A discrete event simulator of the “three lambings in two years” intensive lamb production system

cournut@enitac.fr

S. Cournut[1], B. Dedieu[2],

[1] ENITAC Département Agriculture et Espaces , Marmilhat F63370 Lempdes (France)

[2] INRA Transformation des Systèmes d’Elevage Theix, F63122 Saint-Genès-Champanelle (France)

Summary-The “three lambings in two years” (3-in-2) is a complex reproduction system in sheep, combining high level of productivity goals (with an individual pattern of three lambings in two years) and regular sales throughout the year (with three lambing sessions). We present the TUTOVIN model, which can simulate, in that 3-in-2 system, the effects of i) changes of reproductive and replacement management decisions and ii) fertility parameters on the flock production (number of lambs born alive per year, distribution over the year, long term production and demographic stability. The simulator design is presented. The conceptual model associate a decisional process (with both strategic and operational levels) and biotechnical components (fertility, conception date, number of lamb born, functional longevity). The discrete event modelling technique is well appropriate for characterizing the flock system as it includes various levels of abstraction and needs the management of biological time and decision calendar. We detail the inputs (initial state and history of the flock, reproduction and replacement rules, biological laws or parameters) and the procedures for analysing the outputs within the stabilization or the stability phase (20 years x 15 replications per simulation). These procedures combine a cross analysis of i) annual and seasonal performance parameters, ii) flock replacement movements and demography, iii) animal flows between batch production cycles ; and a longitudinal analysis relative to the diversity of ewe lifetime production. Concrete examples based on an experimental framework of simulations with changes either of management rules or of fertility parameters illustrate the intelligence of the regulation properties of the 3-in-2 system allowed by the simulator.

Keywords - Herd dynamics, simulation, sheep, discrete events, three lambing per two years

1. Introduction

Meat sheep farming in France is particularly sensitive to the combination of overall production and lambing and sales distribution challenges (Girard & Lasseur 1997; Dedieu et al. 1997). Various reproduction management systems can be observed on farms from the simple organisation of one single period of lambing per year with a uniform individual pattern of one lambing per ewe per year to more complex reproduction organisations. These organisations multiply lambing periods and allow accelerated lambing patterns such as the STAR system, where ewes can have five lambings in three years (Lewis et al. 1996). In France, the “three lambings in two years” system aims at obtaining an individual pattern of three lambings in two years, with three lambing periods for the flock in the year (Marzin and Brelurut 1979). These intensive production system are difficult to model because of the complex interaction between the flock reproduction, replacement and batching management decisions and the biological responses of the ewes, either reproductive or survival. Since farmers often re-evaluate the way they manage such intensive production systems in order to cope with a changing context involving income, work, market, dynamic herd models are therefore useful in order to evaluate the consequences of new management schemes on production (level, distribution) over long time periods.

We present a discrete event model called "TUTOVIN" of the "three lambings in two years" system ("3-in-2"). It can simulate the effects of changes of reproductive and replacement management decisions, and of reproduction parameters (fertility) on the flock production e.g. number of lambs born per year, distribution over the year, long term production and demographic stability. TUTOVIN is detailed in Cournut 2001 and Cournut & Dedieu (2004) : we summarize here briefly the conceptual model characteristics and the discrete event modelling principles. Then, we show how the use of this model lets us understand the functioning of the flock system, and shed light on its regulation properties resulting from the complex interactions between decisions and animal responses.

2. Context of the simulator construction

2.1. The 3-in-2 reproduction management system

The 3-in-2 system was conceived in the 1970's but it is still considered by economists as being very well suited for sheep farms in the Centre of France considering the sheep breeds and market chain (Benoit et al. 1999). The management principles of the 3-in-2 are (Marzin & Brelurut 1979) : i) the flock is divided into two batches ; ii) three reproduction sessions are organised yearly; each session concerns one of the two batches. For example, in a given year, a batch is mated in January and October, the other in June and vice versa the following year. So, a reproduction session is organized for each batch approximately every eight months, iii) after a mating session, the infertile ewes either change of batch in order to participate to the immediate following mating session, or have a repeat mating synchronised with this immediate following mating session. Three other major guidelines for 3-in-2 success are given: the mating session must be short, as well as sucklings in order to present dry ewes to the rams; ewe lambs must be old enough at first mating : their production lifetime is supposed to be very intensive; infertility phases within the reproductive trajectory of the ewes should be accepted.

2.2. Dynamic herd modelling : principles and application

Dynamic herd models develop a particular point of view on the livestock farming system (Gibon et al. 1996), since it focuses on the management and replacement of a flock (i.e., females used for reproduction). These dynamic models, based on Markovian, demographic or stochastic models (Frasier & Pfeiffer 1994, Lehenbauer & Oltjen 1998, Lesnoff 2000, Ostergaard et al. 2000), require the formalisation of information, decisions and biotechnical aspects (Keating & McCown 2001). The degree of formalisation of each sub-system can be rather variable (Girard & Hubert 1999).

- The decisional sub-system is often reduced to a set of rules without the decision process being formalised. We consider that the decision model must include i) the link between the expression of a production project by the farmer and a combination of rules, ii) the existence of production management entities intermediary between the animal and the whole herd (Romera et al. 2004) such as the batch (Ingrand & Dedieu 1996), iii) dates of decisions and actions and the schedule for implementing the decisions, iv) procedures for adjusting the management system.

-The biotechnical sub-system is generally more detailed up to the biological mechanisms (for example Oltenacu et al. 1980). Therefore, the flock functioning leads to particular sets of animal and environmental factors values which has to be modelled step by step. It is particularly important to be considered in sheep production where the seasonal component of the reproductive performance (i.e. the animal factor) is often associated with a specific – longer- mating session (environmental factor).

