.2.2.2 Modulation of the ketosis incidence depending on lactation rank

A cow's lactation rank determines her likelihood of developing ketosis within two months of calving. The relative risk presented here takes into account both the effect of age itself and the effect of a cow producing more milk as her lactation rank increases and therefore being more at risk for ketosis.

	Lactation rank			Reference
	1	2	≥3	
Relative risk	0,8	1	1,6	Adapted regarding (Tatone *et al.*, 2017), (Santschi *et al.*, 2016)

Table 64: Relative risk of ketosis according to lactation rank

2.2.3.2.1.2.2.3 Modulation of the ketosis incidence depending on production level

The level of the cow's milk production influences its risk of developing ketosis: the higher the cow's milk production, the more sensitive it is. However, as a cow's milk production potential is linked to its genetics and parity, this effect is not represented here in order to avoid double counting.

2.2.3.2.1.2.2.4 Modulation of the ketosis incidence depending on season

Several studies note an influence of the season on the incidence of ketosis (Berge et Vertenten, 2014), (Tatone *et al.*, 2017), (Vanholder *et al.*, 2015) and (Santschi *et al.*, 2016), but they do not have significant data for all periods of the year. There would seem to be more ketosis in spring than in summer and autumn, with no consensus on what happens in winter. The biological explanations put forward by the authors are hypothetical, but a priori they reside in the management and feeding of the herd. (Vanholder *et al.*, 2015) believes that silages consumed at the end of winter are the oldest and therefore at risk for the development of butyric acid, which would favour ketosis.

Given these uncertainties, the effect of the season on the incidence of ketosis is not taken into account.

2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes

The risk of subclinical ketosis may be increased if the cow has or has had episodes of disease. Currently only mastitis is taken into account in the simulator, as follows:

	Risk	Temporality	Reference
Clinical mastitis in progress	1,9 (OR)	Met since the beginning of the current lactation	(Gröhn *et al.*, 1989)
Lameness	1,7 (RR)	Concomitant with the disease	(Peeler, Otte et Esslemont, 1994)

Table 65: Modulation of the incidence of ketosis related to competition from other disease episodes

The effect of the history of ketosis is taken into account in determining the probability of aggravation described in paragraph *2.2.3.2.1.4.2 Aggravation of an episode of subclinical ketosis*.

2.2.3.2.1.2.2.6 Modulation of the incidence of ketosis, in multiparous women, linked to the duration of the previous lactation

Cows with a moderate to high fattening status before calving are more likely to develop ketosis in early lactation, due to rapid and massive mobilization of accumulated fat. This is why cows in the herd with a delayed start to reproduction, whose lactation or dry-off has been prolonged are indirectly at risk because they have benefited from a positive energy balance for a longer period of time, which has allowed them to significantly increase their fattening status.

The risks associated with the duration of the calving interval, adapted from (Tatone *et al.*, 2017), are as follows:

Calving to calving interval	12-13 months	14-15 months	>15 months
Risk of ketosis at the beginning of the next lactation (OR)	0,86	1	1,4

Table 66: Risk of ketosis depending on the calving to calving interval

2.2.3.2.1.2.2.7 Modulation of the incidence of ketosis, in primiparous females, related to age at first calving

Similarly, heifers with moderate to high fatness prior to calving are more likely to develop ketosis in early first lactation. This is why heifers in the herd with a later age at first calving present an additional risk of ketosis according to (Tatone *et al.*, 2017) (OR = 1.41 for a calving between 25 and 33 months, compared to a calving before 25 months in Prim'Holsteins). However, this observation depends on the growth objective of the pre-herd depending on the breed and the breeding system under consideration. Thus, this risk could be significant for heifers with a strong delay in insemination, which can occur during group calving rearing. This risk is not currently implemented in the simulator, but will be sized and modelled on the basis of the analysis of the initial results obtained by comparing the different types of management.

2.2.3.2.1.2.2.8 Modulation of the incidence of ketosis by the use of intra-ruminally administered monensin boluses (Kexxtone®)

According to the meta-analysis by (Duffield, Rabiee et Lean, 2008), the preventive use of monensin boluses during dry-off is associated with a 0.75 reduction in the risk of clinical ketosis in the next lactation. If this option is chosen, the bolus is taken 30 days before the next calving date and its effect lasts for the next 95 days. The choice of using this preventive treatment is the subject of the parameter defined in paragraph *2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®).*

2.2.3.2.1.3 Ketosis detection

In its clinical form, ketosis causes phenomena that can be systematically observed externally (e.g. weight loss, decreased production level, feeding behaviour, constipation, characteristic breath, nervous disorders, etc.). The detection of a ketosis in its subclinical form would require the implementation of specific means.

2.2.3.2.1.3.1 Subclinical ketosis

Two methods can be used to estimate the level of ketosis risk that will lead the farmer to take sanitary action related to the detection of subclinical ketosis: methods Cetodetect ® and Herd Navigator ®. The use of these detection tools can be parameterized according to the methods defined in the paragraph *2.2.3.2.2.2 Detection options*.

When a sub-clinical ketosis has been detected, the cow is given the appropriate treatment for ketosis of severity G1 (see paragraph *2.2.3.2.2.3 Treatment plan*), even in the case of a false positive. It would then have no curative effect but could nevertheless be protective if necessary.

2.2.3.2.1.3.1.1 Cetodetect ®

Optional method to quantify the risk of ketosis monthly during milk control by an assay of BHB and acetone in milk in combination with other zootechnical data in a way that is not known (Vincent, 2019). If cases of clinical ketosis are systematically detected by the breeder, the use of the Cetodetect ® option is interesting for the detection of sub-clinical cases. Thus, if this system is implemented (resulting in costs, see paragraph *2.2.7.1.7 Other accounting items*), a case of subclinical ketosis (G1) can be detected on a spot sample analysed during the monthly milk control, under the following conditions (Vincent, 2019):

Sensibility	91%
Specificity	88%

Table 67: Sensitivity and specificity of the Cetodetect ®test

The error of specificity can only occur during the period at risk of ketosis.

2.2.3.2.1.3.1.2 Herd Navigator ®

This optional tool allows the precise analysis of each cow's milk, every 3 days of milking, and to design an action plan based on the results obtained. The detection of ketosis cases requires the BHB to be measured in combination with other zootechnical data in a way that is not known. The tool does not assign a score; it alerts the breeder when the significant level of risk is reached. It is therefore accepted that with this tool, a cow suffering from ketosis will necessarily have a BHB dosage in her milk. Sensitivity and specificity data have not been communicated by the company, however those of a biochemical analysis with optical reading are respectively 86% and 82% (Vincent, 2019). It can be assumed that the Herd Navigator® algorithm optimises the sensitivity and specificity results in order to reach at least those of the Cetodetect® tool, which is what is implemented by the simulator.

The cost of the initial investment in this tool is not taken into account in the simulation accounting data. As for the operating cost (defined in paragraph *2.2.7.1.7 Other accounting items*), it includes the dosage of progesterone and LDH in milk.

2.2.3.2.1.3.1.3 Blood test

This method is only used if a breeding contract has been signed with a veterinarian (see paragraph *2.2.3 Health*) and is not invoiced. It consists of taking a blood sample on the 15th of the month for any cow that calved the previous month. Thus, a case of subclinical ketosis (G1) may be detected under the following conditions (Macmillan *et al.*, 2017):

Sensibilité	98%
Spécificité	95%

Table 68: Sensitivity and specificity of the blood test for ketosis

2.2.3.2.1.3.2 Clinical ketosis (detected)

Cases of clinical ketosis are those detected (by the farmer himself or by the detection options chosen, with a negligible effect on the sensitivity of detection and confirmation by the veterinarian), on the basis of the signs noticed on a daily basis during his driving actions without the use of detection means other than his own perception. These cases systematically lead to taking the appropriate treatment for ketosis of G2 severity, the plan of which is defined in paragraph *2.2.3.2.2.3 Treatment plan*.

2.2.3.2.1.4 Evolution and healing of ketosis

The dynamics of disease progression are defined according to the following model:

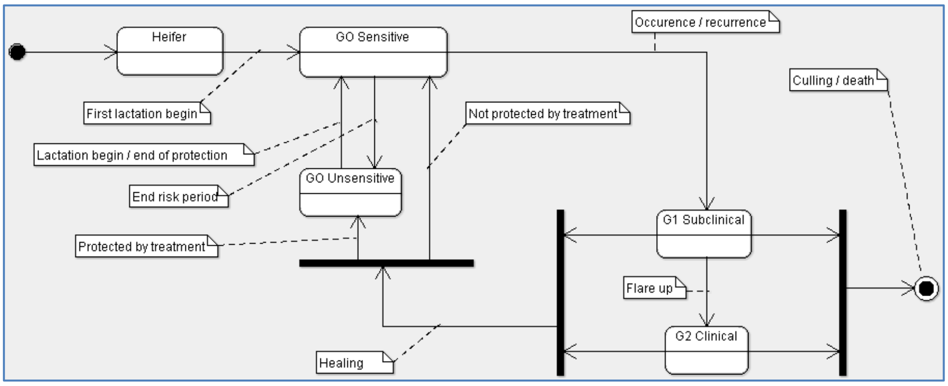


Figure 20: Dynamics of ketosis evolution

The principle implemented by the simulator is to trigger, when the conditions are met (age of the animal, risk periods, etc.) and stochastically from the incidence described in paragraph *2.2.3.2.1.2 Incidence*, a case of sub-clinical ketosis which, depending on the elements involved, will heal spontaneously or with the taking of one or more treatments, will worsen (thus becoming a case of clinical ketosis), or will lead to culling or even death.

2.2.3.2.1.4.1 Duration of ketosis

According to the 16-day observations of (McArt, Nydam et Oetzel, 2012a), subclinical ketosis develops over a period of 2 to 14 days, with a median of 4 to 5 days. Approximately 85% of cases are resolved after 14 days. The duration of a subclinical ketosis implemented by the simulator therefore varies over time according to a triangular law between 2 and 20 days with a peak at 5 days.

For clinical ketosis cases, it is agreed that the duration of an episode (G2) is to 5 days.

2.2.3.2.1.4.2 *Aggravation of an episode of subclinical ketosis*

The risk of worsening from G1 subclinical ketosis to G2 clinical ketosis is 5% for a primiparous cow and 7% for a multiparous cow (McArt, Nydam et Overton, 2015). This risk is multiplied by 3 when the cow has experienced at least one episode of ketosis during the previous lactation (Østergaard, Sørensen et Houe, 2003). Aggravation occurs at the end of the initially planned subclinical duration of the episode (see paragraph above).

2.2.3.2.1.4.3 *Detection of a case of clinical ketosis, treatment*

While cases of clinical ketosis are systematically detected by the farmer, cases of sub-clinical ketosis can only be detected by the implementation of specific means (see paragraph *2.2.3.2.1.3 Ketosis detection*). They shall then give rise to one or more treatments under the conditions set out in paragraph *2.2.3.2.2.3 Treatment plan*. In the case of subclinical ketosis, if the treatment given was not effective, it will have the advantage of reducing the original duration by one day. In the case of clinical ketosis, if the first treatment was not effective, the cow is given a second treatment with a 100% success rate.

2.2.3.2.1.4.4 *Recurrence of ketosis*

Two days after the end of an episode, the cow is again susceptible to ketosis if she is still in the risk period, whether she has been treated or not. According to data from (Bareille *et al.*, 2003), about 40% of affected cows show a recurrence (modalities: N = 1050 VL in experimental farm, definition of ketosis as "cow with a decrease in milk production and intake between 1 week and 1 month of lactation, having a favourable response to propylene glycol administration"). In simulation, cases of recurrence are triggered by taking into account this probability, weighted by the genetic value of the cow's BHBlait index. They can be consecutive and are triggered on average 15 days after the first day of the sensitivity period following the case of subclinical ketosis (normal distribution with a standard deviation of 5).

2.2.3.2.2 Ketosis-related husbandry parameters

The simulator's parameterization makes it possible to define the overall prevention factor, the detection options and the treatment plan.

2.2.3.2.2.1 *Prevention factors*

Significant relationships are observed between the level of milk production of one farm compared to another farm, and the prevalence of ketosis within these farms (Tatone *et al.*, 2017). However, these links are trends related to indirect effects, because from one farm to another, the difference in production level is explained by a multitude of factors that directly influence the level of ketosis prevalence (reproductive efficiency, feeding of heifers, dry cows, early lactation cows, genetic level of the herd, etc.), some of which are already accounted for. This is why this modulation of incidence according to the production level of the herd is not developed in the simulator.

2.2.3.2.2.1.1 *Global prevention factor*

A multiplicative value improves ketosis prevention (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), it allows for the effect of husbandry factors that influence the incidence but are not explicitly represented (see paragraph *2.2.3.2.1.2.2 Incidence risk* modulation). This is the case, for example, for prevention related to dry period management, the feed system and lifestyle. The default value is 1.0.

The effects of this parameter can be modulated according to the terms of the veterinary care contract. If taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), the veterinary care contract makes it possible to improve the prevention of ketosis in the herd over time. This level of prevention is then modulated to improve by 25% after 24 months, and by a further 25% after 42 months. This modulation achieves the following progression in terms of clinical incidence (Beaugrand, personal data):

Number of effective months of veterinary care contract	Clinical incidence obtained depending on the prevention **parameter** (see paragraph *2.2.3.2.2.1.1 Global prevention factor*)		
	0.4	**1.0**	**1.7**
0	27.2%	14.1%	7.5%
24	22.8%	10.6%	5.2%
42	16.9%	7.6%	4.3%

Table 69: Clinical incidence of ketosis obtained with the veterinary care contract as a function of the prevention parameters set and the effective length of the contract

For intermediate values of parameterised prevention, progress is weighted. For marginal values, the closest modelled level of progress is used.

Note: Where a veterinary care contract is in place, a flat-rate annual cost for mastitis prevention on one cow is added at the end of the financial year based on the average number of adult cows present (see Table 110: Default rates for health-related accounting transactions and Table 115: Structure of the economic balance sheet data expressed in euros.

2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®)

The option of using monensin preventive treatment to reduce the incidence in the next lactation can be set (see paragraph *2.2.3.2.1.2.2.8 Modulation of the incidence of ketosis by the use of intra-ruminally administered monensin boluses*). This is an activity scheduled by the farmer (see *Table 87: Structure of data on technical production results*), it is not retained by default.

2.2.3.2.2.2 Detection options

Different detection options are offered to the experimenter.

2.2.3.2.2.2.1 Cetodetect ® option during milk control

The simulator systematically implements monthly milk control.

The paid option Cetodetect ® (see paragraph *2.2.7.1.7 Other accounting items*) is not retained by default. However, it is compulsory in the case of a veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*).

2.2.3.2.2.2.2 Herd Navigator ® option of the milking robot

This option incurs an employment cost (see paragraph *2.2.7.1.7 Other accounting items*), it is not retained by default.

2.2.3.2.2.3 Treatment plan

When a ketosis is detected by the breeder, the latter provides treatment. The recommended treatment for subclinical ketosis is based on oral administration of 300 grams of propylene glycol per day for 5 days (Gordon, LeBlanc et Duffield, 2013). This treatment reduces the duration of ketosis progression by one day, and has beneficial effects on the risk of worsening subclinical ketosis to clinical ketosis, as well as on fertility and milk production (McArt *et al.*, 2011), (McArt, Nydam et Oetzel, 2012a).

The treatment of G2 clinical ketosis is controversial depending on the suspected majority etiological origin:

Type 1 ketosis: Hyper-acetonaemia linked to the massive mobilisation of ketone bodies for use in the face of an energy deficit in high-producing dairy cows at the time of peak lactation, without associated hepatic steatosis. This form of ketosis generally appears between 3 and 6 weeks of lactation and is characterised by hypoglycaemia associated with hypoinsulinemia (Vanholder *et al.*, 2015), (Douart, 2015). The use of glucocorticoids is indicated here because it helps to boost the appetite and promote gluconeogenesis and therefore the use of proteins by the liver as an energy substrate (Douart, 2015).

Type 2 ketosis: Hyperacetonaemia exacerbated by a dysfunction of the hormonal adaptation of the metabolism due to a phenomenon of primitive hepatic steatosis. This ketosis is characterised by sub-normal blood glucose levels associated with hyperinsulinemia. Hepatic steatosis is favoured by poor feed management during the dry period and occurs in animals with a high fat content. This type of ketosis appears in early lactation (Douart, 2015), (Han van der Kolk *et al.*, 2017). The use of glucocorticoids is controversial here because glucocorticoids also have a lipolytic effect which theoretically risks accentuating the phenomenon of hepatic steatosis (Seifi *et al.*, 2007). However, the randomised therapeutic trial of (van der Drift *et al.*, 2015) did not demonstrate a lipolytic effect associated with the use of dexamethasone in the treatment of clinical ketosis.

We therefore consider that the treatment of clinical ketosis is unique, because the boundary between these two etiological tables is not always so distinct in practice (only liver biopsies would make it possible to sort type 1 ketosis from type 2 ketosis (Bobe, Young et Beitz, 2004)), because the epidemiological elements distinguishing the two ketoses in animal husbandry are not known to us, and because the difference in treatment between the two is controversial. Thus, the default treatment plan, which can be parameterised, is as follows:

Name	G1 Ketosis treatment	G2 Ketosis treatment
Type	Propylène glycol PO 300g SID 5days	500 mL glucose 30% IV lente Niacine (vitB3), carnitine, méthionine, vitB12, Cobalt
Delay before effect (d)	5	0
Milk waiting delay (d)	0	3
Healing probability	0,5	0,42
Flareup to G2 risk	0,54	
References	(McArt *et al.*, 2011) (McArt, Nydam et Oetzel, 2012a)	(Foster, 1988), (Douart, 2015), (van der Drift *et al.*, 2015)

Table 70: Default values for ketosis treatment plan

The curative treatment of ketosis requires unplanned activity on the part of the farmer, compounded by the unscheduled arrival of the vet to treat the cow in the event of G2 severity (see *Table 87: Structure of data on technical production results*). The veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), improves the success rate of treatments for G2 ketosis by 5%.

It should be noted that no protective effects are expected for ketosis treatments. The cost of processing is set up in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.2.3 Produced ketosis data

The data produced concern cases of ketosis (clinical and non-clinical) encountered in the herd.

Type of production: annual.

Information level: Herd.

Result file name: « AnnualKetosisResults.csv »

The available fields are as follows:

Field name	Format	Value
Herd_cow_average	integer	Average number of adult cows in the herd (*)
Clinical_ketosis_per_100_cows	integer	Number of clinical cases treated per 100 cows present
First_subclinical_ketosis_per_100_cows	integer	Number of first subclinical cases for a one-cow lactation occurring per 100 cows present
First_clinical_ketosis_per_100_cows	integer	Number of first clinical cases for a lactation of one cow occurring per 100 cows present
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 71: Data structure for annual results of subclinical and clinical ketosis

(*) Average of cows present at monthly milk recording.

2.2.3.3 Lameness

Lameness is a clinical sign of pain when the animal moves. Except for sporadic accidents, lameness in cattle is caused by foot lesions of various origins, both infectious and non-infectious. Foot conditions therefore have an effect on the development of lameness, which in turn has an impact on the productive life of the cow. Different husbandry parameters vary the risk of lameness developing and persisting.

2.2.3.3.1 Biological and technical constant values for lameness

The purpose of this chapter is to describe lameness, its incidence, the detection of cases and their evolution.

2.2.3.3.1.1 Description of lameness

The occurrence of lameness in cows can be due to different foot lesions and has zootechnical consequences. A cow can have lesions on all four feet, but it is more often the hind feet that are affected. There is little information on the relationship between lesions on each of the hind legs of the same cow, but often both feet are affected by the same or different lesions and at different levels of severity (Manske, Hultgren et Bergsten, 2002a). Therefore, we only represent an overall condition of the cow's feet.

Furthermore, we consider that it is the lameness that causes the technical and economic impacts and not the presence of a lesion. The latter can still affect a cow's lying behaviour when the cows are not lame (Berry *et al.*, 1998). Furthermore, only 21% of cows with a lesion show lameness (van Huyssteen *et al.*, 2020).

2.2.3.3.1.1.1 Lameness types

Several foot lesions are at risk of causing lameness. To simplify, they are represented by 2 types:

<u>Non-infectious lameness</u>: Sole ulcers, bleeding and white line lesions are considered as non-infectious lameness. It refers to all diseases that affect the hoof.

<u>Infectious lameness</u>: Mortellaro's disease or digitis dermatitis, Fourchet's disease or interdigital dermatitis, interdigital hyperplasia or slugs, sole panic and sole abscess are of infectious origin. They affect the skin of the bovine foot. Here we only consider dermatitis.

These two types of lameness, which can be concomitant, are managed in the simulator by two different epidemiological systems.

2.2.3.3.1.1.2 Lameness severity levels

Only the clinical forms are represented, with 2 levels of severity:

Severity	Definition
G0	Healthy lameness status
G1	Mild to moderate lameness
G2	Severe lameness

Table 72: Lameness Severity Levels

These two levels of severity have been distinguished because in most recent publications lameness is graded according to its intensity with locomotion scores that vary according to several scales: from 1 to 5 (Sprecher, Hostetler et Kaneene, 1997), from 1 to 3 (Walker *et al.*, 2008) and even from 0 to 3 ((Barker *et al.*, 2010). The most commonly used locomotion score is the 1-5 scale. In this case, a cow can be considered lame when her locomotion score is equal to or higher than 2 or 3 depending on the publications. In addition, authors choose the scores they assign to mild to moderate lameness and severe lameness.

2.2.3.3.1.1.3 Zootechnical consequences of lameness

Lameness affects reproduction, milk production, feeding and susceptibility to mastitis and ketosis, and even culling decisions and mortality.

As a cow can be affected by both types of lameness simultaneously, the consequence that applies in this case will be that of the disease with the greatest impact on the effect under consideration.

2.2.3.3.1.1.3.1 Effect of lameness on reproductive performance

The occurrence of lameness can disrupt the reproductive cycle by affecting heat detection sensitivity. Ovarian recovery and fertility are also affected but these are a consequence of poor heat detection in a lame cow.

