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Modelling as a tool for the teaching of livestock dynamics

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Abstract – Modelling is a way of integrating and formalising the knowledge about how a system works. Thus, it is a relevant approach for teaching agricultural systems analysis to undergraduate students. In most cases, research models or decision support tools cannot be easily used for teaching purposes because conceptual models are too complex to be handled by students during a short training course or do not fit pedagogic goals. However, from our own modelling research, we developed two techniques to support our teaching program in herd dynamics. The first one was based on a deterministic approach and used simple flow diagrams. Students had to fill in a paper chart that depicts the breeding scheme of a flock for several years. Thus, they test if a combination of decision rules (e.g., breeding, replacement, culling) allows to reach a given production objective. Then, students had to suggest technical means or management decisions that could improve flock productivity. The second technique relied on a stochastic matrix model that was used to illustrate the sensitivity of herd productivity in a tropical environment. The model was computerised using spreadsheets. On the basis of the simulation results, students had to comment on the behaviour of the system and to appraise the model, with respect to the choice of assumptions and formalisation. Because our teaching approach is progressive and interactive, we are confident that students will become well-informed users of more elaborated models such as decision support tools.

teaching / livestock management / flock / herd / sensitivity analysis / modelling / stochastic / spreadsheet / flow diagram

Résumé – **L'utilisation de modèles pour l'enseignement sur le fonctionnement des troupeaux.** La modélisation permet de résumer un ensemble de connaissances sur le fonctionnement d'un système. C'est ainsi un outil pertinent pour la formation des futurs ingénieurs à la complexité des systèmes agricoles. Les modèles de recherche ou les outils d'aide à la décision ne peuvent pas toujours être facilement utilisés pour la formation parce qu'ils ne correspondent pas toujours à nos objectifs pédagogiques ou parce qu'ils sont trop complexes pour être manipulés par les étudiants dans des séances d'enseignement de courte durée. En utilisant nos travaux de recherche sur la dynamique des troupeaux ovins ou bovins, nous avons développé deux techniques pour l'enseignement. La première est fondée sur l'utilisation de diagrammes de flux d'animaux. Les étudiants doivent remplir des graphes qui décrivent, de façon déterministe, l'organisation de la reproduction d'un troupeau ovin

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sur plusieurs années. Ils vérifient ainsi si une combinaison de règles de décision concernant la mise à la lutte, le renouvellement et la réforme permet de satisfaire un objectif de production donné. Les étudiants doivent alors réfléchir aux moyens techniques et organisationnels pour améliorer la productivité du troupeau. La seconde technique est fondée sur l'utilisation d'une feuille de calcul. Les étudiants doivent évaluer la sensibilité des performances de troupeaux bovins élevés dans un environnement difficile en milieu tropical. Nous avons développé un formulaire avec un modèle matriciel stochastique afin de simuler la dynamique démographique d'un troupeau. Les étudiants sont capables de faire une analyse critique du simulateur parce qu'ils ont au préalable élaboré le modèle conceptuel du système. Notre approche pédagogique étant progressive et interactive, nous pensons qu'à long terme, les étudiants seront des utilisateurs avertis de modèles plus élaborés comme ceux qui sont le support d'outils d'aide à la décision.

enseignement / gestion du troupeau / bovin / ovin / analyse de sensibilité / modélisation / stochastique / feuille de calcul / diagramme de flux

1. INTRODUCTION

Future animal science specialists will have to face the complexity of livestock production systems. The teaching of animal sciences to undergraduate students is fairly difficult because they have to learn basic skills in numerous fields of the biology of farm animals (i.e. reproduction, nutrition, genetics, forage production…) in a short period of time. They also have to be able to analyse hierarchy and interactions among factors that influence animal productivity in on-farm situations. Thus, we use training courses based on a systemic approach of livestock production in order to help students to integrate knowledge and then to focus on how the system is regulated and controlled. For several training courses, we used a representation of the demographic dynamics of a group of farm animals, bred, culled, and replaced according to the strategy of the livestock farmer, which is called herd functioning [15, 21].

In teaching agricultural systems, new techniques [23] can be used that may help students to handle complexity emerging not only from the dynamics of the biological system but also from its interrelationships with a decisional system and the environment. Modelling is often cited as a way of summarising knowledge about how a system works [4, 18, 19]. We present here two techniques, based on herd modelling, that have been successfully used in training courses. The first uses paper charts depicting ewe flows within a flock, the second uses computer-assisted analyses of cattle herd productivity. The interest and limitations of these techniques are further discussed.