- Few models take animal lifetime production into account either in management or biotechnical sub-models. Thus some studies suggest that the series of productive events is a significant factor on the production level or the survival responses in cattle (Coulon et al. 1995) or in sheep (Ercanbrack & Knight 1995, Lee & Atkins 1996, Nugent & Jenkins 1992). More importantly, lifetime trait data is used by farmers, experts and genetic scientists as information for culling decisions (Ducrocq 1994, Oltjen et al. 1990).

2.3. Data used

Three types of information were used to build the simulator:

- Ewe data from an ovine management database (i.e., Gestion Ovin) concerning the Limousin breed flock of the INRA Clermont – Ferrand Center when managed in "3-in-2" (1974 – 1982). The data specify all the reproductive events and the culling /deaths dates and causes.
- Reports and interviews of managers and agents in charge of the flock at the time of the "3-in-2" system. They made it possible to specify the way in which management of reproduction and replacement of the flock was organised.
- References on other management practices, implemented by private farmers, to ensure the generality of the approach.

In the INRA Limousin breed flock, the ewes were synchronised at each mating session and the dose of PMSG was adjusted according to the season. At each mating, rams are introduced for 35 days in the whole flock. During this period, synchronised ewes in the batch can be mated, as well as the non-pregnant ewes of the other batch (repeated mating). Suckling lasts for a month and a half. At each production period, ewe lambs are kept for first mating at one year old. At the end of a lambing session, the non-lambing ewes change batch. Ewes with health problems (e.g., mastitis, no milk one or two teats) are systematically eliminated from the flock. Voluntary culling is based on age (the maximum age is 8 years) and succession of infertility periods (the maximum value is 3).

The data of the INRA flock has the advantage of reliability of information over a long time period, although not all management practices have been specified. Following the flock managers opinion, we assume that feed and health were not limiting factors for the expression of animal production performances and that the experimental function of the flock did not unduly disturb the management. Ewes with a lifetime production and a longevity distorted for experimental reasons were identified in the ovine management database and eliminated from the file. The flock population was about 400 ewes between 1974 and 1976, and was reduced to 270 ewes in 1982. Data concerned 5237 registrations relative to mating of ewes (for 913 ewes).

3. Description of the simulator

The model developed is « decisions driven »: the dynamic of the system is dominated by the management actions which interact with the animal responses to lead to production (Romera et al. 2004). The modelling objective was to understand the flock functioning and the performance construction over the year and in the long time, and to identify the management influence in this construction.

The flock was limited to the reproductive females. The ewe lambs integrate the flock at the beginning of their first mating session. The voluntary culled ewes quit the flock at the culling session, which occurs, with the drying off, at the end of each suckling session. Involuntary culled ewes quit the flock every fortnight in relation with the functional longevity model application. Only decisions about reproduction and replacement management were considered with respect to the "3-in-2" basis (batches ; series of mating sessions).The flock production was expressed as the number of live-born lambs per calendar fortnight.

3.1. Decision component

For decisions of reproduction and replacement management, procedures for analysing the management of production processes in an industrial environment were used. They were already applied to farm management (Hemidy et al. 1993, Allain 1999) and crop and forage systems management (Aubry 2000, Coleno & Duru 1999). These authors rely on notions of production projects, strategic steering and operational steering. The formalisation of the management component resulting is shown in Figure 1.

We proposed the notion of batch production cycle (BPC) as the basic management entity in order to account for the organisation of the production and the replacement of the flock. It is defined as the aggregation of ewe production cycles around a same reproduction period, organised by the farmer at the level of a batch with a view to obtaining a lambing session. The production organisation configures and coordinates the batch production cycles (Fig. 2).

The configuration of a BPC concerns blocking on the calendar the mating session (dates and duration) and the end of drying off, and determination of the initial composition of the batch of reproductive females. The coordination between BPC refers to: i) the organisation of the linkage of successive BPC of a same batch (how to ensure that the ewes lamb approximately every 8 months), ii) the way in which the movement of infertile ewes from one batch to another is organised (how to manage the rapid recycling of infertile ewes).