2.2.3.3.1.1.3.1.1 Effect of lameness on estrus detection sensitivity

When lameness affects the cow, her sensitivity to heat detection is immediately affected (see paragraph *2.2.1.1.2.3.4 Effect of lameness on estrus detection sensitivity*). Indeed, a lame cow lies down more often, walks less and overlaps less with other conspecifics (Gaude *et al.*, 2017). This is modelled in the simulator as follows for severity G1 and G2 lame cows:

	Risk of detection of 1st postpartum estrus for G1 and G2 lameness	**Risk of detecting the following estrus for G1 and G2 lameness**
Sensor	1	0,98
Farmer	0,45	0,70
Robot	1	1
Bull	1	1

Table 73: Effect of lameness on heat detection sensitivity (Gaude *et al.*, 2017)

The risk is factorised when the cow has both infectious and non-infectious lameness (Risk(I) x Risk(NI)).

2.2.3.3.1.1.3.1.2 Effect of lameness on the recovery of ovarian activity

The effects on heat detection are so strong that they largely explain the delay in first insemination. As a result, the effect of lameness on the resumption of ovarian activity is not directly modelled.

2.2.3.3.1.1.3.1.3 Effect of lameness on fertility

As in the previous paragraph and for the same reasons, the effect of lameness on fertility is not directly modelled.

2.2.3.3.1.1.3.2 Impact of lameness on milk production performance

Lameness has an effect on milk production (see paragraph *2.2.2.1.2.11 Lameness effect on dairy production*). The amount produced as well as the composition (TB and TP) are affected throughout the lameness episode to a degree that depends on the type of lameness and its severity. According to (O'Connor *et al.*, 2020) and (Kofler *et al.*, 2021), lameness has little effect on TP, but the average TB over a full lactation is increased according to the severity and duration of the lameness. The effects apply as soon as the cow is lame and are cancelled out when the cow is cured. The effects are simulated as follows:

<table>
<tr><th rowspan="2">Severity</th><th rowspan="2">Impacted feature</th><th colspan="2">Effect on milk production</th><th rowspan="2">Reference</th></tr>
<tr><th>Infectious lameness</th><th>Non-infectious lameness</th></tr>
<tr><td rowspan="3">G1</td><td>Quantity (kg/day)</td><td>Stabling(*): -0.7
Pasture : 0</td><td>-1,8</td><td>Infectious: (Relun, Lehebel, Chesnin, et al., 2013)
Non-infectious: Adapted from (Chesnin et Bareille, 2011)</td></tr>
<tr><td>TB (g/kg)</td><td colspan="2">+0,30</td><td rowspan="2">Adapted from (O'Connor et al., 2020) and (Kofler et al., 2021)</td></tr>
<tr><td>TP (g/kg)</td><td colspan="2">0</td></tr>
<tr><td rowspan="3">G2</td><td>Quantity (kg/day)</td><td>Stabling(*): -0.7
Pasture : 0</td><td>55 days</td><td>Infectious: (Relun, Lehebel, Chesnin, et al., 2013)
Non-infectious: Adapted from (Chesnin et Bareille, 2011)</td></tr>
<tr><td>TB (g/kg)</td><td colspan="2">+1,5</td><td rowspan="2">Adapted from (O'Connor et al., 2020) and (Kofler et al., 2021)</td></tr>
<tr><td>TP (g/kg)</td><td colspan="2">0</td></tr>
</table>

Table 74: Effect on milk production as a function of severity of lameness compared to healthy cows (G0)

(*) Effect halved in case of mixed stall/pasture system.

2.2.3.3.1.1.3.3 Feeding impact

Because of the reduction in the quantity of milk produced in the event of lameness, feed consumption is reduced as follows: a reduction of 2 kg of milk leads to a reduction in consumption of 1 kg divided proportionally between forage and concentrate (Bareille *et al.*, 2003).

2.2.3.3.1.1.3.4 Effect of ketosis on susceptibility to other diseases

Lameness has an effect on susceptibility to other diseases. The diseases considered in DHM are intramammary infections (see paragraph *2.2.3.1.1.2.2.1.7 Modulation of mastitis incidence due to competition from other disease episodes*) and ketosis (see paragraph *2.2.3.2.1.2.2.5 Modulation of the incidence of ketosis related to competition from other disease episodes*). These are discussed in the relevant chapters.Lameness-related culling and mortality

For hoof disease mortality, the figures from (Ettema, Østergaard et Kristensen, 2010), were adapted from the HR of (Bicalho *et al.*, 2007). In addition, in this publication the HR of moderate lameness included severe lameness so it was modified by taking the weighting 2/3 moderate and 1/3 severe. Thus, the risk is modelled as follows:

	Infectious		**Non-infectious**	
	G1	G2	G1	G2
Mortality	0,16 % (*)		3,6 % (**)	4,2 % (**)
Culling	0,14 % (*)		2,5 % (***)	4,5 % (***)

Table 75: Culling and lameness-related mortality

(*) (Ettema, Østergaard et Kristensen, 2010)

(**)Adapted from (Ettema, Østergaard et Kristensen, 2010) and (Bicalho *et al.*, 2007)

(***)Adapted from (Ettema, Østergaard et Kristensen, 2010)

The time of exit, whether for culling or mortality, is fairly linear between 15 days after the onset of lameness and its theoretical end. The model implemented in the simulator, adapted from (Booth *et al.*, 2004), removes the animal from the herd after a period of time that is uniformly within the 15 to 30 day window.

The presence of a non-infectious lameness lasting 5 months or more (150 days) and not cured at the time of drying off leads the farmer not to inseminate the cow during the next heat. She will be culled at the end of her last extended lactation. Cows culled for uncured lameness have a "cull cow" value, i.e. half the value of a healthy cow.

2.2.3.3.1.2 Incidence

The incidence has two dimensions: the basic incidence based on a basic behaviour causing only spontaneous cases, and a modulation allowing to integrate individual characteristics of the cows that may favour the appearance of additional cases (or if necessary to reduce the basic incidence).

2.2.3.3.1.2.1 Basic incidence

The baseline incidence is to be determined for nominal prevention methods. It therefore only reflects the spontaneous occurrence of the disease in the herd. Two risk periods are identified: peak lactation and dry period. The incidence is therefore set when the cow is lactating or drying off. And given the lack of epidemiological evidence for severe lameness, the G2 severity level is described as a G1 aggravation (see paragraph *2.2.3.3.1.4.2 Aggravation of a lameness episode*). Thus, only the baseline incidence of G1 lameness is described here for both types of lameness.

And so the incidence of all lameness combined is 20.3 cases/100 cows/year. In France, the incidence of digitis dermatitis lesions is 48 cases/100 feet/year (Relun, Lehebel, Bruggink, *et al.*, 2013) but only 20% of cows with lesions are lame (van Huyssteen *et al.*, 2020). In the dry period, only one author looked at the incidence of lameness, which is 8.2/100 cows/week, but the farming system is not representative of the one simulated. Based on this and on expert opinion, it was possible to model the reference incidence as follows:

Risk period	Basic incidence of infectious lameness	Basic incidence of non-infectious lameness
Lactation	20 cases/100 dairy cows/year (Relun, Lehebel, Bruggink, *et al.*, 2013)	15 cases/100 dairy cows/year Adapted from (Afonso *et al.*, 2020)
Dry off	4 cases/100 dairy cows/year Adapted from (Daros *et al.*, 2019)	

Table 76: Baseline incidence of infectious and non-infectious lameness according to risk periods

The daily risk curve is shown in the following figure:

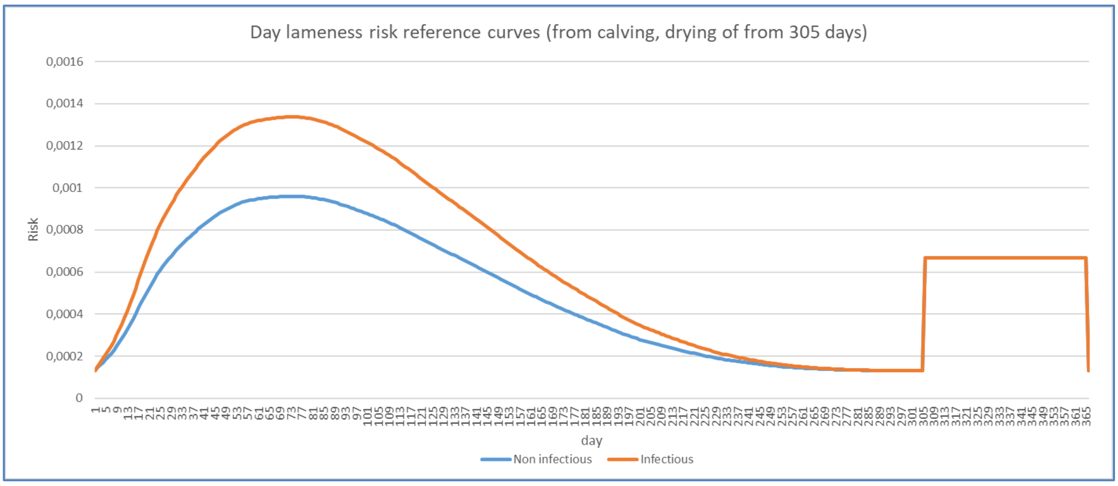


Figure 21: Basic daily risk curve for the incidence of lameness, starting from calving and for a 305-day lactation

For long lactations, this risk is extended beyond day 305 in a uniform manner.

2.2.3.3.1.2.2 *Incidence risk modulation*

The risk of lameness incidence can be modulated according to individual situations and farming conditions.

2.2.3.3.1.2.2.1 Individual modulation of impact risk

2.2.3.3.1.2.2.1.1 Modulation of the ketosis incidence depending on genetics

Foot health in dairy cows can be improved through genetic selection. Indeed, two indexes have been developed as a result of recording lesions during trimming and genotyping of trimmed animals. These indices are: "RLi" for resistance to infectious lesions and "RLni" for resistance to non-infectious lesions. As the simulator only takes lameness into account, these two indexes are called "RBi" and "RBni". These indices are discussed in section *2.2.4.1 Biological and technical constants related to genetics*.

2.2.3.3.1.2.2.1.2 Modulation of the lameness incidence depending on lactation rank

A meta-analysis (Oehm *et al.*, 2019) modulates the incidence of lameness according to cow parity, i.e. a cow's chance of lameness increases as her lactation rank increases. As a result, the base incidence is modulated as follows:

Lactation rank	Infectious lameness	Non-infectious lameness
1	1	1
2	1	1
3	1,1	1,8
≥4	1,3	2,7
Reference	Adapted from (Relun, Lehebel, Chesnin, *et al.*, 2013)	Adapted from (Oehm *et al.*, 2019)

Table 77: Risk of lameness according to lactation rank

2.2.3.3.1.2.2.1.3 Modulation of the lameness incidence depending on production level

Based on the analysis of the results of different publications (O'Connor *et al.*, 2020), (Solano *et al.*, 2015), (Green *et al.*, 2014) and (Relun, Lehebel, Chesnin, *et al.*, 2013), we decide not to include the level of milk production in the modulation of the incidence. Indeed, when an effect was observed, the statistical analysis did not take into account parity, which is likely to explain the effect on lameness risk by itself. Furthermore, the indexes "RBi" and "RBni" show a genetic correlation with milk production (see *Table 89: Genetic correlation ρ between each phenotypic trait*).

2.2.3.3.1.2.2.1.4 Modulation of lameness incidence due to competition from other diseases

A cow is more likely to develop lameness in a given time interval when she develops another disease. Depending on the nature of the disease, the associated relative risk is as follows:

	Mastitis (G1 à G3)	Subclinical and clinical ketosis (G1 et G2)
Relative risk	2	2
Risk duration	Concomitant with the disease	Concomitant with the disease
References	From (Dohoo *et al.*, 1983) and (Peeler, Otte et Esslemont, 1994)	Based on (Raboisson, Mounié et Maigné, 2014) and (Dohoo *et al.*, 1983)

Table 78: Relative risk of occurrence of lameness due to competition from other diseases

2.2.3.3.1.2.2.2 Modulation of the risk of incidence linked to herd management

2.2.3.3.1.2.2.2.1 Modulation of the incidence of infectious lameness due to batch contagion

A cow in a batch with a certain prevalence of infectious lameness has a higher risk of becoming lame itself from infectious lameness (Relun, Lehebel, Bruggink, *et al.*, 2013). This applies in the following ways:

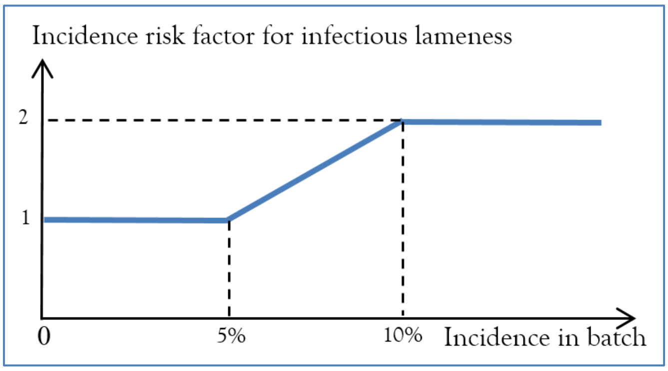


Figure 22: Risk of becoming lame from an infectious disease as a function of batch prevalence

2.2.3.3.1.2.2.2.2 Modulation of the incidence of season-related lameness (housing effect)

A cow that stays in a building for a long period of time is more likely to become lame from an infectious disease in the following ways:

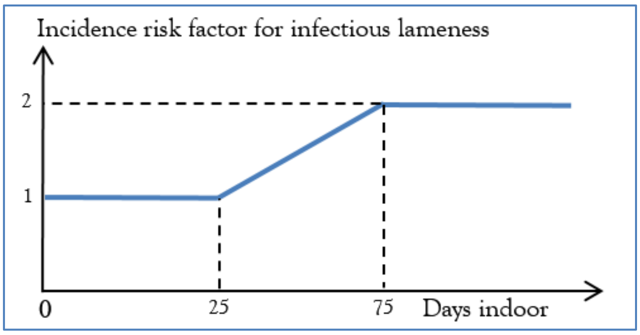


Figure 23: Risk of becoming lame from an infectious disease by staying in a building for a certain period of time

This effect is halved in the case of a mixed grazing/stabling season.

2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures

Foot trimming of cows allows prevention of non-infectious (Hernandez *et al.*, 2007) and (Manske, Hultgren et Bergsten, 2002b), and infectious diseases (Relun, Lehebel, Chesnin, *et al.*, 2013) and to treat cases that would not have been detected routinely. In addition, the use of a foot bath treats infectious lameness cases in short (Relun, Lehebel, Bruggink, *et al.*, 2013) and (Ariza *et al.*, 2017). Thus, trimming and the use of a foot bath are the two available prevention options.

The costs of trimming, foot bath operation and associated care are set in the accounting module (see paragraph *2.2.7.1.3 Health*).

Trimming:

The preventive trimming of a group of cows involves scheduled activity for the vet, and un scheduled activity in the case of group curative trimming of cows detected as lame (see *Table 87: Structure of data on technical production results*). It also generates activity for the farmer under the same conditions.

Actions of collective preventive trimming on non-infectious lameness:

Trimming prevents non-infectious lameness. The simulator applies the latest recommendations by preventively trimming the cows concerned at the rate defined by the experimenter. This rate can be set (see paragraph *2.2.3.3.2.1.4 Option to prevent infectious and non-infectious lameness through trimming*).

The risk of non-infectious lameness in trimmed cows is presented in the table below:

	Non-infectious lameness prevention for a trimmed cow	Non-infectious lameness prevention and untrimmed cows	References
Incidence risk	0,7	1	(Hernandez *et al.*, 2007) and (Manske, Hultgren et Bergsten, 2002a)
Risk duration	2 months	0	Expert opinion

Table 79: Risk of incidence of non-infectious lameness in trimmed cows

Cows that have been recently trimmed, i.e. closer than the duration of the protection offered by a non-infectious curative trim, are not preventively trimmed.

Actions of collective preventive trimming on infectious lameness:

Incidentally, trimming also prevents infectious lameness. The risk of infectious lameness in trimmed lactating cows is shown in *Table 80: Risk of incidence of infectious lameness in trimmed cows*. The risk was lower according to (Relun, Lehebel, Chesnin, *et al.*, 2013) and was lower than the preventive effect of trimming on non-infectious lameness. It was therefore decided to increase it to the same level as for non-infectious lameness. The risk of infectious lameness in trimmed cows is shown in the table below:

	Infectious lameness prevention for a trimmed cow	Infectious lameness prevention and untrimmed cows	References
Incidence risk	0,7	1	Adapted from (Relun, Lehebel, Chesnin, *et al.*, 2013)
Risk duration	3 weeks	0	Expert opinion

Table 80: Risk of incidence of infectious lameness in trimmed cows

<u>Curative actions on infectious and non-infectious lameness during collective preventive trimming:</u>

During trimming, lame cows, which have not been detected by the farmer but are detected by the trimmer, are also treated as they are inspected individually. Their collective curative treatment is the same as when the farmer detects lameness and is outlined in paragraph *2.2.3.3.2.4 Treatment plan*.

<u>**Foot bath:**</u>

<u>Collective preventive actions of the foot bath on infectious lameness:</u>

The foot bath helps to prevent the occurrence of infectious lameness (Relun *et al.*, 2012). The risk of incidence of infectious lameness in cows that have passed through a foot bath is presented in the table below:

	Prevention of infectious lameness for a cow in the foot bath	Prevention of infectious lameness in a cow that has not passed through the foot bath	Reference
Incidence risk	0,89	1	(Ariza *et al.*, 2017)

Table 81: Risk of incidence of infectious lameness of cows in a foot bath

The operating procedures for the foot bath can be configured (see paragraph *2.2.3.3.2.1.3 Foot bath frequency option*).

<u>Curative actions on infectious lameness when using the foot bath:</u>

The foot bath can be used to treat infectious lameness. When the foot bath is used, dairy cows with infectious lameness, not yet detected, are treated as follows:

	Treatment of infectious lameness for a cow in the foot bath		References
	G1	**G2**	
Healing risk	Factor 1.3 of the spontaneous recovery rate (see paragraph 2.2.3.3.1.4)		Adapted from (Ariza *et al.*, 2017) and (Relun *et al.*, 2012)
Duration before effect (days)	5	9	Expert opinion

Table 82: Risk of recovery from infectious lameness of cows in a foot bath

This data is not shown in paragraph *2.2.3.3.2.4 Treatment plan* as it is derived from a collective treatment. The risk of recovery is reduced to the day by a ratio of the duration of the effectiveness of the foot bath.

2.2.3.3.1.3 Lameness detection

In its clinical form, lameness causes phenomena that are easier to observe externally. Cows move slower, shift their weight to the unaffected foot, have a bent back and a rocking effect of their head.

Two means of detection are available: the farmer or an on-board sensor. Breeders generally have difficulty detecting G1 severity lameness but are better at detecting G2 severity lameness according to (Cutler *et al.*, 2017), (Whay, Main et Green, 2003) and (Wells *et al.*, 1993). A distinction in case detection is made between a sensitive and a less sensitive breeder as described in the table below.

An on-board sensor is being researched that will detect a lame cow based on their approach. Ideally, this data should be coupled with milking, feeding and body condition data.

The means of detection can be set up as defined in paragraph *2.2.3.3.2.2 Detection options*.

	Infectious and non-infectious lameness		References
	G1	G2	
Sensitive farmer	40%	95%	Adapted from (Thomsen, 2009) and expert opinion
Less sensitive farmers	20%	70%	
Sensor	90%	100%	Expert opinion

Table 83: Sensitivity of detection of lame cows

The veterinary care contract may change the farmer's sensitivity during the simulation (see paragraph *2.2.3.3.2.2 Detection options*). Lameness cases, when detected, systematically lead to the implementation of an adapted treatment according to the cause of the lameness, the plan of which is defined in paragraph *2.2.3.3.2.4 Treatment plan*. Detection occurs with a uniform law from day 5 to day 10 of lameness.

2.2.3.3.1.4 *Evolution and healing of lameness*

The dynamics of disease progression are defined according to the following model:

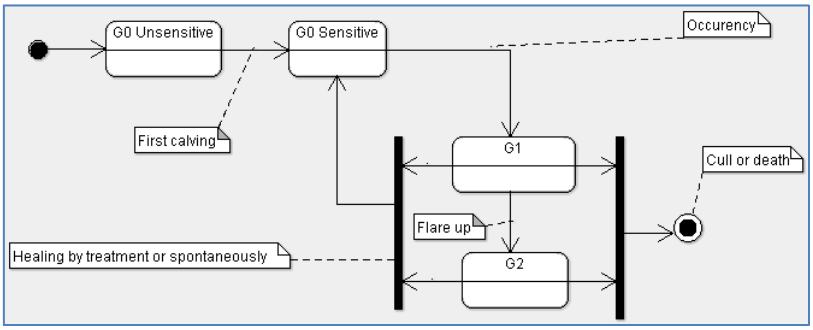


Figure 24: Dynamics of lameness evolution

The principle implemented by the simulator is to trigger, when the conditions are met (in lactation or at drying off, parity, competition with the episode of another disease, etc.) and in a stochastic manner from the incidence described in paragraph *2.2.3.3.1.2 Incidence*, a case of G1 lameness, whether infectious or non-infectious, which, depending on the factors involved, will heal following collective preventive treatment or with the introduction of one or more treatments, worsen (thus becoming a case of G2 lameness), or lead to culling or even death.

G1 lameness can heal spontaneously according to the values described in the table below. Spontaneous recovery of G2 severity lameness is neglected.

Severity lameness G1		Reference
Infectious	Non-infectious	
50% healed by day15	5% healed by day 20	Adapted from (Relun *et al.*, 2012)

Table 84: Spontaneous healing from G1 severity lameness

Spontaneous healing of G2 severity lameness is overlooked.