2. THE FLOW DIAGRAM TECHNIQUE APPLIED TO SHEEP FLOCK FUNCTIONING

French students attend their first applied animal science unit during the third year of the curriculum. We used the case of sheep farming in order to illustrate how reproduction management influences flock dynamics. For this approach, we developed a deterministic model based on a flow diagram representing, in a simple way, different categories of animals.

2.1. Materials and methods

2.1.1. The choice of sheep production

Several lectures dealt with the reproductive physiology of farm animals at the animal level, i.e. dam and sire. At this stage, we focused on the underlying physiological mechanisms, factors affecting their variations, and the technical means used to control the successive events from ovulation to conception and parturition. During the training course, and as a complement to the previous lectures, breeding was considered at the herd or flock level. In sheep production, because of the short duration of pregnancy (148 d) and the wide variation in litter size

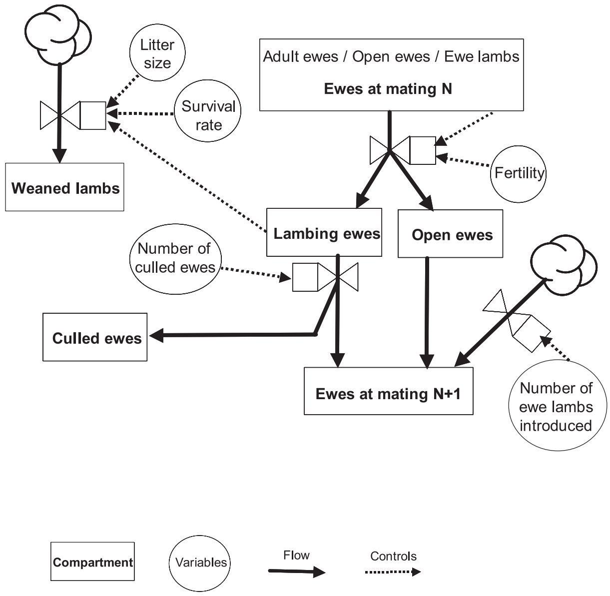

Figure 1. Flow diagram depicting a ewe flock functioning for two mating periods.

(1 to 3 or even 4 lambs), together with large seasonal variations of reproductive parameters [17], the annual lamb output may vary widely. Hence, in France, according to the farming systems in mountains or in lowlands the annual number of lambs reared per ewes ranges from 0.7 to 2.5 [2]. The breeding management of ewes, from the traditional once a year lambing to an accelerated breeding system, such as 3 lambings in 2 years [20], and the culling and replacement practices [16] are major factors determining whole flock productivity. This is why we chose this species as a good case study for the training courses, to make students understand the complex interactions between physiological constraints and farmers' practices.

2.1.2. Principles of flow diagram conception

The flow diagram was made of icons and arrows that display the important steps of the productive life of ewes. It allowed students to analyse the number of ewes in different groups (i.e. compartments), according to their physiological status, and the flows of ewes between compartments through time [1, 12]. We depicted (Fig. 1) five compartments: ewes at mating, lambing ewes, open ewes, culled ewes and weaned lambs. The compartment of ewes at mating is supplied by three flows: adult ewes just after lambs' weaning, open ewes that did not conceive at the previous mating period and ewe-lambs. Fertility (pregnant ewes relative to mated ewes) does not only determine the flow between ewes at mating and lambing ewes but also, as a complement, the flow of open ewes that can be mated at the next mating period. Litter size and lamb survival until weaning determine the flow of weaned lambs. The culling practices (number of culled ewes after weaning of the lambs) and the replacement practices (number of ewe-lambs introduced) determine the state of the group that will be mated at the next period. We assumed that there was no death of adult ewes.

2.1.3. Tool utilisation and progress during the training courses

The students were assigned exercises consisting of flow charts of increasing difficulty. The basic flow diagram (Fig. 1) was arranged according to the breeding scheme and was presented as a chain representing several years. The initial state of the system was given as the following: number of ewes in each compartment for year 1 and the values of variables. The students therefore had to fill in the compartments for the next years and to analyse the final state and the annual reports. The calculations were fairly simple and could be rapidly executed so that there was time left for analysing and understanding the situation and for discussing the technical proposals that were exposed during the lectures.