Figure 1. The decisional process

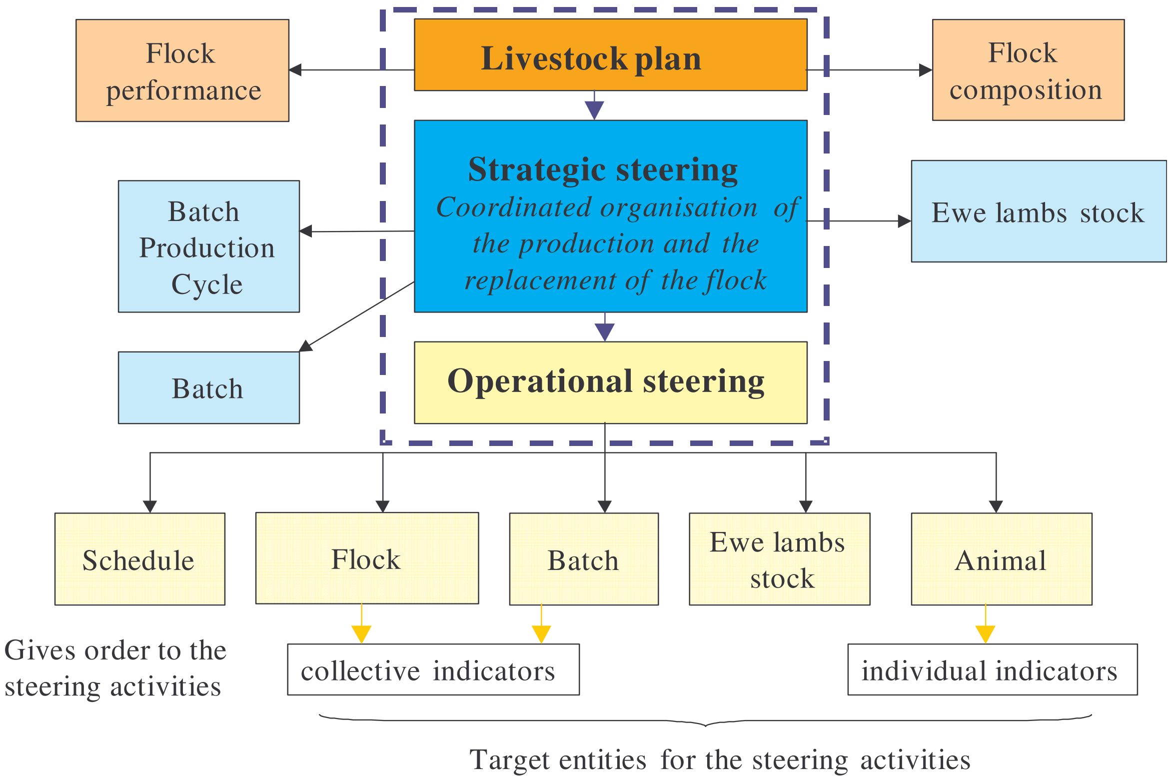
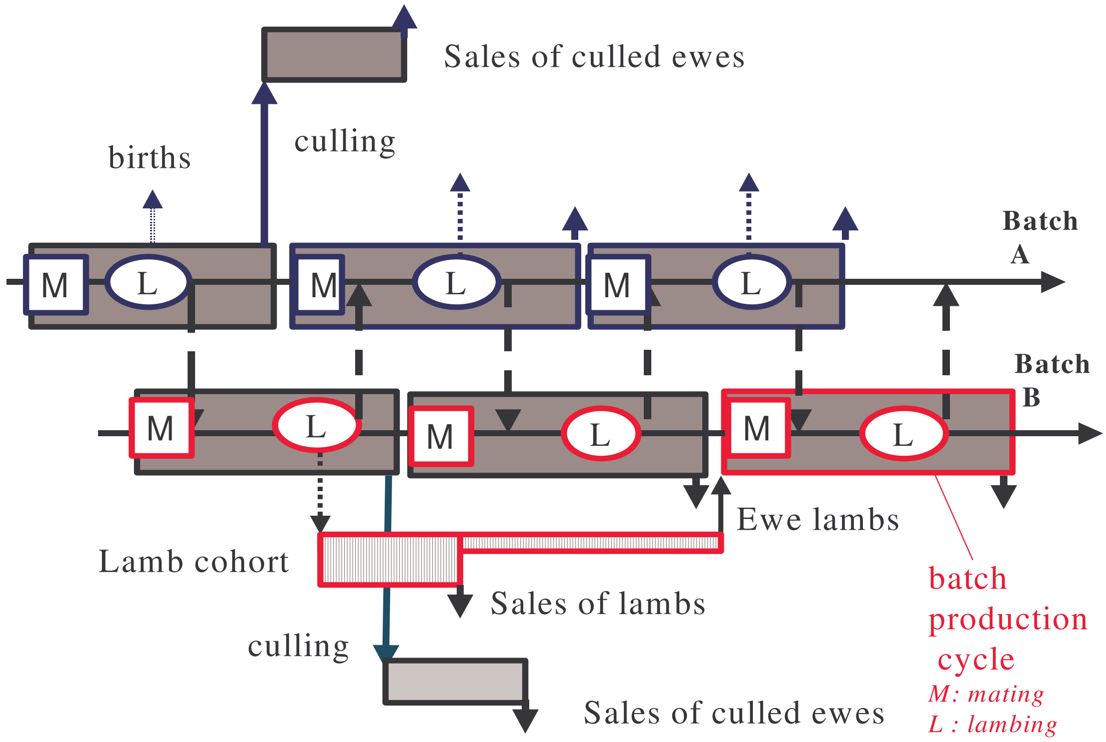


Figure 2. Production organization: configuration and coordination of Batch Production Cycles (BPC)



3.2 Biotechnical component

With our specification, four components of the biological responses were considered: fertility, conception date, number of born-alive lambs and functional longevity. The biological phenomena responsible for these responses undergo the influence of factors linked to the environment and factors associated with the animals including the previous productive trajectory of the ewe. Using the data of INRA flock, we studied the factors affecting these variables like they are combining themselves over time. The statistical analyses are detailed in Cournut and Dedieu (2004). We modelled all these responses as random variable laws. The probability distribution laws are included in the parameter setting of the simulators, and used by the pseudo-random number generation mechanisms activated by events. These events are those that determine the biological response of each ewe.

3.3 The discrete events simulation technique

The discrete event simulation (DES) technique corresponds to a conceptualisation of the system based on the discrete organisation of time and the notion of an event being a modification of the state of a system (Cocquillard & Hill 1997, Blasco & Weill 1999). It is translated by the description in algorithmic form of the occurrences of events as well as the precise nature of changes of variables of state associated with the events. Between two events the state of the system does not change and virtual time does not pass by during an action accompanying or characterizing a change of state. This technique uses a scheduler ordering and activating events that modify the objects' variables of the model, or adding new events in the scheduler. The main objects are those involved in the flock system analysis: ewes, ewe productive trajectories, batches, flock, batch production cycles and ewe lambs stock. Appendix 1 illustrates the management of the simulation scheduler. Implementation was made with the Visual Basic (®) language.

4. The use of the simulator

The use of the simulator is firstly devoted to the validation phase. The confrontation of the model with the real data of the INRA flock will not be presented here. It showed the capacity of the simulator to reconstruct the functioning and the performances of the real flock. Then, we defined an experimental framework in order to make the so – called “functional validation” (Balci 1998). It corresponds to the use of the simulator as a measurement instrument to check its correct functioning and test the influence of parameters changes. We designed the inputs and outputs, a plan of experiments and the analysis procedures.