2.2.3.3.1.4.1 *Duration of lameness*

When undetected, lameness goes untreated and can last for a long time. The duration of lameness is not defined as it depends on the circumstances described in the following lines.

2.2.3.3.1.4.2 *Aggravation of a lameness episode*

All G1 severity lameness that is not cured spontaneously or by treatment will worsen to G2 severity lameness. The time to aggravation depends on the type of lameness. For infectious lameness it is 30 to 90 days spread according to a uniform law, and for non-infectious lameness it is 70 to 170 days spread in the same way.

2.2.3.3.1.4.3 *Recurrence of lameness*

Infectious lameness may not recur until 3 weeks after recovery (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009), and 2 months for non-infectious lameness (by expert opinion). These durations are modelled in the simulator as temporary periods of insensitivity.

2.2.3.3.2 Lameness-related husbandry parameters

The simulator settings allow you to define the overall prevention factor, the prevention and detection options, and the treatment plan.

2.2.3.3.2.1 *Prevention factors*

2.2.3.3.2.1.1 *Global prevention factors*

A multiplicative value is used to improve the prevention of lameness (value between 1.0 and 2.0) or to reduce it (value between 0.2 and 1.0), and allows the effect of management factors that influence incidence but are not explicitly represented (see paragraph *2.2.3.3.1.2.2 Incidence risk modulation*). A global prevention factor is described for lameness of infectious origin and another for lameness of non-infectious origin. The default value is 1.0.

2.2.3.3.2.1.2 *Option to prevent infectious lameness by using a foot bath*

The use of preventive treatment by using a foot bath to reduce the incidence of infectious lameness can be set (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures). The option to use the foot bath is not selected by default. When selected, the protection, which can be parameterised, defaults to 21 days (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009).

2.2.3.3.2.1.3 *Foot bath frequency option*

When the foot bath is used for lactating cows, it is possible to set the frequency of its use (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures), differently for the three housing systems (see paragraph *2.2.5.2.2.1 Stabling and grazing*). The default value for each of the grazing, stabling and mixed housing systems is 21 days (Relun *et al.*, 2012) and (Nielsen, Thomsen et Sørensen, 2009).

2.2.3.3.2.1.4 *Option to prevent infectious and non-infectious lameness through trimming*

Different trimming methods are proposed to reduce the incidence of infectious and non-infectious lameness (see paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures), they are as follows:

- No trimming,

- Systematic and grouped preventive trimming of the batch of lactating cows at stalling only (default),

- Systematic and grouped preventive trimming of the batch of lactating cows at stalling and at grazing,

- Preventive trimming of lactating cows in small groups after calving (enrolled after 60 days) and at dry-off (enrolled immediately)

For the last option, trimming is carried out when the list of registered cows contains enough individuals for the trimming workshop to be set up and group trimming to be carried out. The size of the small group of cows to be trimmed preventively is the same as for curative trimming, which can be configured (see paragraph *2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment*).

The application of a veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), may modify the preventive trimming option initially chosen during the simulation. The practical effect in this case is to recommend preventive trimming twice a year, regardless of the option initially chosen. This option is put into practice after one year of contract.

Preventive trimming activities are a planned veterinary activity included in the results (see paragraph *2.2.3.4 General health produced data*).

2.2.3.3.2.2 Detection options

Three detection options are offered to the experimenter: visual detection by the sensitive farmer, by a less sensitive farmer and detection using a sensor.

Visual detection by a less sensitive farmer is chosen by default as described in paragraph *2.2.3.3.1.3 Lameness detection*. However, the application of a veterinary care contract, if taken out (see paragraph *2.2.3.1.2.7 Veterinary care contract option*), can change the breeder's sensitivity over the course of the simulation. Indeed, the advice given to the farmer by the veterinarian under this contract, as well as his proximity to the farmer, means that a farmer initially set as "not very sensitive" can become "sensitive" after 6 months.

2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment

Cows found to be lame are treated in small groups. This is also the case when the option of preventive trimming by small groups is selected (differentiated group). The size of these small groups is configurable, the default value is 10.

The veterinary care contract option (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) can reduce the time taken to process cases by reducing the size of these groups during simulation. In this case, if the trimming group size initially set was larger, it is reduced to 5 cows after 6 months, which reduces the time taken to treat cases.

2.2.3.3.2.4 Treatment plan

This section only covers individual treatments resulting from routine detection of a lame cow. The treatment of cows detected as lame through the use of collective preventive measures such as trimming or the use of a foot bath is described in paragraph 2.2.3.3.1.2.2.2.3 Modulation of the incidence of lameness due to prevention measures.

When lameness is detected by the farmer (alone or with the means of detection available to him), he will only treat when there are a certain number of lame cows in this case, whether infectious or not. This number of cows to be treated can be set (see paragraph *2.2.3.3.2.3 Trimming grouping and individual lameness cases for treatment*), which can be reduced during the simulation in the event of a veterinary care contract (see paragraph *2.2.3.1.2.7 Veterinary care contract option*) to ensure that it is taken into account more quickly. It performs a curative trimming, it provides veterinary care for the cow (see *Table 87: Structure of data on technical production results*).

The treatment plan applied is configurable, its default values are as follows:

	All periods			
	Non-infectious lameness		**Infectious lameness**	
Severity	**G1**	**G2**	**G1**	**G2**
Name	Fitting a heel pad		Dressing with disinfectant	
Delay before effect (d)	3 à 7 (*)	7 à 14 (*)	3	7
Milk waiting delay (d)	0			
Healing probability 1st treatment	55%	55%	90%	85%
Healing probability if 1st treatment failure	45%	25%	90%	85%
References	(Thomas *et al.*, 2015) and expert opinion		Expert opinion	

Table 85: Valeurs par défaut du plan de traitement de la boiterie

(*) uniform distribution

The same curative treatment is carried out when a cow is found to be lame during preventive collective trimming. If it was not effective at the first attempt, the treatment of a G2 lameness is repeated every 40 days until it is cured.

The cost of the treatment is set in the accounting module (see paragraph *2.2.7.1.3 Health*).

2.2.3.3.3 Data produced on lameness

The data produced relate to cases of lameness (non-infectious, infectious, severity 1 or 2) encountered in the herd.

Type of production: annual.

Information level: Herd.

Result file name: « AnnualNonInfectiousLamenessResults.csv » and « AnnualInfectiousLamenessResults.csv ».

The available fields are as follows:

Field name	Format	Value
Herd_cow_average	integer	Average number of adult cows in the herd
G1_lameness_per_100_cows	real	Number of cases of G1 severity lameness / number of cows present (percentage)
G2_lameness_per_100_cows	real	Number of cases of G2 severity lameness / number of cows present (percentage)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 86: Structure of the data on annual lameness results

2.2.3.4 General health produced data

The general health data that are produced relate to the annual technical data for the diseases managed.

Production type: annual.

Information level: Herd.

Result file name: these results are included in the structure of technical results described in paragraph *3.4 Result structure*.

The available fields are:

Field name	Format	Value
G1_Ketosis_occurency_by_cow	real	Number of subclinical ketosis cases / number of cows calving in the campaign (percentage)
G2_Ketosis_occurency_by_cow	real	Number of clinical ketosis cases / number of cows calving in the campaign (percentage)
Subclinical_Mastitis_occurency_by_cow	real	Number of subclinical mastitis cases / number of cows present (percentage)
Clinical_Mastitis_occurency_by_cow	real	Number of clinical mastitis cases / number of cows present (percentage)
G1_Non_infectious_lameness_occurency_by_cow	real	Number of non-infectious subclinical lameness cases / number of cows present (percentage)
G2_Non_infectious_lameness_occurency_by_cow	real	Number of non-infectious clinical lameness cases / number of cows present (percentage)
G1_Infectious_lameness_occurency_by_cow	real	Number of infectious subclinical lameness cases / number of cows present (percentage)
G2_Infectious_lameness_occurency_by_cow	real	Number of infectious clinical lameness cases / number of cows present (percentage)
Mastitis_mortality_by_cow	real	Number of mastitis dead cows / number of cows present (percentage)
Ketosis_mortality_by_cow	real	Number of ketosis dead cows / number of cows present (percentage)
Non_infectious_lameness_mortality_by_cow	real	Number of non-infectious lameness dead cows / number of cows present (percentage)
Infectious_lameness_mortality_by_cow	real	Number of infectious lameness dead cows / number of cows present (percentage)
Health_treatment_count	integer	Number of treatments carried out for health trouble
Curative_clinical_ketosis_vet_treatment_count	integer	Number of treatments carried out for each heatlh trouble class
Curative_clinical_ketosis_farmer_treatment_count	integer	
Curative_subclinical_ketosis_vet_treatment_count	integer	
Curative_subclinical_ketosis_farmer_treatment_count	integer	
Curative_clinical_mastitis_vet_treatment_count	integer	
Curative_clinical_mastitis_farmer_treatment_count	integer	
Curative_subclinical_mastitis_vet_treatment_count	integer	
Curative_subclinical_mastitis_farmer_treatment_count	integer	
Preventive_ketosis_farmer_treatment_count	integer	
Preventive_Mastitis_farmer_treatment_count	integer	
Curative_clinical_lameness_vet_treatment_count	integer	
Preventive_lameness_vet_treatment_count	integer	
Unscheduled_cow_vet_care_count	integer	Number of unplanned cow treatments carried out by the vet
Scheduled_cow_farmer_care_count	integer	Number of planned cow treatments carried out by the farmer
Unscheduled_cow_farmer_care_count	integer	Number of unplanned cow treatments carried out by the farmer
Scheduled_vet_activity_count	integer	Number of planned veterinary interventions (contractual visits care and presence at preventive triming sessions)
Unscheduled_vet_activity_count	integer	Number of unplanned veterinary interventions (over contractual visits care and presence at curative triming sessions)
Scheduled_farmer_activity_count	integer	Number of planned farmer interventions
Unscheduled_farmer_activity_count	integer	Number of unplanned farmer interventions
Mastitis_culling_by_cow	real	Number of cows culled due to mastitis / Average number of cows present (percentage)
Ketosis_culling_by_cow	real	Number of cows culled due to ketosis / Average number of cows present (percentage)

Non_infectious_lameness_culling_by_cow	real	Number of cows culled due to non-infectious lameness / Average number of cows present (percentage)
Infectious_lameness_culling_by_cow	real	Number of cows culled due to infectious lameness / Average number of cows present (percentage)

Table 87: Structure of data on technical production results

2.2.4 Genetics

The simulator makes it possible to consider values specific to each individual that affect its different performances (production, reproduction and health).

2.2.4.1 *Biological and technical constants related to genetics*

All animals are endowed with a genetic heritage from their creation. This heritage brings together the genetic value of each of their phenotypic traits. Three cases are to be differentiated for the assignment of individual genetic values:

- animals bought during the simulation,
- bulls whose semen is used for inseminations (including natural),
- calves born from an identified dam and sire.

The environment effect is not dealt within this chapter; however, it is dealt in each of the modules concerned.

2.2.4.1.1 Genetic values associated with phenotypic traits

The genetic value of each phenotypic trait consists of the following values:

- the true genetic value A,
- the corrected performance P.

These genetic values are calculated in the simulator by the application of three common criteria of the dairy breeds (heritability, heterosis and genetic correlation), and two others that are breed-dependant (reference phenotypic mean and genetic standard deviation).

2.2.4.1.1.1 *Common criteria of genetic values associated with phenotypic traits*

Phenotypic trait's name	Definition	Performance trait	Unity	Heritability (h^2) [1]	Heterosis (H) [2]
Milk	Milk quantity	Production [3]	kg	0.30	510
FC	Fat content		g/kg	0.50	0.15
PC	Protein content		g/kg	0.50	0
Fer	Fertility	Functional [3]	Standard deviation	0.02	0.07
MACL	Mastitis resistance		Standard deviation	0.02	0
BHBlait	BHB level in milk	Functional	Standard deviation	0.15 [4]	0 [6]
RBi	Resistance to infectious limping	Functional	Standard deviation	0.04 [5]	0 [6]
RBni	Resistance to non-infectious limping		Standard deviation	0.03 [6]	0 [6]

Table 88: Common parameters of genetic values associated with phenotypic traits

[1] (Dezetter, 2015) Holstein basis, [2] ECOMAST, [3] France génétique Elevage – index des races bovines laitières – 2018, [4] (Benedet *et al.*, 2019), [5] Adapted from (Pérez-Cabal et Charfeddine, 2015) and (Croué *et al.*, 2017), [6] Data not available.

With regard to the genetic correlation ρ that can exist between the true genetic values of each phenotypic trait, it is the following:

ρ	Milk	FC	PC	Fer	MACL	BHBlait	RBi
FC	-0.45 [1]						
PC	-0.4 [2]	0.6 [2]					
Fer	-0.23 [2]	0.1 [2]	0.1 [2]				
MACL	0.26 [2]	-0.1 [2]	-0.1 [2]	-0.24 [2]			
BHBlait	0.03 [3]	0.035 [4]	-0.29 [4]	0 [11]	0.23 [5]		
RBi	0.26 [6]	-0.07 [7]	-0.02 [7]	0.23 [8]	0.37 [9]	0.09 [5]	
RBni	0.26 [6]	-0.07 [7]	-0.02 [7]	0.23 [8]	0.37 [9]	0.09 [5]	-0.01 [10]

Table 89: Genetic correlation ρ between each phenotypic trait

[1] (Beaudeau *et al.*, 2016), [2] (ECOMAST), [3] adapted from (Benedet *et al.*, 2019), [4] (Belay *et al.*, 2017), [5] (Oliveira Junior *et al.*, 2021), [6] adapted from (Koeck *et al.*, 2014), (Khansefid, Haile-Mariam et Pryce, 2021) and (Van Dorp *et al.*, 1998), [7] (Gernand *et al.*, 2012), [8] (Khansefid, Haile-Mariam et Pryce, 2021), [9] adapted from (Pritchard *et al.*, 2013), (Koeck *et al.*, 2012) and (Oliveira Junior *et al.*, 2021), [10] Idele 2021 data, [11] Data not available.

Remarque : les corrélations génétiques entre la résistance aux boiteries et à la fertilité, le TB et le TP, sont chacune issues d'une seule publication donc leur fiabilité est limitée.

2.2.4.1.1.2 Criteria of genetic values associated with breed-dependent phenotypic traits

The phenotypic mean and genetic standard deviation specific values for dairy breeds are as follows:

Phenotypic trait name	**Phenotypic mean reference**			**Genetic standard deviation** ($\sigma_{A=\sqrt{0.7*variance}}$) [2]	
	Montbeliarde	Normande	Holstein	Montbeliarde and Normande	Holstein
Milk	7 832 kg[1]	7 028 kg[1]	9 518 kg[1]	553	599
FC	38.9 g/kg[1]	42.1 g/kg[1]	40.1 g/kg[1]	2.03	2.48
PC	33.1 g/kg[1]	34.5 g/kg[1]	31.9 g/kg[1]	1.16	1.24
Fer	1[2]			0.059	0.059
MACL	1[2]			0.037	0.034
BHBlait	1			0.048[3]	0.046[3]
RBi	1			0[5]	0.1[4]
RBni	1			0[5]	0.06[4]

Table 90: Breed-dependent parameters of genetic values associated with phenotypic traits

[1] (Institut de l'élevage, 2021b), they concern the average lactation results «adult-level corrected – all lactations», they are the basis of simulation for two daily milking, [2] (ECOMAST), [3] Expert opinion, [4] Adapted from (Pérez-Cabal et Charfeddine, 2015) and (Croué *et al.*, 2017), [5] Data not available.

2.2.4.1.2 Individual genetic value

The genetic value of an individual depends on the average true genetic value of the herd A¯_two. The levels of these values are defined in *Table 90: Breed-dependent parameters of genetic values associated with phenotypic traits*.

2.2.4.1.2.1 True genetic value

For each individual *i*, the true genetic value A of each of its phenotypic traits is calculated according to the following formula:

$$A_{i,trait} = N(\bar{A}_{,herd,trait}, \sigma_{A,trait})$$

Variability is applied considering the correlation between traits defined in *Table 89: Genetic correlation ρ between each phenotypic trait*.

2.2.4.1.2.2 Individual potential in adult stage

Individual potential is calculated differently if the unit linked to the index is to be a performance (quantitative index) or a standard deviation (qualitative index).

<u>Individual potential based on a performance:</u>

If the phenotypic trait is a performance (milk, FC and PC), the potential P of the individual "i" is calculated from the true genetic value as follows:

$$P_{i,trait} = \bar{P}_{herd,trait} + \frac{A_{i,trait} - \bar{A}_{herd,trait}}{h^2_{trait}}$$

It has the same unit measure as the performance (kg or g / kg).

<u>Individual potential based on a standard deviation:</u>

If the phenotypic trait is to be a standard deviation (Fer, MACL, BHBlait and RB), the potential P of the individual "i" will be centred on 1 and calculated from the true genetic value (centred on 0), with a X performance corresponding to a value of the genetic standard deviation defined to 3 for the increasing direction and -3 for the decreasing direction, according to the following equations:

Direction (*)	Equation for a true genetic value < 0	Equation for a true genetic value >= 0
Increasing	$P_{i,trait} = \frac{1}{\frac{(X-1)*A_{i,trait}}{-3}+1}$	$P_{i,trait} = \frac{(X-1)*A_{i,trait}}{3} + 1$
Decreasing	$P_{i,trait} = \frac{(X-1)*A_{i,trait}}{-3} + 1$	$P_{i,trait} = \frac{1}{\frac{(X-1)*A_{i,trait}}{3}+1}$

Table 91: Equations for calculating individual potentials P_i for indexes expressed as genetic deviation, where X is the performance for a value of genetic standard deviation defined as 3 for the increasing direction and -3 for the decreasing direction

(*) The direction is increasing if P_i increases when the true genetic value increases, decreasing otherwise.

The more heritable a trait is, the higher the value of X is, so heritability is intrinsically taken into account.

For Fer, BHBlait, MACL, RBi and RBni indexes, the individual performances are determined according to the following value table:

Phenotypic trait	Corrected performance used in simulation	X performance value (*)	Direction depending on the genetic value	Individual performance boundary
Fer	Coefficient applied to the probability of a successful insemination	2	Increasing	1/X for a -3 standard deviation X for a +3 standard deviation
BHBlait	Coefficient applied to the probability of occurrence of ketosis	1.5		
MACL	Coefficient applied to the probability of occurrence of mastitis	5	Decreasing	X for a -3 standard deviation 1/X for a +3 standard deviation
RBi	Coefficient applied to the probability of occurrence of infectious lameness	1.6		
RBni	Coefficient applied to the probability of occurrence of non-infectious lameness	1.6		

Table 92 : Individual performance values for standard deviations indexes

(*) Data not available, estimated by experts.

Therefore, for Fer, MACL, BHBlait and RB (i and ni) indexes, represented as standard deviations, the coefficient used in the simulation to accentuate or reduce the effect will have the following values:

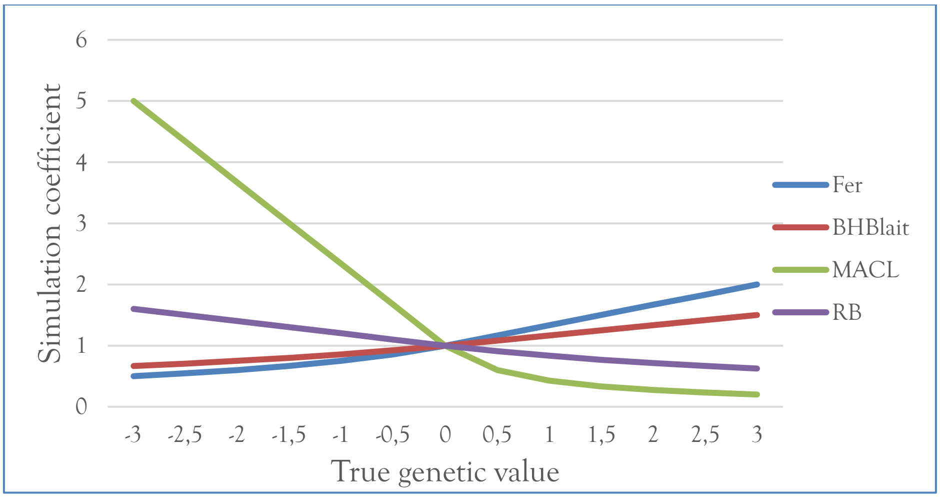


Figure 25: Coefficient to be applied to the performance in order to consider the true genetic value

2.2.4.1.3 Genetic value of bulls for insemination (including natural)

Bulls are not simulated as individuals; they are summarized to "bull" genetic values gathered in a catalogue. In the case of dairy breeds, these values benefit from annual genetic progress.

2.2.4.1.3.1 Catalogue of "bulls" genetic values

The catalogue of genetic values of dairy bulls (before genetic progress) is dimensioned according to the data loaded (see paragraph *2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue*).

For beef bulls used for the birth of calves for sale, and to ensure the biological consistency of the simulation, their true genetic value is 0 and their adult stage values are generically defined as:

- Milk: 2000 kg,
- FC: 50 g/kg,
- PC: 50 g/kg,
- Fer: 1 (centred coefficient),
- MACL: 1 (centred coefficient).
- BHBlait: 1 (centred coefficient).
- RBi: 1 (centred coefficient).
- RBni: 1 (centred coefficient).

No variability is applied in this case.

2.2.4.1.3.2 Annual genetic progress

An annual genetic progress of the dairy cattle herd is simulated. It involves increasing the performance of new individuals (births or purchases) in the following proportions:

Phenotypic trait	**Montbeliarde**	**Normande**	**Holstein**
MILK (kg) (1)	52	62	80
FC (g/kg) (1)	0.03	0	0
PC (g/kg) (1)	0.08	0.09	0.04
Fer (1)	0.05	0.02	0.05
MACL (1)	0.04	0.02	0.04
BHBlait (2)	0.00	0.00	0.00
RBi (2)	0.00	0.00	0.00
RBni (2)	0.00	0.00	0.00

Table 93: Annual population genetic progress according to dairy breeds for each phenotypic trait

(1) (Dezetter, 2015), (2) Data not available.

The genetic progress is applied each year in a general way on the state of the breed (annual modification of the phenotypic reference averages of *Table 90: Breed-dependent parameters of genetic values associated with phenotypic traits* with the phenotypic traits in the proportions of the genetic progress defined in *Table 93: Annual population genetic progress according to dairy breeds for each phenotypic trait* and in the same proportions for the genetic values "Bulls" of the catalogue.

No progress is simulated with regard to inseminations by bulls of beef breeds.

2.2.4.1.4 Genetic value of calves born from identified parents

The calculation principle implemented in the simulator to determine the true genetic value for each phenotypic trait of a calf born from identified parents involves additively heredity, a meiosis hazard and a heterosis effect (Dezetter, 2015):

$$VG_{calf,trait} = \overline{VG}_{parents,trait} + meiosis\ hazard_{trait} + heterosis_{trait}$$

2.2.4.1.4.1 Heredity

For each phenotypic trait, in expectation, the calf inherits half of the true genetic value of the dam and half that of the sire (Dezetter, 2015):

$$\overline{VG}_{parents,trait} = \frac{VG_{dam,trait} + VG_{sire,trait}}{2}$$

2.2.4.1.4.2 Meiosis hazard

The meiosis hazard $\emptyset$ is added to the genetic value of the calf previously calculated from its parentage. Correlated according to *Table 89*: *Genetic correlation ρ between each phenotypic trait*, it is calculated as follows (Dezetter, 2015):

$$\emptyset_{trait} = N(0, \frac{\sigma_{A,trait}}{\sqrt{2}})$$

The standard deviation σ_A is described in *Table 90*: *Breed-dependent parameters of genetic values associated with phenotypic traits.*

2.2.4.1.4.3 Heterosis

The heterosis effect is calculated as follows:

$$heterosis_{trait} = h \times H_{trait}$$

With h = 1 – percentage of the sire's breed in the dam's genetics (Dezetter, 2015), knowing that the calf will be 50% of the dam's breed (s) and 50% of the sire's breed.

The effect of heterosis H is defined in *Table 88*: *Common parameters of genetic values associated with phenotypic traits.*

The value of corrected P performance of the calf is then calculated in the same way as for a generated adult, described in paragraph *2.2.4.1.2 Individual genetic value*.

2.2.4.2 Parameters for genetic management

This paragraph describes the parameters to be considered for the application of genetic effects. This concerns the catalog of genetic character of bulls that will be used for insemination and natural mating, and the herd's performance level.

2.2.4.2.1 Dairy bull genetic character for the inception of insemination and natural mating catalogue

It is possible to create a specific catalog of the genetic dairy bull genetic character. Therefore, it is necessary to put a text file at the simulator's disposal, in which the required information can be found with ";" as field separator and "," as decimal separator, and structured for each genetic value as follows:

Field	Format
Bull breed	Breed (*)
Genetic strategy	Genetic strategy (**)
Milk index	real
FC index	real
PC index	real
Fer index	real
MACL index	real
BHBlait index	real
RBi index	real
RBni index	real

Table 94: Structure of the file of the bulls' genetic character

(*) See *Table 2: Type data formats* page *12.*

(**) Values to set genetic strategies defined in Table 118: Keys and formats for farm management parameters.

In order to benefit from the widest possible range of strategies, it is recommended that at least one bull is to be included in this file for each dairy breed and genetic strategy. Only the character of dairy breeds will be taken into account.

By default, the following values are used:

Genetic strategy (bull choice)	Breed *(Bull name)*	LGF	Phenotypic trait							
			Milk (kg)	FC (g/kg)	PC (g/kg)	Fer (standard deviation)	MACL (standard deviation)	BHBlait (standard deviation)	RBi (standard deviation)	RBni (standard deviation)
Balanced	Montbéliarde *(Omelo)*	-0.1	1643	-1.1	0.4	0.5	-0.7	0.0	0.0	0.0
	Normande *(Ottoman)*	0.5	1552	3.5	1.9	0.0	0.4	0.0	0.0	0.0
	Prim'Holstein *(Oprod)*	0.9	1173	3.7	3.3	0.0	-0.1	0.0	0.0	0.0
Priority to milk quantity (best Milk index)	Montbéliarde *(Omelo)*	-0.1	1643	-1.1	0.4	0.5	-0.7	0.0	0.0	0.0
	Normande *(Ottoman)*	0.5	1552	3.5	1.9	0.0	0.4	0.0	0.0	0.0
	Prim'Holstein *(Polibay)*	2.1	1266	1.6	0.1	2.2	1.3	0.0	0.0	0.0
Priority to functional longevity (best LGF index)	Montbéliarde *(Pavloff)*	2.8	1007	0.1	-0.1	1.6	0.4	0.0	0.0	0.0
	Normande *(Picasso)*	3.0	1148	-1.2	.9	1.7	2.1	0.0	0.0	0.0
	Prim'Holstein *(Pleslin p)*	3.6	835	1.7	2.2	2.7	0.9	0.0	0.0	0.0

Table 95: Default values for bulls' genetic indexes

These values are those of existing bulls (except BHBlait and RB), from the genetic evaluation of artificial inseminations (Institut de l'élevage, 2021a).

2.2.4.2.2 Genetic strategy

The simulator makes it possible to choose the genetic strategy for reproduction in the herd. They are of three types: balanced (INEL index), with priority to the quantity of milk produced (Milk index) and with priority to functional longevity (LGF index). Depending on the strategy chosen by the experimenter, the reproduction bull used for insemination or natural reproduction will be drawn from among those of the expected breed present in the catalog and meeting this criterion. By default, the balance strategy is selected.

2.2.4.3 Data produced

No genetic data is currently produced.

2.2.5 Population and batch management

The management of the herd population, including renewal and culling, and the distribution of animals in batches are proposed to the user.

2.2.5.1 Constant biological and technical values

The paragraph "Population and batch management" defines the population management method (number, culling, renewal, mortality), as well as the batch distribution.

2.2.5.1.1 Herd population

Throughout the simulation, the herd size is regulated by sales and purchases.

2.2.5.1.1.1 Gradual herd increase

Before the simulation starts on the set dates, a pre-simulation is carried out starting from a situation where there are no cows in the herd yet, dedicated to ramping up the herd, by purchasing heifers in stages. If the option of grouping calvings is opted, the heifers are purchased in such a way that they only calve during the planned periods.

2.2.5.1.1.2 Herd population management

For a herd composed of a nominal size, the renewal will be applied under the conditions defined by the user. The aim being that at the end of a campaign, the herd has been renewed at the level of what has been planned (see paragraph *2.2.5.2.1.3 Annual herd renewal rate*). This renewal, taking into account possible exits due to mortality or health or fertility problems, is organized every day. It makes possible to determine the animals for sale because if the purchase of new pregnant heifers. If there are not enough cows in the herd and no pregnant heifers from the "Bred heifers" batch to join the "Dried cows and pregnant heifers" batch within one month weighted by the target numbers divided by 100, the purchase of pregnant heifers will be made.

Only the observation is taken into account by the simulator when comparing performances in order to determine the best candidates for sale (female calves and pregnant heifers). Genotyping of breeding stock is not implemented.

2.2.5.1.1.2.1 Sale of female calves

Several strategies are planned for the sale of female calves, they are described in the paragraph *2.2.5.2.1.4 Female calves management strategy*.

2.2.5.1.1.2.2 Heifer sales and adult cow culling

Except in cases where a health problem requires immediate culling, culling of cows is generally done in two steps: the decision to no longer inseminate and the culling at the end of lactation. Moreover, if this principle is not sufficient for the regulation of the number of cows, or depending on the renewal strategy adopted, the sale of pregnant heifers can be carried out.

2.2.5.1.1.2.2.1 Decision to no longer inseminate

The decision to no longer inseminate cows and heifers can be made for various reasons:

- fertility problems, i.e. those described in paragraph *2.2.1.2.8 Individual decision of stop inseminations related to heifer and cow infertility*. This also applies to females that have lost their embryos or have aborted (without lactation) after the end of the insemination period,
- when the maximum number of lactations is reached, this parameter is defined in paragraph *2.2.5.2.1.5 Maximum number of lactations*,
- an observed production in early lactation (from the calving day to the day of the insemination decision) that is lower than the herd average calculated on the basis of the last 12 months of observed production. This does not apply to cross-bred dairy cows. The setting of the applicable ratio is described in paragraph *2.2.5.2.1.6 Production performance of the cow regarding the one of the herd*,

- when the cow does not recover from her last mastitis, determined by a SCC level exceeded during the last two milk controls of the previous lactation and the first milk control for the new lactation (see paragraph *2.2.5.2.1.7 SCC level*),
- in case of long lameness (see paragraph *2.2.3.3.1.1.3.5 Lameness-related culling and mortality*),
- in the case of group calving, where the cow or heifer has not been fertilised within the planned period.

2.2.5.1.1.2.2.2 Culling for population regulation

Decision:

Some cows are culled immediately. This is the case for cows with a health problem that is so serious that recovery is not an option. The other culls are carried out with a view to regulating the number of cows. In this context, the decision not to inseminate a cow with a view to culling her is taken according to her genetic value in relation to the others in the light of the breeder's genetic strategy (see § *2.2.4.2.2 Genetic strategy*) or because of infertility.

Culling:

The culling of a cow scheduled to be culled is actually carried out at the end of her lactation, in priority according to an individual score determined by the following equation:

$$Score = \frac{\overline{SCC}_{7\ last\ days}}{\overline{Milk\ quantity}_{7\ last\ days}}$$

Whatever, the principle for considering that a cow to be culled has completed her lactation (after a plateau of 250 days of lactation) is based on the threshold of the quantity of milk produced (smoothed over the last 7 days), weighted by a ratio which, depending on the objective of the herd, makes it possible to define the break-even point. The break-even point calculated for two levels of production is as follows:

Production level of the herd (kg/cow)	Break-even point (kg)
6000	10
9500	16

Table 96: Break-even point of production according to the level of the herd

This threshold can be adjusted by a configurable factor (see paragraph *2.2.5.2.1.8 Break-even point for milk production*).

2.2.5.1.1.2.2.3 Pregnant heifer sale

In case of heifers overcrowding in relation to the desired renewal rate (observed over a period of four months), the herd size is regulated by the sale of heifers, chosen according to the performance of their dam cow, with the same conditions as for the conservation of female calves.

2.2.5.1.1.2.3 Purchase of heifers

When the herd size is insufficient, the simulator carries out the purchase of pregnant heifers, inseminated according to the conditions of the first insemination provided in the mating plan, and for an estimated date of calving a two weeks later. The genetic value of bought pregnant heifers takes into account the progress made at the relevant stage of simulation since its beginning.

2.2.5.1.1.3 Mortality

Calves and cows are exposed daily to a natural risk of mortality. This risk is determined on the basis of the average mortality observed in dairy herds, and in suckling herds for crossbred calves (Perrin *et al.*, 2011), as follows:

Age group	Average annual risk (%)	
	dairy	beef
< 7 days (*)	F : 6.0 M : 7.9	4.36
7 days to 1 month	2.96	1.63
1 to 2 months	1.26	0.88
2 to 6 months	2.31	1.69
6 months to 1 year	1.52	1.35
1to 2 years	1.53	1.56
2 to 3,5 years	2.6	1.5
3,5 to 5 years	3.01	1.67
5 to 10 years	4.42	1.84
> 10 years	7.54	4.28

Table 97: Mortality risk among the herd

(*) according to the "Reproscope" observatory of the “Institut de l'Elevage” (IDELE), out of 65381 French dairy herds observed for the 2013-2014 campaign, the risk of stillbirths (between birth and two days) is quite the same as the one of the first week of life, so it is not treated specifically.

These data represent basic mortality, integrating the lethalities due to the various simulated health disorders.

For crossbred dairy-beef calves, the mortality risk is the average mortality risk of both breeds.

The veterinary care contract option provides a de facto improvement in mortality due to managed diseases. For unmanaged diseases, the simulator applies a 10% reduction in mortality after one year's contract.

2.2.5.1.2 Batch management

All animals are assigned to a lot which, depending on the current location (housing, Outdoor), constitutes the environment of the animal.

2.2.5.1.2.1 Assignment

The assignment dynamics in batches is as follows:

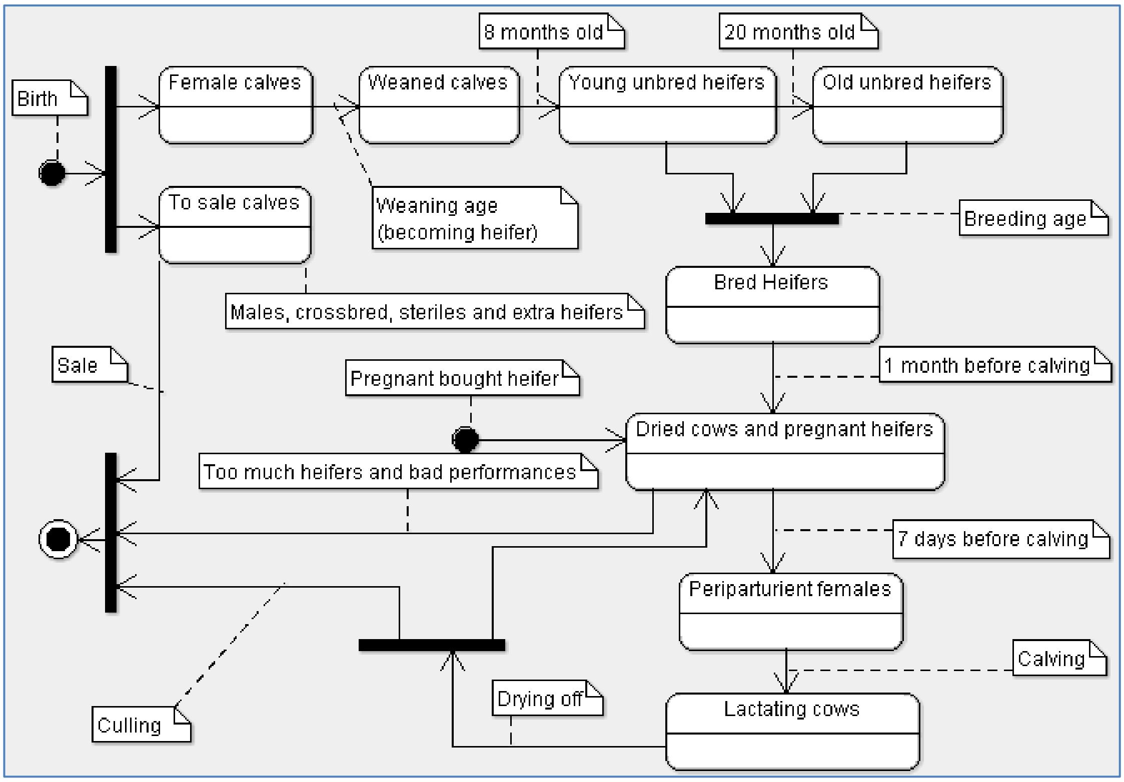


Figure 26: Assignment dynamic in batches within the farm

From birth, male calves, crossbred beef calves and sterile females are put in a batch that will be sold weekly, when they have reached the minimum age of 2 weeks, as are the extra female calves. Females destined to be raised are affected in the batch of female calves. Once weaned, they join the weaned calves batch, and at the age of 8 months the young unbred heifers batch. If the breeding age exceeds 20 months, they are grouped together once they reach this age in the batch of old unbred heifers, until they reach the breeding age that leads them into the bred heifers batch. At 1 month from the calving date, if they can contribute to an excess number of cows renewed with respect to the parameterized rate, their theoretical production performance is evaluated based on that of their dam. In case of a lower performance than the other heifers in the dried cows and pregnant heifers batch, they will be sold. Otherwise, they will be included in the batch to replace others with lower estimated performance that will be sold. Furthermore, at this stage and in case of understaffing, the necessary number of heifers will be bought and integrated into the same lot. At 7 days from calving, heifers and dry cows are integrated into the periparturient females batch until calving, which will lead them into the lactating cow batch.

Therefore, the different batches managed within the farm are the following:

- calves meant for sales (males, beef crossbreed, sterile and extra females,
- female calves (unweaned),
- weaned calves (under 8 months old),
- young unbred heifers (under 20 months old),
- old unbred heifers (if breed age is over 20 months),
- bred heifers,
- dried cows and pregnant heifers (at less than 1 month for calving),
- periparturient females (at less than 7 days for calving).
- lactating cows (inseminated or not).

2.2.5.1.2.2 *Indoor/outdoor housing*

The 3 batches are never outdoor. Heifer and cow batches are outdoor according to the planning set (see paragraph *2.2.5.2.2.1* ***Stabling and grazing***), it will define the diets (see paragraph *2.2.6.2.1 Balanced diet*) and may influence health risks.

2.2.5.2 Parameters for population and batch management

This module makes it possible to better the population management and outdoor schedule.

2.2.5.2.1 Population

Different parameters enable different strategies to manage the population.

2.2.5.2.1.1 Initial cow breed

The initial cow breed can be chosen. The default breed is Holstein.

2.2.5.2.1.2 Average number of adult cows

The average number of adult cows is configurable. Its default value is 50.

2.2.5.2.1.3 Annual herd renewal rate

It is possible for the user to define the annual herd renewal rate. This parameter is expressed as a decimal value between 0.25 (renewal of a quarter per year) and 0.5 (renewal of half per year). The default value is 0.33 (renewal of one third per year).
In addition, a parameter allows the renewal rate initially set to be increased annually. This parameter defines the differential to be added each year to the current rate, starting from the year following the first year in which the results are produced. The default value is 0.

2.2.5.2.1.4 Female calves management strategy

Three management strategies for female calves are offered to the user:

- the conservation of all female calves, the excess of which will be sold as heifers, under the same selection conditions as for the next option,
- mandatory sale of females from cows with low milk potential[1] (born of the 10% lowest recorded in the herd), with mandatory retention of females from cows recorded as being the most productive (born of the 20% highest recorded in the herd), and adjusting the number of unweaned female calves to average performance according to the renewal need, calculated on the basis of the number of female calves under one year of age present in the herd not exceeding that of the target adult population multiplied by the expected annual renewal rate plus 5% safety margin (default option),
- The sale of all female calves, and purchase of heifers in the herd according to the desired number of heifers.

2.2.5.2.1.5 Maximum number of lactations

The maximum number of lactations, determining the end of inseminations, is configurable. The default value is 7.

2.2.5.2.1.6 Production performance of the cow regarding the one of the herd

Inseminations are stopped for cows producing less than the herd average. The applicable ratio is configurable, it is 0.86 by default.

2.2.5.2.1.7 SCC level

The SCC level leading to stop the inseminations is configurable, the default value is 1000.

[1] Only the dairy potential is currently taken into account. Depending on the need and in a future version of the simulator, other genetic indexes such as susceptibility to diseases could optionally be considered at the time of selection.

2.2.5.2.1.8 *Break-even point for milk production*

A modulation factor for the break-even point for milk production at the end of long lactation can be set. The default value is 1.

2.2.5.2.2 Batch management

The levers of control for the management of the batches concern the timing of grazing and the use of a straw bed.

2.2.5.2.2.1 *Stabling and grazing*

Calves are never outdoor. For other animals, outdoor periods are configurable, default values are

Calves are never outdoor. For the other animals, the pasture periods can be set according to two modalities: in one hand heifers and dry cows, and in a second hand lactating cows.

For heifers, dry cows and peri-partum cows, the default grazing values are as follows:

Under 20 months unbred heifers	**Other heifers and dry and peri-partum cows**
April 15 to november 10	March 15 to november 10

Table 98: Default grazing schedule for heifers under 20 months, other heifers, dry cows and peri-partum

The rest of the year, the animals are in stalls.

For lactating cows, the default values for grazing and stabling are as follows:

Usage	Vaches en lactation
100% pasture	March 20 to june 30
100% stabulation	November 11 to march 10

Table 99: Default grazing and housing schedule for the lactating cow batch

The rest of the year, lactating cows are on pasture during the day and in stalls at night.

Note: This two calendars are also used for feeding (see paragraph *2.2.6.2.1 Balanced diet*).

2.2.5.2.2.2 *straw bed*

By default, the beds are straw-covered in indoor, as follows:

Calves	Indoor heifers	Indoor adult cows (*)
2	3.5	7

Table 100: Default straw consumption for straw beds (kg/d)

(*) this consumption is halved when the adult cows are indoor at night and outdoor during the day.

2.2.5.3 Data produced

Data produced concern only technical assessment related to population management.

Production type: annual.

Information level: Herd.

Result file name: these results are included in the structure of technical results described in paragraph *3.4 Result structure*.

This result allows for the recording of movements and the population situation in the herd (births, sales, purchases, mortality, culling, renewal rate) for the campaign.

The available fields are:

Field name	Format	Value
Herd_cow_average	integer	Average number of adult cows
Births_count	integer	Number of births
Male_sales_count	integer	Number of male calves sold
Beef_crossed_bred_sales_count	integer	Number of beef crossed calves sold
Sterile_female_sales_count	integer	Number of sterile female calves sold
Extra_female_sales_count	integer	Number of extra female calves sold
Extra_pregnant_heifer_sales_count	integer	Number of extra pregnant heifer sold
Heifer_bought_count	integer	Number of pregnant heifers bought
Primipare_count	integer	Number of heifers having calved
Dead_calves_count	integer	Number of dead calves (calves awaiting sale and unweaned females)
Dead_calve_per_100_calves	integer	Number of dead calves (calves awaiting sale and unweaned females) for 100 births
Dead_heifers_count	integer	Number of dead heifers
Dead_adults_count	integer	Number of dead near calving heifers and adults
Dead_adults_per_100_cows	integer	Number of dead near calving heifers and adults for 100 cows
Infertility_not_bred_decisions_count	integer	Number of not bred decisions for infertility
Lactation_rank_not_bred_decisions_count	integer	Number of not bred decisions because of lactation rank
Low_milk_product_not_bred_decisions_count	integer	Number of not bred decisions for low milk production level
Culling_percent	real	Culling percentage (number of cows culled / average number of cows)
Health_culling_count	integer	Number of animals culled for health reason
Infertility_culling_count	integer	Number of animals culled for infertility
Lactation_rank_culling_count	integer	Number of animals culled because of lactation rank
Low_milk_product_culling_count	integer	Number of cows culled for low milk production level
Longevity	real	Percentage of milk controls with cows of 4 or more lactations among milk controls
Time_between_decision_and_culling_average	integer	Average time between decision and culling (*)
Lactation_stage_at_culling_average	integer	Average lactation stage at culling (*)
Day_milk_quantity_at_culling_average	real	Average day milk quantity at culling (*)
Max_milk_quantity_at_culling	real	Max milk quantity at culling day (*)
Min_lactation_stage_at_culling	integer	Min lactation stage at culling day (*)

Table 101: Data structure on annual results of herd management

(*) Except health reason.