4.1 Inputs and outputs

In order to initialize a simulation, the user must enter four types of information concerning i) the initial state, ii) the flock management rules, ii) the biological responses of the ewes (modelled laws described in files or directs parameters), iv) the duration of simulation and the number of replications. The initial state of the system is the state at t = 0 of the following entities of the model: ewe, ewe lamb stock (the number of ewe lamb kept for replacement during last lambing sessions) and the characteristics of all BPCs in process. The flock management rules are set for the different levels of the decision process: the production plan (lambing pattern and number of lambing periods in the year) and the composition plan (evolution of the flock size), the configuration of the BPC (dates and durations of the mating sessions, date of the end of the suckling periods, synchronisation), the coordination between BPC (use of ultrasound scanning - that lead to a quick change of batch of the infertile ewes, occurrence of a repeat mating), the culling rules (for infertility and age), the recruitment rules (which lambing session ; number ; age at first mating). The model is a stochastic one and so, each simulation must be described and evaluate with an appropriate number of replications. The number of replications is 15 and the duration of simulation is 20 or 40 years depending on the duration of the stabilisation phase of the system.

The model outputs are all text files. They provide information on production (the number of live-born lambs and lambings per calendar fortnight) and on the flock demography and batches composition evolution. They also trace how the flock is functioning during time with ewe productive trajectories files, characteristics of each BPCs (number of mated ewes and ewe lambs, previous BPC of the mated ewes, number of lambing and live born lambs), number of ewe culled per session and causes, number of ewe lambs per session. Software procedures with Excel (®) were built to synthetise the information and to analyse the productive parameters of the BPCs, the animal flows between BPC and flock in-and-out movements, the diversity of productive trajectories within the flock.

4.2 Experimental framework

The plan of experiments involved 50 simulated experiments (Tab 1) respecting the principles of the three lambings in two years reproduction management system, and testing modifications of fertility parameters and rules of management (culling, replacement, duration of mating period, management of infertile ewes). The reference management is that of the INRA flock. In all cases, the initial state of the system is that of this at 1st January 1975 (399 ewes, 64 ewe lambs. For designing the experiments plan, while respecting the coherence of the “3-in-2”t, we have clearly desired to test extreme situations, not observable in the reality but rich in knowledge on the flock functioning.

Table 1. Plan of experiments : type of change in rules and biological parameters

Management rules	Biological parameters	Example	Number of experiments
Ewe lambs recruitment		One period recruitment	5
Culling for infertility		Culling at first mating failure	5
Culling for age		Age limit = 7 years	9
Coordination of BPC		Use of ultrasound scanning	3
Configuration of BPC		Length of mating period = 15 days	4
Two rule modifications		No repeat mating except for autumn session and replacement done for each batch separately	6
	Fertility	-17% drop in fertility	2
Culling rules	Fertility	-17% drop in fertility and culling at second failure	17

4.3 Analysis of the stabilization phase

The stabilization phase (or "warm up" phase) corresponds to the time necessary for the system to find a balance of interactions between the entities that compose it. It was analysed on the basis of the evolution of the annual lambings number: mean, minimum and maximum values for the 15 replications. This phase shows the deviation between the history of the flock system as synthesized in the initial state and the new expression context of its functioning as defined by the management and biological parameters. In a general manner, the system is stabilized after 3 to 5 years of functionning. Only a few experiments are characterized by a longer "warm up" phase (10 years or more): they test extreme management conditions and shows the greater rigidity of these systems to find a balance after the modification of the management rules. It concerns systems (Fig. 3):

- with independent batches. The possibilities of exchanges of ewes between batches are reduced. It concerns experiments with no "repeat" mating for the open ewes who failed to conceive at the last mating session or with culling at the first mating failure;
- whose demographic structure is strongly destabilised by the management change (for instance with a culling rule for an age limit of 5 years (instead of 8).

The stabilization phase points out the mechanisms that into play in the stability phase, where in good and bad years, the random nature of the biological responses of animals can lead to a lack of balance in the numbers of each batch or in the demographic structure of the flock. : the importance of annual fluctuations of performances and the persistence of these fluctuations will thus depend on the possibilities for exchanges between batches (coordination rules) and the capacity of the system to alleviate a lack in the balance of the demographic structure.