2.2.6 Feeding

The simulator doesn't aim to compare dairy cow feeding plans but to integrate the economic impact of food consumption which varies according to the number and production of animals. Therefore, it is essential to determine the quantities of food consumed in the herd.

2.2.6.1 Constant biological and technical values

On the first day of their lives, calves are fed on the dam's colostrum. Then they receive a daily quantity of milk until weaning or sale. The type and quantity of used milk is configurable (see paragraph *2.2.6.2.1.1 Unweaned calf* feeding). Female calves that are to be weaned receive a ration of concentrate, its composition can be configured.

For the rest, the diets implemented depend mainly on two criteria:

- the current batch of belonging (see paragraph *2.2.5.1.2.1 Assignment*),
- the local situation (see paragraph *2.2.5.1.2.2 Indoor/outdoor housing*) if the batch is concerned.

In the special case of the milk production period, two diets may be used:

- the Basic Balanced Diet (BBD) which is systematically granted, it is sized for a milk production determined by the farmer and can be parameterised (see paragraph *2.2.6.2.1.4 Lactating cow feeding*),
- the relative and complementary diet of production concentrate, allocated when the day's production exceeds the threshold corresponding to the parameterised BBD (see paragraph *2.2.6.2.2 Production concentrate diets*)

A primiparous cow consumes only 95% of the multiparous cow diet throughout her first lactation.

For the diets of the animals in the dry cows and pregnant heifers batch, the values used, not configurable, are 1/3 of the BBD given to multiparous lactating cows (see paragraph *2.2.6.2.1.4 Lactating cow feeding*), plus 1 kg Dry Matter (kgDM) of hay for indoor situation. For peripartum cows, their diet (not configurable) is the one defined above for dry cows and pregnant heifers, with the addition of 0.5 kg of Crude Matter (kgCM) of rapeseed and 0.5 kgCM of barley, all specifically reduced by 10% for heifer (Jarrige, 1988).

2.2.6.2 Parameters for feeding management

Various parameters allow the user to define the management rules related to feeding.

This setting deals with balanced diets and production supplements.

2.2.6.2.1 Balanced diet

The following configuration is used to define diets in order to have balanced feeding and nominal production as defined in paragraph *2.2.2.1.1 Basic milk quantity and composition, basic lactation duration, milk destination.*

The biological impact of diet consumption is not simulated. It is solely used for its accounting aspect. The experimenter's choices must therefore be consistent with balanced diets.

2.2.6.2.1.1 Unweaned calf feeding

The calves concerned in this paragraph are unweaned female calves kept for breeding and calves intended for sale (male, crossbred meat, sterile and extra females).

Milk:

For simplicity, the quantity of milk consumed by the calves is constant every day until weaning age. This quantity can be parameterised and is defined by default at 6kg/day. The simulator proposes also the use of 3 kinds of milk that can be defined as following:

- produced milk, taken from the bulk and therefore not sold (default value),
- discarded milk, deducted from discarded milk, then milk produced if the quantity of discarded milk of the day is not insufficient,
- discarded milk, deducted from discarded milk, then reconstituted milk from milk powder purchased by the farmer if the quantity of discarded milk of the day is not insufficient,

- reconstituted milk based on dehydrated milk bought by the farmer.

Preparing for weaning:

The weaning age of female calves (kept for breeding) can be set, its default value is 70 days. For their preparation for weaning, the given diet, which can be adjusted, is based on a concentrate mixture distributed daily and at constant level. By default, this concentrate mixture is 0.35 kgCM constituted of 80% barley and 20% soya meal.

2.2.6.2.1.2 *Weaned calf feeding*

Weaned calves are fed with forage, concentrate and minerals and vitamins intake (MVI). The balance values are configurable, defined by default as follows:

	Maize silage	Hay	Barley	Soybean meal	MVI
Quantity	2 kgDM	1 kgDM	0.5 kgCM	0.5 kgCM	0.02 kgCM

Table 102: Default values for daily feeding of weaned female calves.

These values are distributed daily at a constant level and correspond to a median age of 5 months.

2.2.6.2.1.3 *Heifer feeding*

The heifers are fed differently in indoor and outdoor, with a forage mixture and a possible supplement of concentrate and MVI. The default values for the forage and balance concentrate mixtures, and for MVI, distributed per day, are as follows:

Diet type		Heifers under 20 months (median age to 13 months)		Not bred heifers from 20 months		Bred heifers	
		Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Forage (kgDM/day)	Maize silage	5.5	0	6.5	0	8	0
	Grass	0	6	0	6.5	0	9
	Hay	0	0	0	0	1	0
	Grass silage	0	0	0	0	0	0
Concentrate (kgCM/ day)	Rapeseed meal	0	0	0	0	0	0
	Soybean meal	0,5	0	0.75	0	1	0
	Barley	0	0	0	0	0	0
MVI (kgCM/day)		0.06	0	0.06	0	0.08	0

Table 103: Default values for feeding heifers according to age and location.

2.2.6.2.1.4 *Lactating cow feeding*

The BDD distributed to lactating cows is sized for a dairy production determined by the farmer defined by default at 26 kg/day. Forage and balanced concentrate diets distributed during this period depend on the schedule. The default values are:

Period (*)	**Forage**					**Concentrate**				**MVI (kgCM)**
	Quantity (kgDM)	Maize silage (%)	Grass (%)	Hay (%)	Grass silage (%)	**Quantity** (kgCM)	Rapeseed (%)	Soybean (%)	Barley (%)	
Indoor	16	95	0	5	0	3.1	20	0	80	0.25
Outdoor	20	0	100	0	0	0	0	0	0	0
Outdoor the day and indoor at night	16	38	62	0	0	1.5	20	0	80	0.1

Table 104: Default values for feeding lactating cows according to indoor/outdoor periods.

(*) see calendar paragraph *2.2.5.2.2.1 Stabling and grazing.*

Feeding of lactating cows may be reduced as a result of production losses due to the occurrence of certain diseases. This cumulative impact is described for each disease concerned in their "*Impact on feeding*" paragraph. This only concerns the consumption of forage and concentrate.

2.2.6.2.1.5 *Dry cow feeding*

Dry cows are put in the same batch as the heifers, so they receive the same diet.

2.2.6.2.2 Production concentrate diets

When the milk production level of a cow (primiparous or multiparous) exceeds the threshold corresponding to the defined BBD (see paragraph *2.2.6.2.1.4 Lactating cow feeding*), a daily ration of production concentrate is distributed in addition to them. This ration, in kgCM, corresponds to a parameterized production gain equivalent defined by default to 2.5kg of milk per 1 kgCM of concentrate, the type of which is modifiable. By default, it is 70% barley and 30% soybean meal.

2.2.6.3 Data produced

The data produced make it possible to report forage, concentrate and minerals and vitamins consumption. The difference is made between calves, heifers and cows. The calculation method used is to divide the total annual consumption by the daily average of the animals present in the herd.

2.2.6.3.1 Milk, concentrate and minerals and vitamins consumed by calves

Production type: annual.

Level information: Herd.

Result file name: « CalfFeedingResults.csv »

This data is produced on the last day of the campaign. It concerns the consumption of calves for sale (male, crossbred, sterile and extra females), unweaned female calves and weaned female calves before they join the young heifers batch.

The available fields are:

Field name	Format	Value
Date	Date (*)	Milk consumption assessment date
Liter_discarded_milk	real	Quantity of discarded milk given to calves
Liter_bulk_milk	real	Quantity of milk from the bulk given to calves
Dehydrated_milk	real	Quantity of milk powder given to calves
Maize_silage	real	Quantity of maize silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 105: Data structure on milk consumption by calves

(*) See *Table 2: Type data formats* page *12*.

Milk power quantity is calculated by applying a constant rate of dilution of 125 g of powder per kilo of milk.

2.2.6.3.2 Forage, concentrate and minerals and vitamins consumed by heifers

Production type: annual.

Information level: Herd.

Result file name: « HeiferFeedingResults.csv »

This data is produced on the last day of the campaign. It is calculated taking into account forage, concentrate and minerals and vitamins consumption by the heifers until one month before their first calving.

The available fields are:

Field name	Format	Value
Date	Date (*)	Consumption assessment date
Maize_silage	real	Quantity of corn silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 106: Data structure on forage and concentrate consumption by calves prepared at weaning and heifers

(*) See *Table 2: Type data formats page 12.*

2.2.6.3.3 Forage, concentrate and minerals and vitamins consumed by cows

Production type: annual.

Information level: Herd.

Result file name: « CowFeedingResults.csv »

This data is produced on the last day of the campaign. It is calculated taking into account forage, concentrate and minerals and vitamins consumption by cows.

The available fields are:

Field name	Format	Value
Date	Date (*)	Consumption assessment date
Maize_silage	real	Quantity of corn silage consumed (kgDM)
Grass	real	Quantity of natural grass consumed (kgDM)
Hay	real	Quantity of hay consumed (kgDM)
Grass_silage	real	Quantity of grass silage consumed (kgDM)
Rapeseed_meal	real	Quantity of rapeseed meal consumed (kgCM)
Soja_meal	real	Quantity of soybean meal consumed (kgCM)
Barley	real	Quantity of barley consumed (kgCM)
Minerals_and_vitamins	real	Quantity of minerals and vitamins consumed (kgCM)
< *Simulation framework*>	*Table 116: Structure of the fields defining the simulation framework*	

Table 107: Data structure on forage and concentrate consumption by cows

(*) See *Table 2: Type data formats page 12.*

2.2.7 Accounting

2.2.7.1 Accounting parameters

The accounting model integrates the price of each operation for which accounting is desired. Thus, during the simulation, for each operation carried out for which a price is foreseen, this price is added to the accounting year of the farm.

For all accounting data, negative amounts are expenses for the holding, and positive amounts are income. When what is described as a product is purchased (e.g. heifers), the system uses the value as a product and reverses the sign to make it an expense.

By default, prices do not change during a simulation. However, it is possible to set a trend concerning the annual evolution (decrease or increase) of one or more of these prices, which is taken into account monthly during the simulation. This setting is described in paragraph *3.2.1.2 Accounting models*.

The initial prices (at the beginning of the simulation) are modifiable, the default values for each module are defined below.

2.2.7.1.1 Reproduction

Accounting operation	Accounting class [1]	Charge (€)
Assisted calving by a vet	Reproduction_costs	-3.00
Insemination by service	Reproduction_costs	0.00
Conventional artificial insemination	Reproduction_costs	-40.00
Male sexed artificial insemination	Reproduction_costs	-60.00
Female sexed artificial insemination	Reproduction_costs	-60.00
Cost per cow present and per year of the veterinary breeding contract	Reproduction_costs	-30.00
Cost of veterinary treatment for calved cow not seen in heat	Reproduction_costs	-9.00
Cost of veterinary treatment for successive non-fertilising artificial inseminations	Reproduction_costs	-30.00
Cost of veterinary treatment for negative pregnancy diagnosis	Reproduction_costs	-9.00

Table 108: Default rates for reproduction-related accounting transactions

2.2.7.1.2 Production

Accounting operation	Accounting class [1]	Charge (€)
Sale of a ton of milk (without penalty neither quality criteria)	Milk_sales	330.00
Cell penalty 1st threshold (for 1 ton)	Milk_sales	-3.049
Cell penalty 2nd threshold (for 1 ton)	Milk_sales	-9.147
Cell penalty 3rd threshold (for 1 ton)	Milk_sales	-15.245
TB quality bonus (for 1 ton and 38g/l based)	Milk_sales	2.60
TP quality bonus (for 1 ton and 32g/l based)	Milk_sales	6.60

Table 109: Default rates for production-related accounting transactions

The price of the milk delivered is calculated annually (no seasonal or monthly variation, unless a trend is set, see previous paragraph), it is a function of quality: if it has a cell rate higher than various levels (see paragraph *2.2.2.1.1.5 Milk destination*), a penalty will be applied, by tranche, according to the defined parameterization and whose default values are shown in *Table 109: Default rates for production-related accounting transactions*. With regard to the valuation of TB and TP, if the rate exceeds the reference rate (see *Table 109: Default rates for production-related accounting transactions*), the parameterised bonus is added per tonne according to the difference observed. On the other hand, if the quality is lower than that of the reference, a malus is applied under the same conditions.

[1] See the name of the field in the economic balance sheet published under the *Table 115: Structure of the economic balance sheet data expressed in euros*

2.2.7.1.3 Health

Accounting operation	Accounting class [1]	Charge (€)
Cost per cow present and per year of the veterinary care contract	Other_health_costs	-30.00
Cost per calving and per year of the veterinary care contract	Other_health_costs	-31.50
Cost per kiloliter per year of the veterinary care contract	Other_health_costs	-3.52
Cost out of contract for a basic treatment for lactating G1 mastitis	Mastitis_health_costs	-20.00
Cost under contract for a basic treatment for lactating G1 mastitis	Mastitis_health_costs	-20.00
Cost out of contract for a basic treatment for lactating G2 mastitis	Mastitis_health_costs	-20.00
Cost under contract for a basic treatment for lactating G2 mastitis	Mastitis_health_costs	-18.00
Cost out of contract for a basic treatment for lactating G3 mastitis	Mastitis_health_costs	-250.00
Cost under contract for a basic treatment for lactating G3 mastitis	Mastitis_health_costs	-50.00
Cost out of contract for a basic treatment for mastitis in dry cows	Mastitis_health_costs	-9.00
Cost under contract for a basic treatment for mastitis in dry cows	Mastitis_health_costs	-9.00
Additional cost of mastitis prevention with veterinary care contract / cow / year	Mastitis_health_costs	-9.00
Monensin bolus cost	Ketosis_health_costs	-40.00
Cost out of contract for basic treatment for G1 severity ketosis	Ketosis_health_costs	-6.00
Cost under contract for basic treatment for G1 severity ketosis	Ketosis_health_costs	-5.00
Cost out of contract for basic treatment for G2 severity ketosis	Ketosis_health_costs	-100.00
Cost under contract for basic treatment for G2 severity ketosis	Ketosis_health_costs	-60.00
Additional cost of ketosis prevention with veterinary care contract / cow / year	Ketosis_health_costs	-5.00
	Foot_bath_lameness_costs	-67.00
	Foot_bath_lameness_costs	-324.00
	Foot_bath_lameness_costs	-648.00
	Curative_trimming_lameness_costs or Preventive_trimming_lameness_costs	-75.00
	Curative_trimming_lameness_costs or Preventive_trimming_lameness_costs	-20.00
	Curative_collective_non_infectious_lameness_costs or Curative_individual_non_infectious_lameness_costs	-17.00
	Curative_collective_infectious_lameness_costs or Curative_individual_infectious_lameness_costs	-5.00

Table 110: Default rates for health-related accounting transactions

2.2.7.1.4 Genetics

Not applicable.

2.2.7.1.5 Population

Accounting operation	Accounting class [1]	Charge (€)
Sale of a female dairy calf	Calf_sales	60.00
Sale of a male dairy calf	Calf_sales	80.00
Sale of a beef crossbreed female calf	Calf_sales	300.00
Sale of a beef crossbreed male calf	Calf_sales	320.00
Sale of a live heifer of less than one year old	Heifer_sales	250.00
Sale of a live heifer of more than one year old	Heifer_sales	600.00
Sale/purchase of a pregnant heifer	Heifer_sales/Population_costs	800.00
Sale of a culled cow	Cull_sales	700.00

Table 111: Default rates for population-related accounting transactions

2.2.7.1.6 Feeding

Accounting operation	Accounting class [1]	Charge (€)
Purchase of one ton of a dehydrated milk powder	Feed_costs	-2000.00
Product cost of one ton of corn plant (dry matter)	Feed_costs	-200.00
Product cost of one ton of grass (crude matter)	Feed_costs	-45.00
Product cost of one ton of hay (dry matter)	Feed_costs	-140.00
Product cost of one ton of grass silage (crude matter)	Feed_costs	-130.00
Purchase of one ton of rapeseed (crude matter)	Feed_costs	-300.00
Purchase of one ton of soybean (crude matter)	Feed_costs	-330.00
Purchase of one ton of barley (crude matter)	Feed_costs	-160.00
Purchase of one ton of minerals and vitamins (crude matter)	Feed_costs	-660.00

Table 112: Default rates for feeding-related accounting transactions

2.2.7.1.7 Other accounting items

By default, the various accounting elements modelled have the following values:

Accounting operation	Accounting class [1]	Charge (€)
Rendering of a dead heifer aged up to 1 year	Other_costs	-20.00
Rendering of a dead heifer aged between 1 and 2 years	Other_costs	-30.00
Rendering of a dead cow	Other_costs	-40.00
Monthly test-day (per cow and per year)	Other_costs	-45.00
Cetodetect ® milk control test (per cow per year)	Other_costs	-3.76
Cost Herd Navigator ® (per cow per year)	Other_costs	-35.00
Product cost of one ton of straw (dry matter)	Other_costs	-20.00

Table 113: Default rates for miscellaneous accounting transactions

In order to take into account breeding costs which are not explicitly described but which nevertheless exist, the following flat rates are applied including tariffs and frequency. The modifiable tariff values have the following default values:

Package	Accounting classe (*)	Price (€)	Frequency
Purchase of bedding for a calf	Other_costs	-20.00	One time (2 month old calves)
Veterinary costs per heifer in the herd	Other_health_costs	-50.00	
Other costs of raising a calf	Other_costs	-10.00	
Purchase of bedding per cow present average	Other_costs	-20.00	Annual
Average veterinary costs per cow present (excluding managed diseases)	Other_health_costs	-40.00	
Other livestock costs per average cow present (maintenance of milking infrastructure and udder hygiene)	Other_costs	-80.00	

Table 114: Default rate and frequency of not described costs

2.2.7.2 Data produced

The data produced is about the details of the technical assessment related to economical assessment.

Production type: annual.

Information level: Herd.

Result file name: these results are included in the structure of technical results described in paragraph *3.4 Result structure*.

These data, all expressed in euros, are produced at the end of the campaign.

The available fields are:

Field name	**Method of calculation**
Gross_margin	Gross margin: Total revenue - total expenses
Total_products	Sale of milk + sale of cull cows + sale of heifers + sale of calves
Milk_sales	Proceeds from the sale of milk (including bonuses and penalties)
Cull_sales	Proceeds from the sale of cull cows
Heifer_sales	Proceeds from the sale of heifers
Calf_sales	Proceeds from the sale of calves
Total_expenses	Cost of feed + health + reproduction + other
Feed_costs	Expenses related to the purchase and production of feed
Health_costs	Expenses related to the health management
Mastitis_health_costs	Cost of mastitis treatments
Ketosis_health_costs	Cost of G1 and G2 ketosis treatments + Monensin treatment
Curative_individual_infectious_lameness_costs	Cost of individual treatments for infectious lameness (trimming + treatment)
Curative_individual_non_infectious_lameness_costs	Cost of individual treatments for non-infectious lameness (trimming + treatment)
Curative_collective_infectious_lameness_costs	Cost of collective treatment of infectious lameness (treatment only)
Curative_collective_non_infectious_lameness_costs	Cost of collective treatment of non-infectious lameness (treatment only)
Curative_trimming_lameness_costs	Cost of individual curative trimming (workshop assembly only)
Overall_curative_lameness_costs	Global cost of curative trimming
Preventive_trimming_lameness_costs	Cost of preventive trimming (workshop assembly + trimming)
Foot_bath_lameness_costs	Operating costs of the foot bath
Other_health_costs	Cost of other veterinary expenses
Reproduction_costs	Insemination-related expenses
Population_costs	Expenses related to population management
Other_costs	Residual costs: rendering, milk control

Table 115: Structure of the economic balance sheet data expressed in euros

3 Technical modalities to use the simulator (standalone version)

DHM is available in two versions: a standalone version which can be used to carry out simulations mainly for scientific purposes (long simulation times, large number of repetitions) and a server version which can be used to carry out lighter simulations as part of an on-line decision-support tool (shorter times and fewer repetitions, but making full use of the diversity of parameter settings and the exhaustiveness of the functions). The aim of this chapter is to present the various elements that make up the delivery package for the standalone version, and to describe in detail how the simulator can be used in this context, what actions need to be taken to configure it, run the simulations and obtain the results. The technical procedures for using the server version will be the subject of dedicated documentation.

3.1 Contents of the delivery package

The elements required to use the "DHM" simulator can be downloaded from the UMR BIOEPAR dedicated page: "https://www.bioepar.org/bioepar/index.php/en/dhm-content".

Windows® 10 install:

Once the package is downloaded, double-click to start the installation process. The software is then installed in the designated location (by default in the `"Program Files (x86)"` folder of the OS disk.

Linux install:

Once downloaded, the archive must be decompressed on the experimenter's workstation. For both Windows® 10 and Linux, this results in the following structure:

- `"bin "`: directory in which the `"dhm"` application and libraries are located.
- `"data"`: directory in which the data that may be useful for the simulator are located, containing:
  - o the `"AccountingData"` directory in which is present the file `"DefaultAccountingParameterValues.csv"`, based on the default values of the accounting data and valuable by the user.
  - o the `"DairyFarm"` directory in which with the default values of the breeding parameters file, duplicable and valuable by the user, `"DefaultFarmExploitationParameterValues.csv"` is located.
  - o the `"GeneticCatalogues"` directory in which is present the file `"BaseBullGeneticValues.csv"`, valuable, which is a catalogue of genetic values of bulls identical to those by default, which can be modified by the experimenter,
  - o the `"Protocols"` directory in which is present the file `"Protocols.csv"`, allowing the setting of the simulation protocols to be implemented,
  - o the `"SimulationManagement"` directory in which is present the file `" Example.csv"`, which can be modified, for grouped management of farms and simulation protocols to be implemented,
  - o the `"Technical"` directory in which is present the file `" Example.csv"`, containing technical data that cannot be modified by the user.
  - o
- `"doc"`: directory in which the simulator user documentation can be found.

3.2 Simulation setting

Generally speaking, there are two types of parameterization: static parameterization of the farms to be simulated (real, typical, fictitious and experimental, etc.) with their accounting context, and parameterization of the simulation protocols. In addition, if the simulation objectives so require, a global simulation management system is proposed, integrating the dynamic creation of farms and protocols.

3.2.1 Static settings

This setting is recommended if the range of parameters to be simulated is limited. In this case, each farm, accounting model and protocol will have to be instructed manually. This is what is defined here as the static parameter setting.

3.2.1.1 *Farms*

If the aim of the simulation is to test the behavior of one or more farms in particular, it is recommended to create a parameter file for each farm. On the other hand, if the aim is to compare the combined results of different management options for a given farm, it is preferable to proceed as described in paragraph *3.2.2 Dynamic settings*.

The present setup consists in enhancing and deploying the farm parameter file(s) in the form of text with field separators, and depositing them in the directory provided for this purpose (`"DairyFarm"`).

The technical requirements for these parameter files are as follows:

- the file must have the `".csv"` extension,
- the field separator must be the `";"` character,
- the decimal separator must be the `","` character,
- only two columns (fields) must be valued:
    - the first column is indicating the key of the parameter,
    - the second column is indicating the associated value (the `";"` character should not be used as a field value),
- Purely empty lines are accepted,
- Lines beginning with "//" are considered as comments, they are not interpreted.

The exhaustive list of keys to be valued is the subject of *Appendix I: List of the keys and formats of the husbandry parameters*.

The file `"DefaultFarmExploitationParameterValues.csv"` is an export of all the default values of the breeding parameters. This file can be directly used as an input parameter file.

Concerning the bull catalogue, the exploitable example `"BaseBullGeneticValues.csv"` is proposed in the `"data/GeneticCatalogues/"` directory, it can be modified to include the desired bull genetic values for inseminations.

3.2.1.2 *Accounting models*

The protocols are used to define the conditions of a simulation (see paragraph *3.2.1.3 Simulation protocols* below). To do this, it is necessary to also indicate the file for setting up the accounting model to be used. The accounting model is described in paragraph *2.2.7.1 Accounting parameters*.

The structure of the file for setting up an accounting model is simple and must comply with the following technical requirements:

- the file must have the `".csv"` extension,
- the field separator must be the `";"` character,
- the decimal separator must be the `","` character,
- three columns (fields) must be valued:
    - the first column is indicating the key of the accounting action,
    - the second column is indicating the associated price (positive = product, negative = charge),
    - the third column is indicating the price tendency (neutral value = 1).

The exhaustive list of keys to be valued is the subject of *Appendix II: List of accounting model parameter keys*.

The file `"DefaultAccountingParameterValues.csv"` provided in the `"data/AccountingData/"` directory of the delivery package is an export of all default accounting values. This file can be directly used as an import file.

3.2.1.3 *Simulation protocols*

The protocols enable the desired simulation modes to be defined for each of the parameterised farms, by determining the duration of the simulation (in years) and the number of repetitions ("runs"). The usefulness of multiplying the number of repetitions lies in the fact that, as the simulation is stochastic, each "run", although applying the same probability rules, is carried out with its own randomness and therefore gives its own results, logically different from the other "runs". By carrying out several repetitions, it will be possible to carry out a grouped analysis of the different cases encountered which have given these different results.

The protocol file structure is simple; it must comply with the following technical requirements:

- the file must have the ".csv" extension,
- the field separator must be the ";" character,
- eight columns (fields) must be valued:
    - the first column indicating the reduced protocol name, it is under this directory name that the result files relating to the corresponding protocol will be stored.,
    - the second column showing the full name of the protocol,
    - the third column indicating the duration of the simulation (in number of years, including warmup),
    - the fourth column indicating the warmup duration (in number of years), initial period during which no results will be published,
    - the fifth column indicating the begin month of the simulation and result publication,
    - the sixth column indicating the begin year of the simulation (4 characters),
    - the seventh column indicating the number of repetitions ("runs"),
    - the eighth column indicating the name (without path) of the farm setting file to be used through the protocol (see paragraph *3.2.1.1 Farms*). If no name is specified here (empty field), a farm with default values will be used. If the value "_all" is specified, the protocol will be implemented for all existing farms,
    - the ninth column indicating the name (without path neither extention) of the accounting model setting file to be used through the protocol (see paragraph *3.2.1.2 Accounting models*). If no name is specified here (empty field), an accounting model with default values will be used.
- The columns from ten to thirteen are optional, they allow to determine up to four discriminants which will be found in the last columns in the merged results.

The "Protocols.csv" file provided in the "data/" folder of the delivery package is an example for the setting of three protocols (1 year, 5 years and 15 years) for a start of simulation in January 2022, for respectively eight, eight and sixteen replications without warmup implementing the default breeding and using the default accounting model. Valuable, it is directly usable.

3.2.2 Dynamic settings

The above recommendations may be difficult to implement when the simulation consists, based on a given farm, of comparing the results of a combined and exhaustive variation of one or more parameters. For example, if you wanted to compare the effects of combining the different options of the veterinary care contract (4 values) at 3 production levels, 3 mastitis prevention levels and 3 ketosis prevention levels, you would have to create 4x3x3x3 = 108 different farm files, each one parameterized according to the combination to be tested. To avoid this tedious and error-prone task, we have set up a global simulation management system, which can be used to create a single file describing the protocol and cross-parameterization to be implemented. This file must have the extension ".csv", the field separator must be the character ";", and it must be stored in the dedicated directory ("SimulationManagement"). To be implemented, the "--SimulationManagementFileName" option must be used (see *Figure 27: Console for displaying the simulation launch options*).

The values to be included in this file concern two aspects: the description of the common protocol and the parameter combinations to be implemented.

3.2.2.1 Protocol description

As far as setting the common protocol in this file is concerned, it must respect the rule of the first field being the key and the second being the value to be assigned; any other field on the same line will be ignored. Possible keys are as follows:

- "simulationDuration": simulation duration (in years),
- "warmupDuration": duration of warmup period (in years),
- "simMonth": simulation start month,
- "runNumber": number of repetitions,
- "farmName": name (without path or extension) of the farm parameter file to be used,

The order is not important here.

Example :

```
simulationDuration;5
warmupDuration;0
simMonth;1
simYear;2023
runNumber;8
farmName;FarmToSimulate
```

If these (optional) values are not present in the file, the default values are used. If the `"farmName"` key is present, the associated farm must first have been created (see paragraph *3.2.1.1 Farms*).

3.2.2.2 Parameter combinations

The principle is different for the dynamic combination of breeding parameters to be compared, also to be used in the same simulation management file. It's a matter of defining the range of variation of each of the parameters to be used (maximum 4) in the desired order. The rule is to define the first field as the key (see *Table 118: Keys and formats for farm management parameters*) and the following fields as the successive values to be experimented with in a nested manner. The value `"_basis"` means that the value to be tested will be the one defined when the original farm was created.

Example:

```
vetCareContract;_basis;1;2;3
herdProductionDelta_Lait;-1727;_basis;1810;
individualMastitisIncidencePreventionFactor;0,4;_basis;1,7;
ketosisIncidencePreventionFactor;0,4;_basis;1,7;
```

In this example, 4 breeding parameters are successively implemented:

- the 4 possible options of the `"vetCareContract"` parameter (the first being the original one). This will cause the `"Discriminant1"` to change from `"A"` to `"D"` in the results,
- 3 `"herdProductionDelta_Lait"` parameter values (the second being the original). This will cause `"Discriminant2"` to vary from `"A"` to `"C"` in the results,
- 3 values for the `"individualMastitisIncidencePreventionFactor"` parameter (the second being the original one). This will cause the `"Discriminant3"` to change from `"A"` to `"C"` in the results,
- 3 values of the `"ketosisIncidencePreventionFactor"` parameter (the second being the original one). This will cause `"Discriminant4"` to vary from `"A"` to `"C"` in the results.

The sub-protocols thus generated (and the determination of the 4 discriminants) will therefore go from "AAAA" to "DCCC", implementing all combinations (108 in total for this example).

3.3 Simulation sequence

Once the desired farms and protocols have been configured (as is the case with default deployment), or a simulation management file has been set up, the simulator can be launched.

The following commands examples of starting a simulation based on the default deployment structure:

- For Windows® 10:

```
cd bin
dhm
```

- For linux, it is mandated to export libraries. All can be done with the following command:

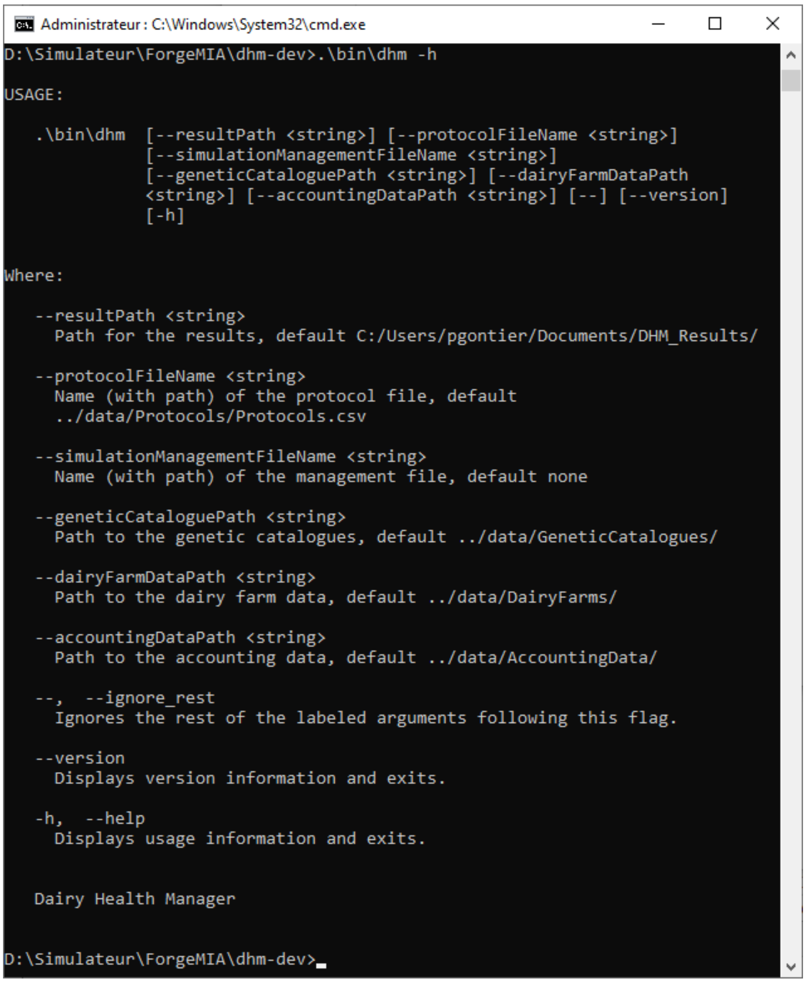
```
LD_LIBRARY_PATH="<pwd>/bin/"
export LD_LIBRARY_PATH
./bin/dhm
```

The `"run.bat"` for Windows® 10 and `"run.sh"` for linux files provided in the root of each of the delivery packages execute this(ese) command(s). For an installation under Windows® 10, the simulation can also be launched from the shortcut in the "DHM" folder of the "Start" menu, or by clicking on the shortcut on the desktop if this option has been chosen.

Depending on your needs, you can set different launch parameters. They are presented in the help command (Windows® 10):

```
.\bin\dhm -h
```

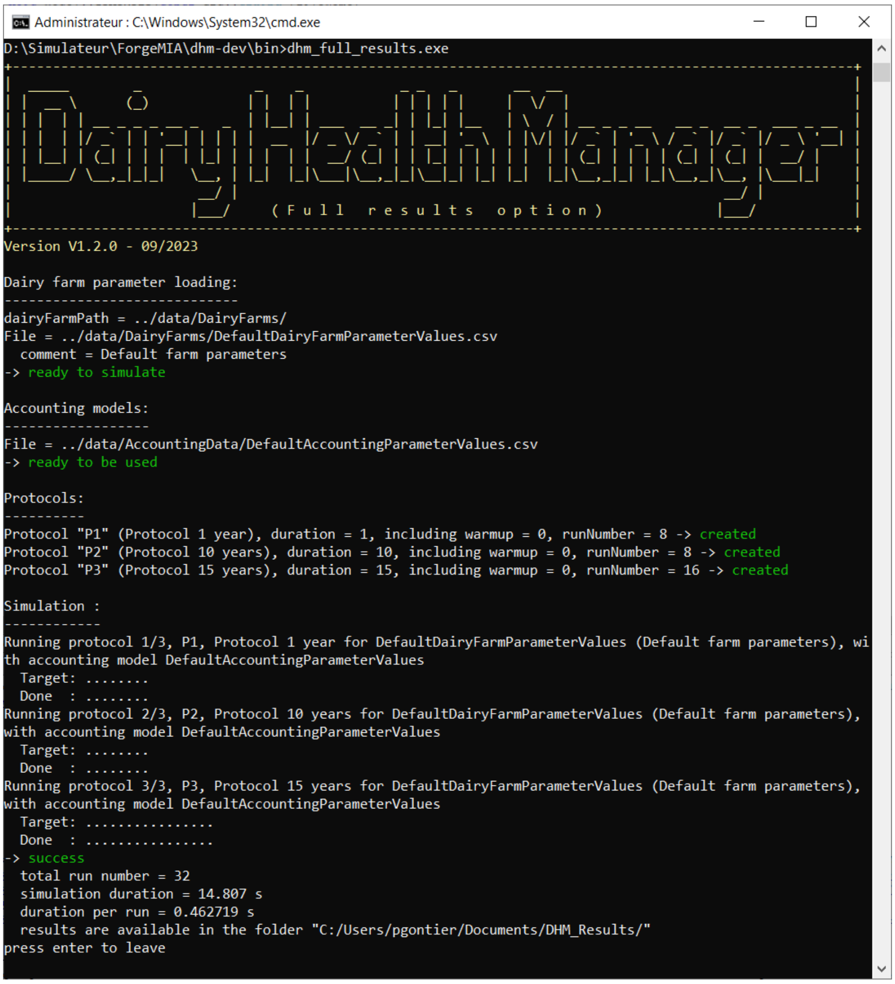
These parameters are as follows:



```
Administrateur : C:\Windows\System32\cmd.exe
D:\Simulateur\ForgeMIA\dhm-dev>.\bin\dhm -h

USAGE:

   .\bin\dhm  [--resultPath <string>] [--protocolFileName <string>]
              [--simulationManagementFileName <string>]
              [--geneticCataloguePath <string>] [--dairyFarmDataPath
              <string>] [--accountingDataPath <string>] [--] [--version]
              [-h]


Where:

   --resultPath <string>
     Path for the results, default C:/Users/pgontier/Documents/DHM_Results/

   --protocolFileName <string>
     Name (with path) of the protocol file, default
     ../data/Protocols/Protocols.csv

   --simulationManagementFileName <string>
     Name (with path) of the management file, default none

   --geneticCataloguePath <string>
     Path to the genetic catalogues, default ../data/GeneticCatalogues/

   --dairyFarmDataPath <string>
     Path to the dairy farm data, default ../data/DairyFarms/

   --accountingDataPath <string>
     Path to the accounting data, default ../data/AccountingData/

   --,  --ignore_rest
     Ignores the rest of the labeled arguments following this flag.

   --version
     Displays version information and exits.

   -h,  --help
     Displays usage information and exits.


   Dairy Health Manager


D:\Simulateur\ForgeMIA\dhm-dev>
```

Figure 27: Console for displaying the simulation launch options

When running a simulation with the default settings, the following information is displayed in the console:



```
D:\Simulateur\ForgeMIA\dhm-dev\bin>dhm_full_results.exe
( F u l l   r e s u l t s   o p t i o n )
Version V1.2.0 - 09/2023

Dairy farm parameter loading:
----------------------------
dairyFarmPath = ../data/DairyFarms/
File = ../data/DairyFarms/DefaultDairyFarmParameterValues.csv
  comment = Default farm parameters
-> ready to simulate

Accounting models:
------------------
File = ../data/AccountingData/DefaultAccountingParameterValues.csv
-> ready to be used

Protocols:
----------
Protocol "P1" (Protocol 1 year), duration = 1, including warmup = 0, runNumber = 8 -> created
Protocol "P2" (Protocol 10 years), duration = 10, including warmup = 0, runNumber = 8 -> created
Protocol "P3" (Protocol 15 years), duration = 15, including warmup = 0, runNumber = 16 -> created

Simulation :
------------
Running protocol 1/3, P1, Protocol 1 year for DefaultDairyFarmParameterValues (Default farm parameters), wi
th accounting model DefaultAccountingParameterValues
  Target: ........
  Done  : ........
Running protocol 2/3, P2, Protocol 10 years for DefaultDairyFarmParameterValues (Default farm parameters),
with accounting model DefaultAccountingParameterValues
  Target: ........
  Done  : ........
Running protocol 3/3, P3, Protocol 15 years for DefaultDairyFarmParameterValues (Default farm parameters),
with accounting model DefaultAccountingParameterValues
  Target: ................
  Done  : ................
-> success
  total run number = 32
  simulation duration = 14.807 s
  duration per run = 0.462719 s
  results are available in the folder "C:/Users/pgontier/Documents/DHM_Results/"
press enter to leave
```

Figure 28 : Console for displaying the simulation based on the default deployment structure

The first operation carried out was to load the only breeding set up (with default values) and present in the indicated directory. This is also the case for the default accounting model and finally for protocols that are also presents. The simulation was then carried out by starting protocols and depositing the results in the indicated directory. The structure of the results is described in paragraph *3.4 Result structure*.

3.4 Result structure

The results files are stored in the directory defined as such when the software was installed. Most of the results are contained in files described in each of the chapters concerned. The specific fields include those defining the simulation framework, i.e.:

Field name	Method of calculation
Campaign (*)	Campaign involved
Run_number	Run number (0 based)
Discriminant1	First discriminant value (see paragraph *3.2.1.3*)
Discriminant2	Second discriminant value (see paragraph *3.2.1.3*)
Discriminant3	Third discriminant value (see paragraph *3.2.1.3*)
Discriminant4	Fourth discriminant value (see paragraph *3.2.1.3*)

Table 116: Structure of the fields defining the simulation framework

(*) See *Table 2: Type data formats* page *12*.

For each of the results files, the following fields are as described in the corresponding chapters.

However, to facilitate their analysis, some specific results have been merged into a single file called "TechnicalAndEconomicalResults.csv". This is the case for the technical results relating to reproduction,

production, diseases managed, population management and the economic balance sheet. This file is organised as follows:

Field class	Reference
Simulation framework	*Table 116: Structure of the fields defining the simulation framework*
Reproduction data	*§ 2.2.1.3.3*
Production data	*§ 2.2.2.3.4*
Managed diseases data	*§ 2.2.3.4*
Population data	*§ 2.2.5.3*
Economical data	*§ 2.2.7.2*

Table 117: Technical data structure

3.5 Technical data

The characteristics necessary for the simulator use are as follows:

Standalone desk:

The minimum characteristics expected are as follows:

- Memory: 8 GB

- CPU: 2GHz clock, 4 cores

- Disk space: 10 MB (depending on the simulation protocols).

The duration and number of repetitions for the simulations performed with “full results” version from the default farm according to the default protocol are as follows

- 12 years of pre-simulation + 1 year of actual simulation, no warmup, 8 repetitions

- 12 years of pre-simulation + 10 years of actual simulation, no warmup, 8 replicates

- 12 years of pre-simulation + 15 years of actual simulation, no warmup, 16 replicates

This protocol leads to 32 repetitions for a total machine time of about 15 seconds, which represents less than 5/10th of a second per repetition, the results occupy 4.57 MB of disk space.

4 Acknowledgements

We would like to thank Aurélien Madouasse for his expertise in the field of interaction between biology and animal husbandry.

Thanks also to François Beaudeau for his valuable assistance during the development of the genetic module.

Finally, thanks to Claire Jutel and Solène Baussain, students at Oniris, for the bibliographical studies they carried out as part of their veterinary thesis on the subject of respectively ketosis and lameness, and then for their involvement in the development of the relevant parts of the simulator, work which greatly contributed to the enrichment and maturity of the simulator.

5 Documentary sources

Afonso, J.S. *et al.* (2020) « Profiling Detection and Classification of Lameness Methods in British Dairy Cattle Research: A Systematic Review and Meta-Analysis », *Frontiers in Veterinary Science*, 7(August), p. 1-20. doi:10.3389/fvets.2020.00542.

Ariza, J.M. *et al.* (2017) « Effectiveness of collective treatments in the prevention and treatment of bovine digital dermatitis lesions: A systematic review », *Journal of Dairy Science*, 100(9), p. 7401-7418. doi:10.3168/jds.2016-11875.

Bar, D. *et al.* (2008) « Effects of repeated episodes of generic clinical mastitis on mortality and culling in dairy cows », *Journal of Dairy Science*, 91(6), p. 2196-2204. doi:10.3168/jds.2007-0460.

Bareille, N. *et al.* (2003) « Effects of health disorders on feed intake and milk production in dairy cows », *Livestock Production Science*, 83(1), p. 53-62. doi:10.1016/S0301-6226(03)00040-X.

Bareille, N. (Oniris N. *et al.* (2016) *Polycopié n° 1 : Reproduction des bovins laitiers ; Elevage des jeunes et du prétroupeau*.