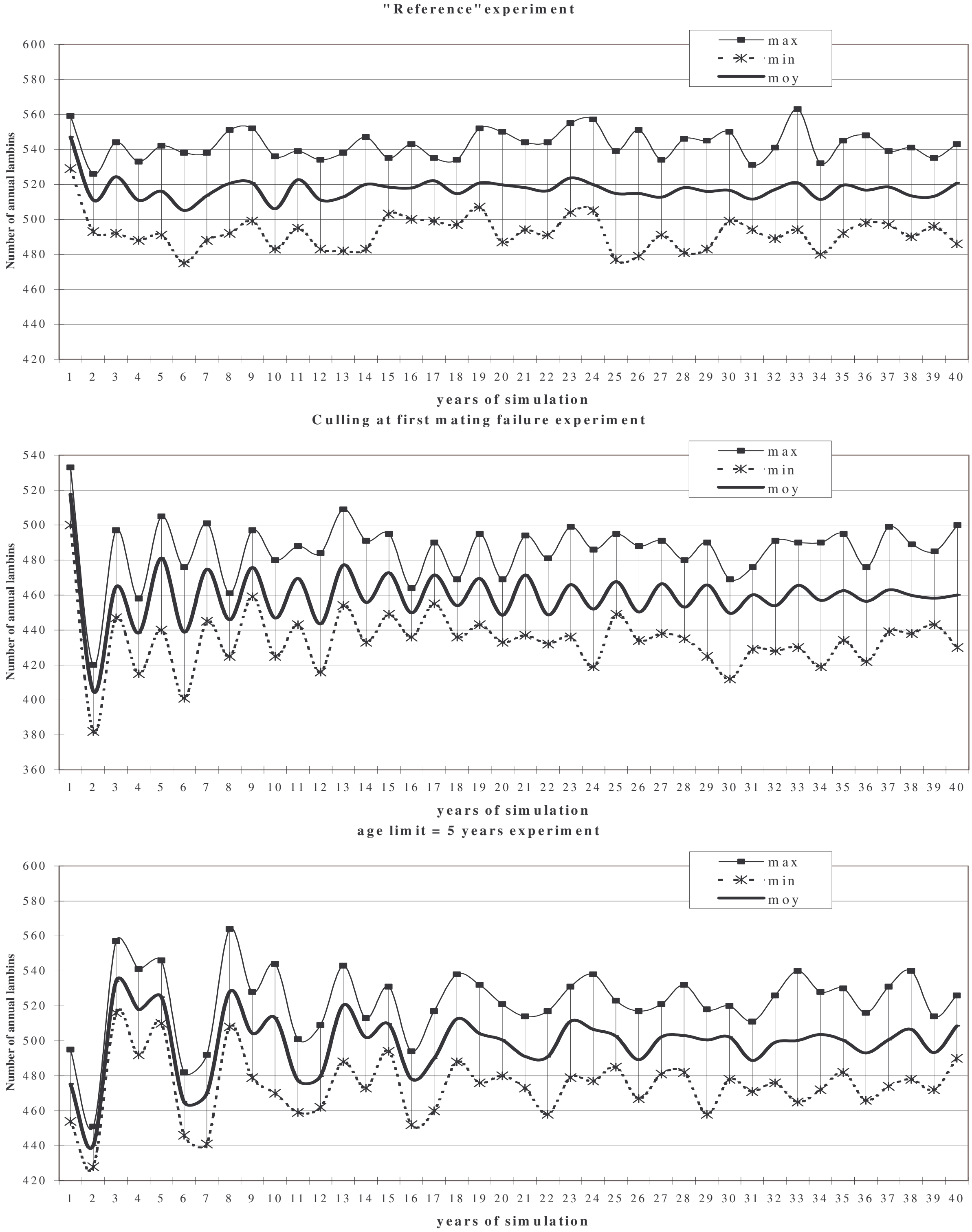
4.4 Analysis of the stable phase

The flock system functioning at the stable state is described on the basis of an average year, represented by the mean of the last ten years of simulation. The analysis grid combines :

- a cross analysis of i) annual and seasonal performance parameters, ii) flock replacement movements and demography, iii) animal flows between BPCs

- a longitudinal analysis relative to the diversity of ewe lifetime production.

Figure 3 : Evolution of the number of annual lambings (3 experiments)



Annual production and flock replacement

In most experiments, the flock system demonstrates its aptitude for rapidly installing a new balance that tends, in terms of level of annual production, to approach that of the reference system reproducing the functioning of the INRA flock. Significant differences in production level are obtained essentially i) when the fertility values are considerably reduced, ii) when the guidelines of the “3-in-2” are very distorted by making impossible to express a diversity of individual reproductive rhythm, iii) when very severe voluntary culling rules are imposed (table 2).

Table 2. Main significant differences in productivity

	INRA flock* Experiment n°1	Bad fertility ** Experiment n°34	Without « repeat » mating Experiment n°22	Culling at first mating failure Experiment n° 8	Use of ultrasound scanning Experiment n°21
Number of lambings per ewe and per year	1.32 (0.011)	1.14 (0.011)	1.25 (0.011)	1.29 (0.009)	1.35 (0.009)
Number of live-born lambs per ewe and per year	2.16 (0.021)	1.87 (0.024)	2.03 (0.019)	2.06 (0.021)	2.21 (0.018)

Means and standard errors over 15 replications
* Simulation with the rules and biological parameters from the INRA flock
** Simulation with: 60 %, 50 % and 80 % of fertility for January, June and October mating (which corresponds to an average –17% drop in fertility)

On the other hand, the production distribution over the year is more sensitive to modifications of management rules or fertility parameters. For example, a fixed reduction in the level of fertility performances at all sessions (bad fertility experiment n°34; see table 2) leads to a rebalancing of the annual production in favour of the most favourable period : autumn mating and spring lambing (table 3).

Table 3. Distribution of the annual production

Proportion of the total lambings in each lambing session	March lambings	June lambings	November lambings
Reference experiment	42%	25%	33%
Bad fertility experiment	51%	20%	29%

In the same way, the 1rst January demographic structure of the flock doesn't differ much from the INRA one in most experiments, except of course for those with extreme voluntary culling rules. But the analysis of the dynamic of the flock size within the years shows that there is a lot of differences between systems as far as in-and-out movements are concerned.