Bareille, N. (Oniris N. *et al.* (2017) « Polycopié N° 2 : Lactation et production de lait chez les bovins laitiers ».

Barker, Z.E. *et al.* (2010) « Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales », *Journal of Dairy Science*, 93(3), p. 932-941. doi:10.3168/jds.2009-2309.

Beaudeau, F. (Oniris N. *et al.* (2016) « Polycopié n° 3 : Amélioration génétique des bovins laitiers ».

Belay, T.K. *et al.* (2017) « Genetic parameters of blood β-hydroxybutyrate predicted from milk infrared spectra and clinical ketosis, and their associations with milk production traits in Norwegian Red cows », *Journal of Dairy Science*, 100(8), p. 6298-6311. doi:10.3168/jds.2016-12458.

Benedet, A. *et al.* (2019) « Invited review: β-hydroxybutyrate concentration in blood and milk and its associations with cow performance », *Animal*, 13(8), p. 1676-1689. doi:10.1017/S175173111900034X.

Berge, A.C. et Vertenten, G. (2014) « A field study to determine the prevalence, dairy herd management systems, and fresh cow clinical conditions associated with ketosis in western European dairy herds », *Journal of Dairy Science*, 97(4), p. 2145-2154. doi:10.3168/jds.2013-7163.

Berry, D.L. *et al.* (1998) « The expression pattern of thyroid hormone response genes in remodeling tadpole tissues defines distinct growth and resorption gene expression programs », *Developmental Biology*, 203(1), p. 24-35. doi:10.1006/dbio.1998.8975.

Besbaci, M. *et al.* (2020) « Association of pregnancy per artificial insemination with gonadotropin-releasing hormone and human chorionic gonadotropin administered during the luteal phase after artificial insemination in dairy cows: A meta-analysis », *Journal of Dairy Science*, 103(2), p. 2006-2018. doi:10.3168/jds.2019-16439.

Bicalho, R.C. *et al.* (2007) « Visual locomotion scoring in the first seventy days in milk: Impact on pregnancy and survival », *Journal of Dairy Science*, 90(10), p. 4586-4591. doi:10.3168/jds.2007-0297.

Billon, D. (Oniris N. (2015) *Simulateur ECOMAST – Présentation générale*.

Bobe, G., Young, J.W. et Beitz, D.C. (2004) « Invited review: Pathology, etiology, prevention, and treatment of fatty liver in dairy cows », *Journal of Dairy Science*, 87(10), p. 3105-3124. doi:10.3168/jds.S0022-0302(04)73446-3.

Booth, C.J. *et al.* (2004) « Effect of lameness on culling in dairy cows », *Journal of Dairy Science*, 87(12), p. 4115-4122. doi:10.3168/jds.S0022-0302(04)73554-7.

Chanvallon, A. (Idele) *et al.* (2011) *DetŒstrus laitier : améliorer la détection des chaleurs dans les troupeaux bovins laitiers*.

Chesnin, A. et Bareille, N. (2011) « Impact de la dermatite digitée sur la production des vaches laitières », p. 106.

Coulon, J.B., Chilliard, Y. et Rémond, B. (1991) « Effets du stade physiologique et de la saison la composition chimique du lait de vache et caractéristiques technologiques », *INRA Productions Animales*, 4(3), p. 219-228.

Croué, I. *et al.* (2017) « Genetic evaluation of claw health traits accounting for potential preselection of cows to be trimmed », *Journal of Dairy Science*, 100(10), p. 8197-8204. doi:10.3168/jds.2017-13002.

Cutler, J.H.H. *et al.* (2017) « Producer estimates of prevalence and perceived importance of lameness in dairy herds with tiestalls, freestalls, and automated milking systems », *Journal of Dairy Science*, 100(12), p. 9871-9880. doi:10.3168/jds.2017-13008.

Daros, R.R. *et al.* (2019) « Lameness during the dry period: Epidemiology and associated factors », *Journal of Dairy Science*, 102(12), p. 11414-11427. doi:10.3168/jds.2019-16741.

Dezetter, C. (2015) *Evaluation de l'intérêt du croisement entre races bovines laitières*. Thèse de doctorat.

Disenhaus, C. *et al.* (2008) « Breed comparison of post partum cyclicity in cows », in, p. 1-4.

Disenhaus, C. *et al.* (2010) « Vers une cohérence des pratiques de détection des chaleurs : intégrer la vache , l'éleveur et le système d'élevage », *Rencontres Recherches Ruminants*, (17), p. 113-120.

Dohoo, I.R. *et al.* (1983) « Disease, production and culling in Holstein-Friesian cows I. The data », *Preventive Veterinary Medicine*, 1(4), p. 321-334. doi:10.1016/0167-5877(83)90003-X.

Van Dorp, T.E. *et al.* (1998) « Genetic Parameters of Health Disorders, and Relationships with 305-Day Milk Yield and Conformation Traits of Registered Holstein Cows », *Journal of Dairy Science*, 81(8), p. 2264-2270. doi:10.3168/jds.S0022-0302(98)75806-0.

Douart, A. (2015) *Pathologie médicale des Ruminants*.

van der Drift, S.G.A. *et al.* (2012) « Routine detection of hyperketonemia in dairy cows using Fourier transform infrared spectroscopy analysis of β-hydroxybutyrate and acetone in milk in combination with test-day information », *Journal of Dairy Science*, 95(9), p. 4886-4898. doi:10.3168/jds.2011-4417.

van der Drift, S.G.A. *et al.* (2015) « Effects of a single glucocorticoid injection on propylene glycol-treated cows with clinical ketosis », *Veterinary Journal*, 204(2), p. 144-149. doi:10.1016/j.tvjl.2015.01.016.

Duffield, T. (2000) « Subclinical ketosis in lactating dairy cattle. », *The Veterinary clinics of North America. Food animal practice*, 16(2), p. 231-253. doi:10.1016/S0749-0720(15)30103-1.

Duffield, T.F. *et al.* (2009) « Impact of hyperketonemia in early lactation dairy cows on health and production », *Journal of Dairy Science*, 92(2), p. 571-580. doi:10.3168/jds.2008-1507.

Duffield, T.F., Rabiee, A.R. et Lean, I.J. (2008) « A meta-analysis of the impact of monensin in lactating dairy cattle. Part 3. Health and reproduction », *Journal of Dairy Science*, 91(6), p. 2328-2341. doi:10.3168/jds.2007-0801.

Ettema, J., Østergaard, S. et Kristensen, A.R. (2010) « Modelling the economic impact of three lameness causing diseases using herd and cow level evidence », *Preventive Veterinary Medicine*, 95(1-2), p. 64-73. doi:10.1016/j.prevetmed.2010.03.001.

Foster, L.A. (1988) « Clinical ketosis. », *The Veterinary clinics of North America. Food animal practice*, 4(2), p. 253-267. doi:10.1016/S0749-0720(15)31047-1.

Fourichon, C., Seegers, H. et Malher, X. (2000) « Effect of disease on reproduction in the dairy cow: A meta-analysis », *Theriogenology* [Preprint]. doi:10.1016/S0093-691X(00)00311-3.

Gaude, I. *et al.* (2017) « Comparison of visual and computerized estrous detection and evaluation of influencing factors », *Animal Reproduction Science*, 184(July), p. 211-217. doi:10.1016/j.anireprosci.2017.07.019.

Germain, M.E. (2009) *La double ovulation chez la vache*.

Gernand, E. *et al.* (2012) « Incidences of and genetic parameters for mastitis, claw disorders, and common health traits recorded in dairy cattle contract herds », *Journal of Dairy Science*, 95(4), p. 2144-2156. doi:10.3168/jds.2011-4812.

Gontier, P., Bareille, N. et Picault, S. (2022) « Dairy Health Manager : un simulateur multi-agents flexible pour l'étude des maladies des animaux d'élevage », in *30. Journées Francophones sur les Systèmes Multi-Agents*. Saint-Etienne, France: Cépaduès Editions (30. Journées Francophones sur les Systèmes Multi-Agents), p. 97-106. Disponible sur: https://hal.inrae.fr/hal-03710369.

Gordon, J.L., LeBlanc, S.J. et Duffield, T.F. (2013) « Ketosis treatment in lactating dairy cattle », *Veterinary Clinics of North America - Food Animal Practice*. Elsevier, p. 433-445. doi:10.1016/j.cvfa.2013.03.001.

Green, L.E. *et al.* (2014) « Temporal associations between low body condition, lameness and milk yield in a UK dairy herd », *Preventive Veterinary Medicine*, 113(1), p. 63-71. doi:10.1016/j.prevetmed.2013.10.009.

Gröhn, Y.T. *et al.* (1989) « Epidemiology of Metabolic Disorders in Dairy Cattle: Association Among Host Characteristics, Disease, and Production », *Journal of Dairy Science*, 72(7), p. 1876-1885. doi:10.3168/jds.S0022-0302(89)79306-1.

Hagen, N. (ENV T. et Gayrard, V. (ENV T. (2005) « Mémento des critères numériques de reproduction des mammifères domestiques », p. 1-9.

Han van der Kolk, J.H. *et al.* (2017) « Disturbed bovine mitochondrial lipid metabolism: A review », *Veterinary Quarterly*. Taylor and Francis Ltd., p. 262-273. doi:10.1080/01652176.2017.1354561.

Hernandez, J.A. *et al.* (2007) « Evaluation of the efficacy of prophylactic hoof health examination and trimming during midlactation in reducing the incidence of lameness during late lactation in dairy cows », *Journal of the American Veterinary Medical Association*, 230(1), p. 89-93. doi:10.2460/javma.230.1.89.

Hortet, P. *et al.* (1999) « Reduction in milk yield associated with somatic cell counts up to 600 000 cells/ml in French Holstein cows without clinical mastitis », *Livestock Production Science*, 61(1), p. 33-42. doi:10.1016/S0301-6226(99)00051-2.

Hortet, P. (2000) *Evaluation ex-ante de l'efficacité économique des programmes de maîtrise des infections intramammaires en élevage bovin laitier*. Thèse de doctorat.

Humblot, P. (2001) « Use of pregnancy specific proteins and progesterone assays to monitor pregnancy and determine the timing, frequencies and sources of embryonic mortality in ruminants », *Theriogenology*, 56(9), p. 1417-1433. doi:10.1016/S0093-691X(01)00644-6.

van Huyssteen, M. *et al.* (2020) « Association between lameness risk assessment and lameness and foot lesion prevalence on dairy farms in Alberta, Canada », *Journal of Dairy Science*, 103(12), p. 11750-11761. doi:10.3168/jds.2019-17819.

Institut de l'élevage (2021a) « Bilan Génétique de l'Insémination en races bovines laitières ».

Institut de l'élevage (2021b) « Résultats de contrôle laitier - Espèce bovine - France 2021 ».

Jarrige, R. (1988) *Alimentation Des Bovins, Ovins & Caprins*. Édité par Inra. Disponible sur: http://books.google.co.ma/books?id=SQxJAAAAYAAJ.

Kaufman, E.I. *et al.* (2016) « Association of rumination time with subclinical ketosis in transition dairy cows », *Journal of Dairy Science*, 99(7), p. 5604-5618. doi:10.3168/jds.2015-10509.

Kerbrat, S. et Disenhaus, C. (2004) « A proposition for an updated behavioural characterisation of the oestrus period in dairy cows », *Applied Animal Behaviour Science*, 87(3-4), p. 223-238. doi:10.1016/j.applanim.2003.12.001.

Khansefid, M., Haile-Mariam, M. et Pryce, J.E. (2021) « Including milk production, conformation, and functional traits in multivariate models for genetic evaluation of lameness », *Journal of Dairy Science*, 104(10), p. 10905-10920. doi:10.3168/jds.2020-20074.

Koeck, A. *et al.* (2012) « Health recording in Canadian Holsteins: Data and genetic parameters », *Journal of Dairy Science*, 95(7), p. 4099-4108. doi:10.3168/jds.2011-5127.

Koeck, A. *et al.* (2014) « Genetic relationships of clinical mastitis, cystic ovaries, and lameness with milk yield and somatic cell score in first-lactation Canadian Holsteins », *Journal of Dairy Science*, 97(9), p. 5806-5813. doi:10.3168/jds.2013-7785.

Kofler, J. *et al.* (2021) « Auswirkung von Lahmheit auf Fruchtbarkeits-merkmale bei Fleck-vieh-Kühen in Österreich – Ergebnisse aus dem Efficient-Cow-Projekt », *Schweizer Archiv fur Tierheilkunde*, 164(11), p.

721-736. doi:10.17236/sat00323.

Macmillan, K. *et al.* (2017) « Accuracy of a cow-side test for the diagnosis of hyperketonemia and hypoglycemia in lactating dairy cows », *Research in Veterinary Science*, 115(November 2016), p. 327-331. doi:10.1016/j.rvsc.2017.06.019.

Manske, T., Hultgren, J. et Bergsten, C. (2002a) « Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows », *Preventive Veterinary Medicine*, 54(3), p. 247-263. doi:10.1016/S0167-5877(02)00018-1.

Manske, T., Hultgren, J. et Bergsten, C. (2002b) « The effect of claw trimming on the hoof health of Swedish dairy cattle », *Preventive Veterinary Medicine*, 54(2), p. 113-129. doi:10.1016/S0167-5877(02)00020-X.

Marceau, A. *et al.* (2014) « Can routinely recorded reproductive events be used as indicators of disease emergence in dairy cattle? An evaluation of 5 indicators during the emergence of bluetongue virus in France in 2007 and 2008 », *Journal of Dairy Science*, 97(10), p. 6135-6150. doi:10.3168/jds.2013-7346.

McArt, J.A.A. *et al.* (2011) « A field trial on the effect of propylene glycol on milk yield and resolution of ketosis in fresh cows diagnosed with subclinical ketosis », *Journal of Dairy Science*, 94(12), p. 6011-6020. doi:10.3168/jds.2011-4463.

McArt, J.A.A., Nydam, D. V. et Oetzel, G.R. (2012a) « A field trial on the effect of propylene glycol on displaced abomasum, removal from herd, and reproduction in fresh cows diagnosed with subclinical ketosis », *Journal of Dairy Science*, 95(5), p. 2505-2512. doi:10.3168/jds.2011-4908.

McArt, J.A.A., Nydam, D. V. et Oetzel, G.R. (2012b) « Epidemiology of subclinical ketosis in early lactation dairy cattle », *Journal of Dairy Science*, 95(9), p. 5056-5066. doi:10.3168/jds.2012-5443.

McArt, J.A.A., Nydam, D. V. et Overton, M.W. (2015) « Hyperketonemia in early lactation dairy cattle: A deterministic estimate of component and total cost per case », *Journal of Dairy Science*, 98(3), p. 2043-2054. doi:10.3168/jds.2014-8740.

Meignan, T. (2018) *Thomas MEIGNAN*, *Evaluation des effets de l'utilisation de la graine de lin extrudée en élevages bovins laitiers*.

Le Mézec, P. (Idele) (2015) « Le point sur l ' utilisation de la semence sexée en 2014 Les génisses donneront des génisses ... », 2011, p. 4-7.

Morgan, W.F. et Lean, I.J. (1993) « Gonadotrophin-releasing hormone treatment in cattle: a meta-analysis of the effects on conception at the time of insemination. », *Australian veterinary journal*, 70(6), p. 205-209. doi:10.1111/j.1751-0813.1993.tb03304.x.

Mostert, P.F. *et al.* (2017) « Estimating the economic impact of subclinical ketosis in dairy cattle using a dynamic stochastic simulation model », *Animal*, 12(1), p. 145-154. doi:10.1017/S1751731117001306.

Nielsen, B.H., Thomsen, P.T. et Sørensen, J.T. (2009) « A study of duration of digital dermatitis lesions after treatment in a Danish dairy herd. », *Acta veterinaria Scandinavica*, 51, p. 27. doi:10.1186/1751-0147-51-27.

O'Connor, A.H. *et al.* (2020) « Associating mobility scores with production and reproductive performance in pasture-based dairy cows », *Journal of Dairy Science*, 103(10), p. 9238-9249. doi:10.3168/jds.2019-17103.

Oehm, A.W. *et al.* (2019) « A systematic review and meta-analyses of risk factors associated with lameness in dairy cows », *BMC Veterinary Research*, 15(1), p. 1-14. doi:10.1186/s12917-019-2095-2.

Oliveira Junior, G.A. *et al.* (2021) « Estimated genetic parameters for all genetically evaluated traits in Canadian Holsteins », *Journal of Dairy Science* [Preprint], (2019). doi:10.3168/jds.2021-20227.

Østergaard, S., Sørensen, J.T. et Houe, H. (2003) « A stochastic model simulating milk fever in a dairy herd », *Preventive Veterinary Medicine*, 58(3-4), p. 125-143. doi:10.1016/S0167-5877(03)00049-7.

Peeler, E., Otte, M. et Esslemont, R. (1994) « Inter-relationships of periparturient diseases in dairy cows », *Veterinary Record*, 134(6), p. 129-132. doi:10.1136/vr.134.6.129.

Pérez-Cabal, M.A. et Charfeddine, N. (2015) « Models for genetic evaluations of claw health traits in Spanish dairy cattle », *Journal of Dairy Science*, 98(11), p. 8186-8194. doi:10.3168/jds.2015-9562.

Perrin, J.B. *et al.* (2011) « Analyse de la mortalite bovine en France de 2003 a 2009 », *Productions Animales*, 24(3), p. 235-244.

Pritchard, T. *et al.* (2013) « Genetic parameters for production, health, fertility and longevity traits in dairy cows », *Animal*, 7(1), p. 34-46. doi:10.1017/S1751731112001401.

Raboisson, D. *et al.* (2015) « The economic impact of subclinical ketosis at the farm level: Tackling the challenge of over-estimation due to multiple interactions », *Preventive Veterinary Medicine*, 122(4), p. 417-425. doi:10.1016/j.prevetmed.2015.07.010.

Raboisson, D., Mounié, M. et Maigné, E. (2014) « Diseases, reproductive performance, and changes in milk production associated with subclinical ketosis in dairy cows: A meta-analysis and review », *Journal of Dairy Science*, 97(12), p. 7547-7563. doi:10.3168/jds.2014-8237.

Relun, A. *et al.* (2012) « Effectiveness of different regimens of a collective topical treatment using a solution of copper and zinc chelates in the cure of digital dermatitis in dairy farms under field conditions », *Journal of Dairy Science*, 95(7), p. 3722-3735. doi:10.3168/jds.2011-4983.

Relun, A., Lehebel, A., Chesnin, A., *et al.* (2013) « Association between digital dermatitis lesions and test-day milk yield of Holstein cows from 41 French dairy farms », *Journal of Dairy Science*, 96(4), p. 2190-2200. doi:10.3168/jds.2012-5934.

Relun, A., Lehebel, A., Bruggink, M., *et al.* (2013) « Estimation of the relative impact of treatment and herd management practices on prevention of digital dermatitis in French dairy herds », *Preventive Veterinary Medicine*, 110(3-4), p. 558-562. doi:10.1016/j.prevetmed.2012.12.015.

Rémond, B., Kérouanton, J. et Brocard, V. (1997) « Effets de la réduction de la durée de la période sèche ou de son omission sur les performances des vaches laitières », *INRA Productions Animales*, 10(4), p. 301-315.

Rémond, B., Pomiès, D. et Pradel, P. (2005) « Effect of once daily milking of dairy cows on their production , according to their level of feeding », (1), p. 229-232.

Robert-Briand, A. (2006) *Infections intramammaires de la vache laitière en l'absence de traitement antibiotique systématique au tarissement*.

Roberts, T. *et al.* (2012) « Metabolic parameters in transition cows as indicators for early-lactation culling risk », *Journal of Dairy Science*, 95(6), p. 3057-3063. doi:10.3168/jds.2011-4937.

Rutherford, A.J., Oikonomou, G. et Smith, R.F. (2016) « The effect of subclinical ketosis on activity at estrus and reproductive performance in dairy cattle », *Journal of Dairy Science*, 99(6), p. 4808-4815. doi:10.3168/jds.2015-10154.

Salvetti, P. *et al.* (2011) « FERTILIA : les clés de la réussite en première insémination chez les vaches Prim ' Holstein », *Btia*, 141, p. 34-42.

Santschi, D.E. *et al.* (2016) « Prevalence of elevated milk β-hydroxybutyrate concentrations in Holstein cows measured by Fourier-transform infrared analysis in Dairy Herd Improvement milk samples and association with milk yield and components », *Journal of Dairy Science*, 99(11), p. 9263-9270. doi:10.3168/jds.2016-11128.

Seifi, H.A. *et al.* (2007) « Effect of isoflupredone acetate with or without insulin on energy metabolism, reproduction, milk production, and health in dairy cows in early lactation », *Journal of Dairy Science*, 90(9), p. 4181-4191. doi:10.3168/jds.2006-897.

Shin, E.K. *et al.* (2015) « Relationships among ketosis, serum metabolites, body condition, and reproductive outcomes in dairy cows », *Theriogenology*, 84(2), p. 252-260. doi:10.1016/j.theriogenology.2015.03.014.

Solano, L. *et al.* (2015) « Prevalence of lameness and associated risk factors in Canadian Holstein-Friesian cows housed in freestall barns », *Journal of Dairy Science*, 98(10), p. 6978-6991. doi:10.3168/jds.2015-9652.

Sprecher, D.J., Hostetler, D.E. et Kaneene, J.B. (1997) « A lameness scoring system that uses posture and gait to predict dairy cattle reproductive performance », *Theriogenology*, 47(6), p. 1179-1187. doi:10.1016/S0093-691X(97)00098-8.

Suthar, V.S. *et al.* (2013) « Prevalence of subclinical ketosis and relationships with postpartum diseases in European dairy cows », *Journal of Dairy Science*, 96(5), p. 2925-2938. doi:10.3168/jds.2012-6035.