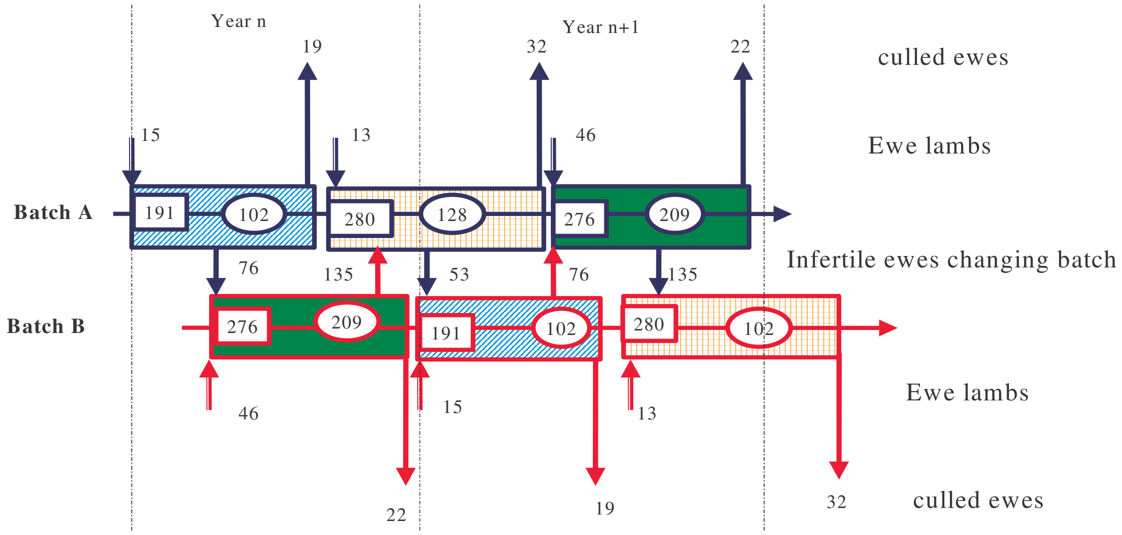
The animal flows between BPC

If production and replacement appear to be relatively stable over the different experiments, where are the regulations? This question led us to another type of results analysis: the animal flows within the systems either between the batch breeding cycles or in and out of the flock. We propose a grid describing the organisation of the production and replacement of the flock, and quantifying the different animal flows. The animal flows built the initial composition of the BPC, at the beginning of the mating session, with i) the ewes of the batch that were not culled at the last culling session, ii) the infertile ewes that are changing batch, iii) the ewe lambs. This initial composition determines a number but also a composition than conditions the global fertility of each CPB with its proportion of synchronised or not ewes and of ewe lambs, with the parity structure.

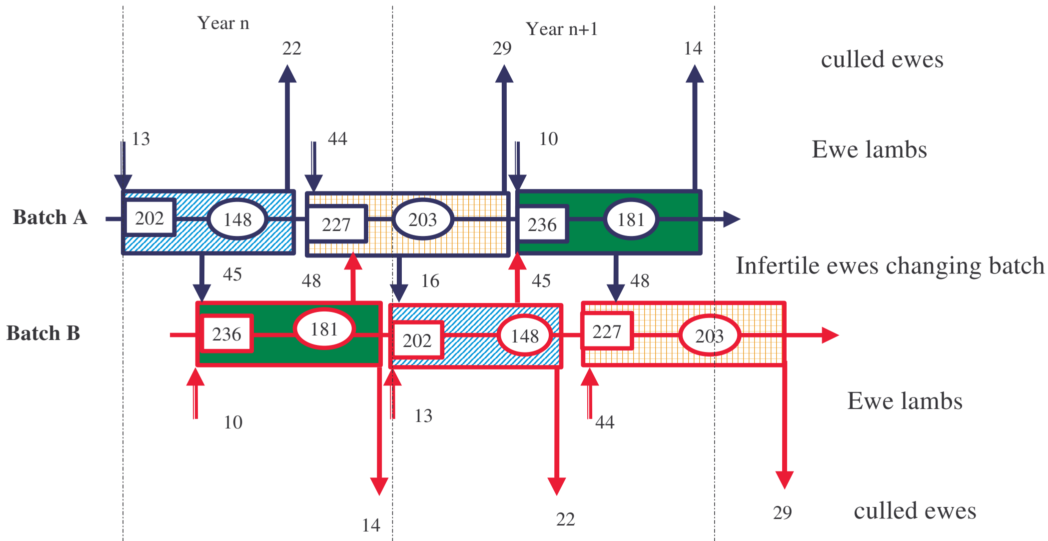
Figure 4 gives an example of an animal flow analysis, with the comparison of two experiments: the bad fertility experiment (n°34 – see table 2) and the use of ultrasound scanning experiment (n°21). Experiment 21 had better annual production results than experiment 34 (mean of 844 live-born lambs vs. 722). They also had a quite different spread of births within the three lambing sessions. For experiment 34, the proportion of lambing was respectively 48, 23 and 29% for the March, June and November lambing sessions. The animal flows grid shows that the fertility at January and June mating seasons are low. This leads to a very big flow of infertile ewes (with one or two mating failures) to the October mating session, and so to a big number of ewes presented to the rams (mean: 276) at this favourable sexual season. The use of scanning to detect infertile ewes was associated with another distribution of lambings, respectively 38, 38 and 34% for March, June and November lambing sessions. The flows of ewes between BPC were here quite different from the previous case. With scanning, all the infertile ewes changed batch quite early and benefited from hormone treatments prior to mating. Thus, ewes that were systematically synchronised had better fertility performances at every out-of-season mating session, with reduced the flows from one BPC to another.

Figure 4. The animal flows between batch breeding cycles: comparison of two experiments

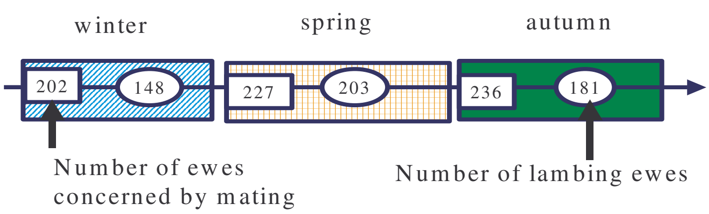
« Bad fertility » experiment (n°34)



« Ultrasound scanning » experiment (n°21)



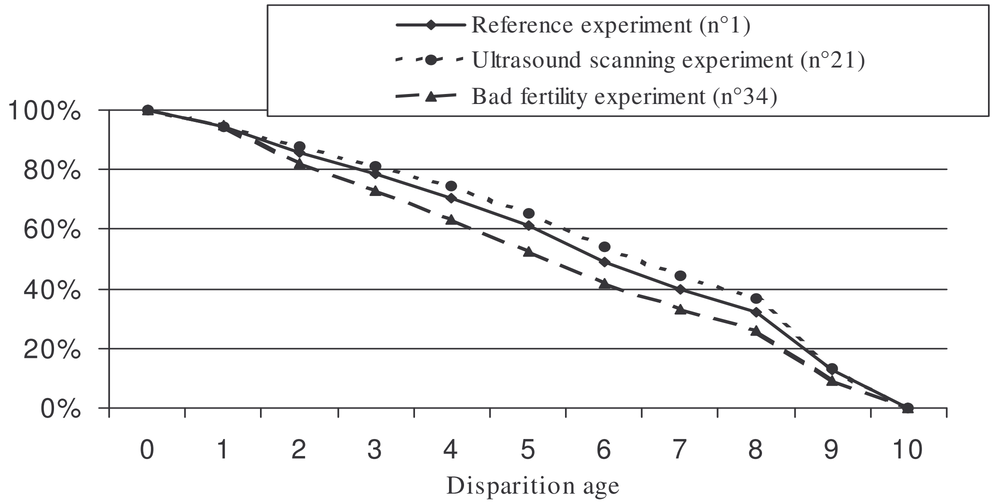
Batch production cycle



The diversity of ewe lifetime production

In the 3-in-2 system, the diversity of ewe productive trajectories is very important. The longitudinal analysis describes it and makes understandable its building. It shows how management decisions and animal biological responses interact and prioritize some lifetime production traits. In experiment 34, scanning and synchronisation of all the ewes improve the productivity at the beginning of the productive life which is the most sensitive to infertility problems. As a consequence, it reduces the number of trajectories ending rapidly by the culling of young ewes because of infertility episodes. The reverse phenomenon was observed in the bad fertility experiment (n° 21) (Fig. 5).

Figure 5 . Survivor curves



5. Discussion - Conclusion

The formalization of the flock system and its dynamic functioning was carried out by considering complex characteristics of the 3-in-2 system, which involves consideration of the batch production cycle (i.e., the management entity of the mating and lambing sessions) and the productive trajectory of the ewes. Modelling of sheep systems that have only one lambing period for the whole flock do not demand such notions since all animals are managed the same way in a single batch and all trajectories of the ewes are similar: the ewes lamb each year at the same period; if not, they are culled. These simple uniform management systems have been described in large grassland flocks in the Centre of France (Dedieu et al. 1997) and are also well referenced in the Anglo-Saxon bibliography (Lee & Atkins 1996, Nugent & Jenkins 1992). Other management systems are developing at the instigation of the market chain, with several lambing periods in the year. These management systems involve less rigid and uniform management of infertility, which generates diversified productive trajectories and batch production cycle coordinations. Taking account of these systems requires consideration of the following:

- temporal and calendar processes. It is notably the calendar that makes it possible to fix production distribution challenges and consistency in linking practices. It also plays a fundamental biological role considering the sensitivity of the ovine species to seasonal anoestrus.
- complex flows of information, coming either from instantaneous performance or medium term productive trajectories of the individual animals, or batches or flock.

Considering the herd as a dynamic and steered system, with interaction between management and animals has two consequences. Firstly, management and practices have no top – down

effect on biological responses and herd production, which is mainly the general background of the herd dynamics models (Kristensen & Jørgensen 2000). Secondly, it is possible to study the regulation properties of the system (Santucci 1991). In our case, the study of the animal flows between BPC (Benoit 1998, Girard & Lasseur 1997) and the diversity of productive trajectories (Moulin 1993) constitutes two complementary trials for the analysis of different flock managements which are accessible with the simulator. They open up to new qualifications of farming systems, beyond the criteria of technical efficiency, and taking account of the flexibility properties of information systems and flock management decisions.
The TUTOVIN discrete events simulator is more an explanatory research model, than a decision support tool for farmers. Nevertheless, it refers to an explicit representation framework of the management process (livestock project; strategic and operational steering) that makes it possible to take finalised sets of rules into account, associated with simple and sophisticated managements, based on little or much information and bringing into play collectives of animals as well as individuals. It is probably this representation framework of decisions coming from management sciences, which most distinguishes our conceptualisation from herd models available in the literature. The entities of flock production management are neither the individual of stochastic models (Oltenacu 1980) nor the animal production categories of estimation of biological parameters of Markovian models, but batches to be replaced, productive trajectories to be questioned, production cycles to be coordinated. This representation framework is presently integrated into beef cattle herd dynamics modelling (Ingrand et al. 2003) and is being used to test the functioning of dairy herds.

REFERENCES

Allain S. 1999. Approche cognitive du pilotage stratégique de l'entreprise agricole, Eco. Rur. 250, 21-30.
Aubry C. 2000. Une modélisation de la gestion de production dans l'exploitation agricole, Revue Française de Gestion 129, 32-45.
Balci O, 1998. Verification, Validation and Testing. In J. Banks (Ed.) Handbook of simulation. Principles, Methodology, Advances, Application and Practice. Engineering & Management Press, 335-395
Benoit M. 1998 : Un outil de simulation du fonctionnement du troupeau ovin et de ses résultats économiques : une aide pour l'adaptation à des contextes nouveaux, INRA Prod. Anim. 11 (3) 349-362
Benoit M., Laignel G., Liénard G., 1999. Facteurs techniques, cohérence de fonctionnement et rentabilité en élevage ovin allaitant. Exemples du Massif Central Nord et du Montmorillonnais, Renc. Rech. Rum. 6, 19-22.
Blasco F., Weill A., 1999. Advances in Environmental and Ecological Modelling, Elsevier, 230 p.
Coleno F.C., Duru M., 1999. A model to find and test decision rules for turnout date and grazing area allocation for a dairy cow system in spring, Agric. Syst. 61 (3) 151-164.
Coquillard P., Hill D.R.C., 1997. Modélisation et simulation d'écosystèmes, eds. MASSON, 273p.
Coulon J.B., Pérochon L., Lescouret F., 1995. Evolution de la production laitière et du poids vif des vaches laitières au cours de leur carrière, Ann. Zoot. 44, 189-199.
Cournut S., 2001. Le fonctionnement des systèmes biologiques pilotés : simulation à événements discrets d'un troupeau ovin conduit en trois agnelages en deux ans. Thèse, Université Claude Bernard - Lyon I, ENITAC, INRA SAD-URH, 418 p. + annexes.