Tatone, E.H. *et al.* (2017) « Investigating the within-herd prevalence and risk factors for ketosis in dairy cattle in Ontario as diagnosed by the test-day concentration of β-hydroxybutyrate in milk », *Journal of Dairy Science*, 100(2), p. 1308-1318. doi:10.3168/jds.2016-11453.

Thomas, H.J. *et al.* (2015) « Evaluation of treatments for claw horn lesions in dairy cows in a randomized controlled trial », *Journal of Dairy Science*, 98(7), p. 4477-4486. doi:10.3168/jds.2014-8982.

Thomsen, P.T. (2009) « SHORT COMMUNICATIONS for lameness in dairy cows », *the Veterinary Record*, 164, p. 689-690.

Vanholder, T. *et al.* (2015) « Risk factors for subclinical and clinical ketosis and association with production parameters in dairy cows in the Netherlands », *Journal of Dairy Science*, 98(2), p. 880-888. doi:10.3168/jds.2014-8362.

Vincent, C. (2019) *UTILISATION DES OUTILS CETODETECT ® ET HERD NAVIGATOR ® EN COMBINAISON OU EN USAGE SEUL DANS LE DIAGNOSTIC DE LA CETOSE SUBCLINIQUE CHEZ LA VACHE*.

Walker, S.L. *et al.* (2008) « Lameness, activity time-budgets, and estrus expression in dairy cattle », *Journal of Dairy Science*, 91(12), p. 4552-4559. doi:10.3168/jds.2008-1048.

Wells, S.J. *et al.* (1993) « Individual cow risk factors for clinical lameness in lactating dairy cows », *Preventive Veterinary Medicine*, 17(1-2), p. 95-109. doi:10.1016/0167-5877(93)90059-3.

Whay, H.R., Main, D.C.J. et Green, L.E. (2003) « measurements: direct ».

6 Tables

7 Figures

Appendix I: List of the keys and formats of the husbandry parameters

The keys used in the husbandry parameter file must be among those shown in the following table:

Module	Parameter key	Format of the associated value	Description
General	"comment"	Char string	Free comment to describe the paramatred farm
Reproduction (see paragraph 2.2.1.2)	"ageToBreedingDecision"	Integer value	See paragraph 2.2.1.2.1 *Breeding age*
	"detectionMode"	0 = embedded sensor 1 = robot 2 = farmer 3 = bull, when mating	See paragraph 2.2.1.2.2 *Estrus detection modes*
	"slipperyFloor"	True (1) or false (0)	See paragraph 2.2.1.2.3 *Slippery floor*
	"matingPlan_TypeInseminationSemen_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Insemination type (*)	See paragraph 2.2.1.2.4 *Mating plans*
	"matingPlan_TypeInseminationRatio_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Decimal value, 0 to 1	
	"matingPlan_BreedInseminationSemen_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Breed (*)	
	"matingPlan_BreedInseminationRatio_<*iaNumber*>_<*h/a*>" <*iaNumber*> = "firstIA", "IA2and3" and "IA4andOver" <*h/a*> = "heifer" and "adult" (6 values in total)	Decimal value, 0 to 1	
	"matingPlan_<*f/l*>ExcludedMonthForHeiferCalving" <*f/l*> = "First" et "Last" (2 values in total)	Included month Integer value (0 = no grouping)	See paragraph 2.2.1.2.5 *Grouped calvings*
	"fertilityFactor"	Decimal value, centred on 1	See paragraph 2.2.1.2.6 *Herd-specific fertility factor*
	"breedingDelayAfterCalvingDecision"	Integer value	See paragraph 2.2.1.2.7 *Minimum post-partum delay before breeding (waiting period)*
	"numberOfDaysAfterHeiferBreedingDecisionForStopFirstInseminationDecision"	Integer value	See paragraph 2.2.1.2.8 *Individual decision of stop inseminations related to heifer and cow infertility*
	"numberOfDaysAfterHeiferBreedingDecisionForStopInseminationDecision"	Integer value	
	"numberOfDaysAfterAdultBreedingDecisionForStopFirstInseminationDecision"	Integer value	
	"numberOfDaysAfterAdultBreedingDecisionForStopInseminationDecision"	Integer value	
	"vetReproductionContract"	True (1) or false (0)	See paragraph 2.2.1.2.9 *Breeding contract*
	"reproductionTreatmentPlan_<No/Too/Negative>_name" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Char string	
	"reproductionTreatmentPlan_<No/Too/Negative>_effectDelay" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Integer value	
	"reproductionTreatmentPlan_<No/Too/Negative>_successProbability" <No/Too/Negative> = "No_oestrus_detected_after_calving", "Too_much_unsuccessful_inseminations" and "Negative_pregnancy_diagnostic" (3 values in total)	Decimal value, 0 to 1	
	"reproductionTreatmentPlan_Too_much_unsuccessful_inseminations_fertilityDelta"	Decimal value, 0 to 1	
Lactation (see paragraph 2.2.2.2)	"driedPeriodDuration"	Integer value	See paragraph 2.2.2.2.1 *Drying-off*
	"milkingFrequency"	0 = once a day, 1 = twice a day, 2 = above twice a day	See paragraph 2.2.2.2.2 *Milking frequency*
	"dayBeforeDeliverMilk"	Integer value	See paragraph 2.2.2.2.3 *Minimum lactation stage for delivered milk*
	herdProductionDelta_<*char*>	Decimal value, centred on 0	See paragraph 2.2.2.2.4 *Herd production level*

	<*char*> = "Lait", "TB" et "TP" (3 values in total)		
Health: Intramammary infection (IMI) (see paragraph 2.2.3.1.2)	"G1MastitisDetectionSensibility"	Decimal value, 0 to 1	See paragraph *2.2.3.1.2.1 Sensitivity detection of low-severity clinical mastitis*
	"mastitisSaisonalityProbabilityFactor_<*bacterium*>_<*month*>" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" and "CB" <*month*> = "jan", "feb", "mar", "apr", "may", "jun", "jul", "aug", "sep", "oct", "nov" and "dec" (60 values in total)	Decimal value, centred on 1	See paragraph *2.2.3.1.2.2 Seasonal impact on IMI incidence*
	"mastitisBacteriumIncidencePart<*bacterium*>" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (5 values in total)	Decimal value, 0 to 1	See paragraph *2.2.3.1.2.3 Share of bacterial type in incidence*
	"mastitisTreatmentPlan_<*stage*>_name" <*stage*> = "Lactation" and "Dry" (2 values in total)	Char string	See paragraph *2.2.3.1.2.4 Treatment plans*
	"mastitisTreatmentPlan_<*stage*>_effectDelay" <*stage*> = "Lactation" and "Dry" (2 values in total)	Integer value	
	"mastitisTreatmentPlan_<*stage*>_milkWaitTime" <*stage*> = "Lactation" and "Dry" (2 values in total)	Integer value	
	"mastitisTreatmentPlan_<*stage*>_healingProbability_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (10 values in total)	Decimal value, 0 to 1	
	"mastitisTreatmentPlan_<*stage*>_protectProbability_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" et "CB" (10 values in total)	Decimal value, 0 to 1	
	"mastitisTreatmentPlan_<*stage*>_protectDuration_<*bacterium*>" <*stage*> = "Lactation" and "Dry" <*bacterium*> = "StaphA", "StreptU", "Gn", "CNS" and "CB" (10 values in total)	Integer value	
	"individualMastitisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.1.2.5 Prevention factor for mastitis at the individual level*
	"herdMastitisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.1.2.6 Prevention factor for mastitis at herd level*
	"vetCareContract"	0 = no veterinary care contract 1 = contract based on cow count 2 = contract based on calving count 3 = contract based on milk quantity	See paragraph *2.2.3.1.2.7 Veterinary care contract option*
Health: Ketosis (or acetonaemia) (see paragraph 2.2.3.2.2)	"ketosisIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.2.2.1 Prevention factor*
	"monensinBolusUsage"	True (1) or false (0)	See paragraph *2.2.3.2.2.1.2 Prevention by the use of monensin-based intra-ruminale boluses (Kexxtone®)*
	"cetoDetectUsage"	True (1) or false (0)	See paragraph *2.2.3.2.2.2.1 Cetodetect ® option during milk control*
	"herdNavigatorOption"	True (1) or false (0)	See paragraph *2.2.3.2.2.2.2 Herd Navigator ® option of the milking robot*
	" ketosisTreatmentPlan_<*severity*>_name" <*severity*> = "G1" and "G2" (2 values in total)	Char string	See paragraph *2.2.3.2.2.3 Treatment plan*
	" ketosisTreatmentPlan_<*severity*>_effectDelay" <*severity*> = "G1" and "G2" (2 values in total)	Integer value	
	" ketosisTreatmentPlan_<*severity*>_milkWaitTime" <*severity*> = "G1" and "G2" (2 values in total)	Integer value	
	"ketosisTreatmentPlan_<*severity*>_healingProbability" <*severity*> = "G1 and "G2" (2 values in total)	Decimal value, 0 to 1	
	"ketosisTreatmentPlan_<*severity*>_flareupRisk" <*severity*> = "G1" and "G2" (2 values in total)	Decimal value, 0 to 1	
	"ketosisTreatmentPlan_<*severity*>_firstIASuccessRisk" <*severity*> = "G1" and "G2" (2 values in total)	Decimal value, 0 to 1	
	"lamenessNonInfectiousIncidencePreventionFactor"	Decimal value, centred on 1	See paragraph *2.2.3.3.2.1.1 Global prevention factors*

Health: Lameness (see paragraph 2.2.3.3)	"lamenessInfectiousIncidencePreventionFactor"		
	"footBathOption"	True (1) or false (0)	See paragraph 2.2.3.3.2.1.2 *Option to prevent infectious lameness by using a foot bath*
	"footBathEffectDuration	Integer value	
	"footBathStabulationFrequency" "footBathFullPastureFrequency" "footBathHalfStabulationPastureFrequency"	Integer value	See paragraph 2.2.3.3.2.1.3 *Foot bath frequency option*
	"preventiveTrimmingOption"	0 = no trimming 1 = trimming once a year 2 = trimming twice a year 3 = trimming by small groups	See paragraph 2.2.3.3.2.1.4 *Option to prevent infectious and non-infectious lameness through trimming*
	"lamenessDetectionMode"	0 = sensor 1 = low sensitive farmer 2 = sensitive farmer	See paragraph 2.2.3.3.2.2 *Detection options*
	"cowNumberForSmallTrimmingOrCareGroup"	Integer value	See paragraph 2.2.3.3.2.3 *Trimming grouping and individual lameness cases for treatment*
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_name" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" (4 values in total)	Char string	See paragraph 2.2.3.3.2.4 *Treatment plan*
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_*<limit>*_effectDelay" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" *<limit>* = "min" and "max" (8 values in total)	Integer value	
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_milkWaitTime" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" (4 values in total)	Integer value	
	"lamenessTreatmentPlan_*<severity>*_*<infectious type>*_healingProbability_*<number>*" *<severity>* = "G1" and "G2" *<infectious type>* = "non_infectious" and "infectious" *<number>* = "1" and "2" (8 values in total)	Decimal value, 0 to 1	
Genetics (see paragraph 2.2.4.2)	"maleDataFile"	Char string	Name (without path) of the bull genetic catalogue file to use, see paragraph 2.2.4.2.1 *Dairy bull genetic character for the inception of insemination and natural mating catalogue*
	"geneticMaleStrategy"	0 = balanced, 1 = priority to the milk quantity produced, 2 = priority to functional longevity	See paragraph 2.2.4.2.2 *Genetic strategy*
Population and batch management (see paragraph 2.2.5.2)	"initialBreed"	Breed (*)	See paragraph 2.2.5.2.1.1 *Initial cow breed* (used too for the default breed for inseminations, see paragraph 2.2.1.2.4)
	"meanAdultNumberTarget"	Integer value	See paragraph 2.2.5.2.1.2 *Average number of adult cows*
	"annualHerdRenewablePart"	Decimal value	See paragraph 2.2.5.2.1.3 *Annual herd renewal rate*
	"annualHerdRenewableDelta"	Decimal value	
	"femaleCalveManagement"	0 = conservation of all female calves, 1 = sale of females from cows with low milk potential, 2 = sale of all female calves	See paragraph 2.2.5.2.1.4 *Female calves management strategy*
	"maxLactationRankForEndInseminationDecision"	Integer value	See paragraph 2.2.5.2.1.5 *Maximum number of lactations*
	"minMilkProductionHerdRatioForEndInseminationDecision"	Integer value	See paragraph 2.2.5.2.1.6 *Production performance of the cow regarding the one of the herd*
	"maxSCCLevelForEndInseminationDecision"	Decimal value	See paragraph 2.2.5.2.1.7 *SCC level*
	"minimumMilkQuantityFactorForRentability"	Decimal value	See paragraph 2.2.5.2.1.8 *Break-even point for milk production*
	"youngHeifer*<b/e>*PastureDate_*<d/m>*" *<b/e>* = "Begin" and "End" *<d/m>* = "day" and "month" (4 values in total)	Integer value	See paragraph 2.2.5.2.2.1 *Stabling and grazing*
	"otherHeiferAndDriedCow*<b/e>*PastureDate_*<d/m>*" *<b/e>* = "Begin" and "End" *<d/m>* = "day" and "month" (4 values in total)	Integer value	
	"lactatingCow*<b/e><p/s>*Date_*<d/m>*"	Integer value	

	<b/e> = "begin" and "end" <d/m> = "day" and "month" (4 values in total)		
	"<c/h/a>StrawConsumption" <c/h/a> = "calf", "heifer" and "adult" (3 values in total)	Decimal value	See paragraph 2.2.5.2.2.2 *straw bed*
Feeding (see paragraph 2.2.6.2)	"calfMilkQuantity"	Decimal value	See paragraph 2.2.6.2.1.1*Unweaned calf feeding*
	"calfMilkType"	0 = produced milk, 1 = discarded milk and produced, 2 = discarded milk and reconstituted 2 = reconstituted milk	
	"weaningAge"	Integer value	
	"unweanedFemaleCalfConcentrateMixture_<q/t>" <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (4 values in total)	Decimal value	
	"weanedFemaleCalf<f/c>Mixture_<q/t>" <f/c> = "Forage" and "Concentrate" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay"and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (9 values in total)	Decimal value	See paragraph 2.2.6.2.1.2 *Weaned calf feeding*
	"youngUnbredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (18 values in total)	Decimal value	See paragraph 2.2.6.2.1.3 *Heifer feeding*
	"youngUnbredHeiferMineralVitamins_<s/p>" <s/p>= "stabulation" and "pasture" (25 values in total)	Decimal value	
	"oldUnbredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (18 values in total)	Decimal value	
	"oldUnbredHeiferMineralVitamins_<s/p>" <s/p>= "stabulation" and "pasture" (2 values in total)	Decimal value	
	"bredHeifer<f/c>Mixture_<s/p>_<q/t>" <f/c> = "Forage" and "Concentrate" <s/p>= "stabulation" and "pasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage" If <f/c> = "Concentrate": <q/t> = "quantity", "type_rapeseed", "type_soja" and "type_barley" (18 values in total)	Decimal value	
	"bredHeiferMineralVitamins_<season>" <season> = "winter", "spring" and "summerAndAutumn" (3 values in total)	Decimal value	
	"RBE_MilkProduction"	Decimal value	See paragraph 2.2.6.2.1.4 *Lactating cow feeding*
	"lactation<f/c>Mixture_<season>_<q/t> " <f/c> = "Forage" and "Concentrate" <s/p/h> = "stabulation", "pasture" and "halfStabulationPasture" If <f/c> = "Forage": <q/t> = "quantity", "maizePlant", "type_grass", "type_hay" and "type_grass_silage"	Decimal value	

	If *<f/c>* = "Concentrate": *<q/t>* = "quantity", "type_rapeseed", "type_soja" and "type_barley" (27 values in total)		
	"lactationPeriodMineralVitamins_*<season>*" *<s/p/h>* = "stabulation", "pasture" and "halfStabulationPasture" (3 values in total)	Decimal value	
	"gainForOneConcentrateKilo"	Decimal value	See paragraph *2.2.6.2.2 Production concentrate diets*
	"productConcentrateMixture_type_*<type>*" *<type>* = "rapeseed", "soja" and "barley" (3 values in total)	Decimal value	

Table 118: Keys and formats for farm management parameters

(*) See *Table 2: Type data formats* page *12*.

Parameters that are not defined in the file will be applied with the default value indicated in the "Farm management parameters" section of each of the modules described in the chapter *2.2 Modules*.

Appendix II: List of accounting model parameter keys

Parameter key	Description
"femaleDairyCalfPrice"	Sale of a female dairy calf
"maleDairyCalfPrice"	Sale of a male dairy calf
"femaleBeefBredCalfPrice"	Sale of a beef crossbreed female calf
"maleBeefBredCalfPrice"	Sale of a beef crossbreed male calf
"underOneYearCalfPrice"	Sale of a live heifer of less than one year old
"underTwoYearCalfPrice"	Sale of a live heifer of more than one year old
"pregnantHeiferPrice"	Sale of a pregnant heifer
"culledCowPrice"	Sale of a culled cow
"underOneYearDeathCalfPrice"	Rendering of a dead heifer aged up to 1 year
"underTwoYearDeathCalfPrice"	Rendering of a dead heifer aged between 1 and 2 years
"deathCowPrice"	Rendering of a dead cow
"calfBirthPrice"	Assisted calving by a vet
"naturalInseminationPrice"	Insemination by service
"conventionalArtificialInseminationPrice"	Conventional artificial insemination
"maleSexedArtificialInseminationPrice"	Male sexed artificial insemination
"femaleSexedArtificialInseminationPrice"	Female sexed artificial insemination
"vetReproductionContractPrice"	Annual price per adult cow of the veterinary breeding contract
"vetNoOestrusSeenTreatmentPrice"	Treatment for recurrence of heat
"vetUnsuccessfulIATreatmentPrice"	Treatment against succession of non-fertile inseminations
"vetNegativePregnancyTreatmentPrice"	Treatment following a negative pregnancy diagnosis
"milkTonPrice"	Sale of a ton of milk (without quality criteria and without penalty)
"milkControlPrice"	Monthly test-day (per cow and per year)
"level1SCCPenaltyPrice"	Penalty 1st threshold (for 1 ton)
"level2SCCPenaltyPrice"	Penalty 2nd threshold (for 1 ton)
"level3SCCPenaltyPrice"	Penalty 3rd threshold (for 1 ton)
"TBQualityBonusPrice"	TB quality bonus (for 1 ton)
"TPQualityBonusPrice"	TP quality bonus (for 1 ton)
"vetCareContractBasedOnCowPrice"	Annual price per adult cow of the veterinary health contract
"vetCareContractBasedOnCavingPrice"	Annual price per calving of the veterinary health contract
"vetCareContractBasedOnKiloliterPrice"	Annual price per kiloliter of the veterinary health contract
"G1mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G1 mastitis without vet contract
"G1mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G1 mastitis with vet contract
"G2mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G2 mastitis without vet contract
"G2mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G2 mastitis with vet contract
"G3mastitisLactationWithoutContractTreatmentPrice"	Cost of a basic treatment for lactating G3 mastitis without vet contract
"G3mastitisLactationWithContractTreatmentPrice"	Cost of a basic treatment for lactating G3 mastitis with vet contract
"mastitisDryWithoutContractTreatmentPrice"	Cost of a basic treatment for clinical mastitis in dry cows without vet contract
"mastitisDryWithContractTreatmentPrice"	Cost of a basic treatment for clinical mastitis in dry cows with vet contract
"mastitisPreventiveActionsPrice"	Annual cost of mastitis prevention per cow
"monensinBolusPrice"	Cost of a monensin bolus
"cetoDetectPrice"	Cetodetect ® milk control test (per cow per year)
"herdNavigatorPrice"	Herd navigator option (per cow and per year)

"G1ketosisWithoutContractTreatmentPrice"	Cost of basic treatment for G1 ketosis without vet contract
"G1ketosisWithContractTreatmentPrice"	Cost of basic treatment for G1 ketosis with vet contract
"G2ketosisWithoutContractTreatmentPrice"	Cost of basic treatment for G2 ketosis without vet contract
"G2ketosisWithContractTreatmentPrice"	Cost of basic treatment for G2 ketosis with vet contract
"ketosisPreventiveActionsPrice"	Annual cost of ketosis prevention per cow
"lamenessAnnualFootBathPrice"	Annual cost of a foot bath
"lamenessMinFootBathUsagePrice"	Minimum cost of using a foot bath
"lamenessMaxFootBathUsagePrice"	Maximum cost of using a foot bath
"lamenessFootTrimmingWorkshopPrice"	Cost of setting up the trimming workshop
"lamenessCowFootTrimmingPrice"	Cost of trimming a cow
"nonInfectiousLamenessCowFootTreatmentPrice"	
"infectiousLamenessCowFootTreatmentPrice"	
"dehydratedMilkTonPrice"	Price of one ton of a dehydrated milk powder
"strawTonPrice"	Price of one ton of a straw (dry matter)
"maizePlantTonPrice"	Price of one ton of corn plant (dry matter)
"grassTonPrice"	Price of one ton of grass (crude matter)
"hayTonPrice"	Price of one ton of hay (dry matter)
"grassSilageTonPrice"	Price of one ton of grass silage (crude matter)
"rapeseedTonPrice"	Price of one ton of rapeseed (crude matter)
"sojaTonPrice"	Price of one ton of soybean (crude matter)
"barleyTonPrice"	Price of one ton of barley (crude matter)
"mineralVitaminTonPrice"	Price of one ton of minerals and vitamins (crude matter)
"calfBeddingPrice"	Bedding costs for a calf
"heiferMiscellaneousVetCost"	Veterinary costs per heifer in the herd
"otherCalfBreedingCost"	Other costs of raising a calf
"annualCowBeddingPrice"	Purchase of bedding per cow present average
"annualCowMiscellaneousVetCost"	Average veterinary costs per cow present
"otherAnnualCowBreedingCost"	Other livestock costs per average cow present

Table 119: Keys to the parameters of the accounting model

Parameters that are not defined in the file will be applied with the default value (see paragraph *3.2.1.2 Accounting models*).