Cournut S., Dedieu B. 2004. A discrete event simulation of flock dynamics : a management application to three lambings in two years. Anim. Research. In press.
Dedieu B., Chabosseau J.M., Benoit M., Laignel G., 1997 . L'élevage ovin extensif du Montmorillonnais entre recherche d'autonomie, exigences des filières et simplicité de conduite, INRA Prod. Anim. 10 (3) 207-218.
Ducrocq V., 1994. Statistical analysis of length of productive life for dairy cows of the Normande breed, J. Dairy. Sci. 77 (3) 855-866.
Ercanbrack S.K., Knight A.D., 1989. Lifetime production of ¼ et ½ Finnsheep ewes from Rambouillet, Targhee and Columbia dams, affected by natural attrition, J. Anim. Sci. 67, 3258-3265.
Frasier W.M., Pfeiffer G.H., 1994. Optimal replacement and management policies for beef cows, Amer. J. Agr. Econ. 76, 847-858.
Gibon A., Rubino R., Sibbald A.R., Sorensen J.T., Flamant J.C., Lhoste P., Revilla R., 1996. A review of current approaches to livestock farming systems in Europe: towards a common understanding, in: Dent J.B., McGregor F., Sibbald A. (Eds.), Livestock farming systems: research, development, socio-economics and the land manager, EAAP Publication No. 79, pp. 7 – 19.
Girard N., Hubert B., 1999. Modelling expert knowledge with knowledge based systems to design decision aids. The example of a knowledge based model on grazing management, Agric. Syst. 59, 123-144.
Girard N., Lasseur J., 1997. Stratégies d'élevage et maîtrise de la répartition temporelle de la production ovine, Cah. Agric. 6 (2) 115-124.
Hemidy L., Maxime F., Soler L.G. 1993. Instrumentation et pilotage stratégique dans l'entreprise agricole, Cah. Eco. Socio. Rur. 28, 91-118.
Ingrand S., Dedieu B., 1996. An approach of grouping management practices as a contribution to the study of livestock farming systems, in: J.B. Dent, M.J. Mc Gregor, A.R. Sibbald (Eds.), Livestock farming systems: research, development socio-economics and the land manager, EAAP Publication No. 79, pp. 353 - 356.
Ingrand S, Cournut S., Dedieu B., Antheaume F., 2003 : La conduite de la reproduction du troupeau de vaches allaitantes : approche modélisatrice des prises de décision, INRA Prod. Anim. 16 (3) 263 – 270.
Keating B.A., McCown R.L., 2001.Advances in farming systems analysis and intervention, Agric. Syst. 70, 555 – 579.
Kristensen A.R., Jørgensen E., 2000. Multi-level hierarchic Markov processes as a framework for herd management support, Annals of Operations Research 94, 69-89.
Lee G.J., Atkins K.D., 1996. Prediction of lifetime reproductive performance of Australian Merino ewes from reproductive performance in early life. Aust. J. Exp. Agric. 36 (2) 123-128.
Lehenbauer T.W., Oltjen J.W. 1998. Dairy cow culling strategies: making economical culling decisions, J. Dairy Sci. 81, 264-271.
Lesnoff M., 2000. Etude de la dynamique et de la productivité des populations domestiques tropicales par des modèles matriciels en temps discret : les populations d'ovins au Sénégal, Thèse, Université de Montpellier II, France, 294 p.
Lewis R.M., Notter D.R., Hogue D.E., Magee B.H., 1996 : Ewe fertility in the Star Accelerated Lambing System, J. Anim. Sci. 74, 1511-1522.
Marzin J., Brelurut A., 1979 : Performances comparées des brebis limousines et croisées Romanov en conduite relativement intensive, Bull. Tech. C.R.Z.V. Theix 37, 15-23.
Moulin C.H., 1993. Le concept de fonctionnement de troupeau. Diversité des pratiques et variabilité des performances animales dans un système agropastoral sahélien, INRA Et. Rech. Syst. Agr. Dév. 27, 73-94.

Nugent R.A., Jenkins T.G., 1992. Effects of alternative lamb production systems, maternal line, and culling strategy on flock age structure, J. Anim. Sci. 70, 2285-2295.
Oltenacu P.A., Milligan R.A., Rounsaville T.R., Foote R.H., 1980. Modelling reproduction in a herd of dairy cattle, Agric. Syst. 5, 193-205.
Oltjen J.W., Selk G.E., Burditt L.G., Plant R.E., 1990. Integrated expert system for culling management of beef cows. Computers and Electronics in Agriculture, 4, 333-341.
Ostergaard S., Sorensen J.T., Kristensen A.R., 2000 : A stochastic model simulating the feeding-health-production complex in a dairy herd, J. Dairy Sci. 83, 721-733.
Romera A.J., Morris S.T., Hodgson J., Stirling W.D., Woodward S.J.R. 2004 : A model for simulating rule based management of cow-calf systems, Computer and Electronics in Agriculture 42, 67-86.
Santucci P.M., 1991 : Le troupeau et ses propriétés régulatrices, bases de l'élevage caprin extensif, Thèse, Université de Montpellier, France, 85 p.

Appendix 1 : The management of the simulator scheduler and the sequence of flock management and biological events

This scheduler handles a time scale with a day unit located in a virtual calendar. Involuntary culling event (ID) occurs every fortnight : all animals are put under risk of being culled for involuntary reasons and some of them will be. Every 1st of January occurs the annual planning event (AP), that define all the production cycles dates for the year, including coordination modalities of theses BPCs, and an anniversary event (Ann) that take into account the aging of the ewes. With this planning event, all the steering activities can be scheduled ; beginning of mating (BM), end of mating (EM), change of batch for infertile ewes (CB), culling and replacement event (CR). Then, depending on biological responses of the animals, the individual events occur, such as conception (eF), lambing (eL) and drying off (DOe).

Scheduler