2.2. The breeding management of a flock with two mating periods

This exercise dealt with the breeding management of a flock divided into two sub-flocks. One sub-flock was mated in the autumn while the other was mated in the spring. During a 2-hour course, students had to fill in a chart made up of 2 connected flow diagrams, each representing a sub-flock. The total number of ewes in this flock was 325, with 50 ewe-lambs (replacement rate: 0.154, age at first mating: 7 months) that were kept annually to replace the 50 culled ewes. The fertility rate was higher in the autumn (0.90) than in the spring (0.75), while the litter size (1.1) was considered to be constant whatever the season. One rule was that the open ewes of a given sub-flock are transferred into the other sub-flock in order to be mated as soon as possible (thus the annual fertility rate for the whole flock may be higher than the fertility rate of 0.90 for the sub-flock mated in the autumn). The other rule was that 25 ewes were culled after weaning and replaced by the same number of ewe-lambs at the next mating period (in some periods of the year, after introducing ewe-lambs and before culling, the flock size reached 350 ewes). In the initial state, 167 ewes were mated in the autumn and 200 in the following spring (17 open ewes after autumn mating + 25 ewe-lambs + 158 adults): in that way, the system was made of an equal number of ewes lambing in each sub-flock (150). As a result for the flock, 300 ewes were lambing and the mean annual output was 0.78 lambs per ewe.

The students had to fill in a 4-year flow diagram. They were supposed to observe that the lambing distribution was not balanced between sub-flocks. The autumn-mated sub-flock increased (223 lambings in year 5) while the spring-mated one gave less lambings (95). They should also have seen that the annual lambing number was slightly increased (318 lambings versus 300). The system reached a long-term equilibrium situation (at year 12), with 241 lambings for the autumn-mated sub-flock and 82 for the spring-mated one.

The objective of this exercise was to lead students to appraise the effects of seasonal variations of the reproductive rate in sheep whose direct effect was a numeric reduction in one sub-flock at the expense of the other. Another objective was to discuss how to replace culled ewes to balance the size of the two sub-flocks. The last objective was to make them propose some ways to increase the reproduction rate of the spring-mated ewes (hormonal treatments, photoperiodic treatments, ram effect…). The relationship between the nutritional status of the ewes in the spring (i.e. body condition) and their reproductive performances was also discussed.

As applied to livestock, the flow diagram was sufficient for a first appraisal of flock dynamics. The students just had to apprehend the flow diagram representation of the flock and to understand the biological significance of the variables. In these conditions, little time was necessary to allow students to understand the meaning of the simulated results and to think about technical or management options that could improve productivity. Several other exercises were built in order to illustrate the consequences of breeding management decisions, or to point out the main problems sheep farmers have to face when managing sub-flocks. Hence, the students could easily understand that, with multiple sub-flocks, open ewes may have been transferred from one sub-flock to another in order to reduce the elapsed time between weaning and the next effective conception. Thus, they frequently suggested the use of early pregnancy diagnosis (e.g. ram detection, progesterone test or ultrasonic diagnosis) in order to detect open ewes soon after the end of the mating period.

2.3. The global appraisal of the breeding management of a flock

During 5 training sessions of 2 h each, the students had to analyse the sensitivity of a livestock farming system to hazards of various origins (e.g., climate, market prices). These hazards may be introduced in the flow diagram by changing the levels of variables such as fertility or survival rate, which control the flows of ewes and lambs. Thereafter, the students had to conceive a profound change of the breeding management in order to better fit new goals of production. The proposed breeding system was based on 3 mating periods per year: autumn, spring and summer. The combination of breeding rules and sub-flock sizes allowed a steady functioning, with a constant number of lambing ewes at each period. The annual reproduction rate was of 1.15 lambings per ewe of over 6 months of age and the annual output was of 1.32 weaned lambs.

The students had to analyse the impact of a lower reproduction rate during one summer mating period: the fertility rate decreased from 0.88 to 0.58 and litter size from 1.35 to 1.15. They had to fill in a 4-year flow diagram and to calculate, for each year, the turnover of sold lambs (Tab. I). If a problem of reproduction occurred during year 2, the system was only disturbed during year 3 and came back to a steady state by the end of year 4. Hence, the students were expected to conclude that such a system is very robust because a low fertility rate at a given mating period has a weak impact on the lamb output. They could also see that the major impact is a change in the distribution of the annual lamb production that leads to an immediate, severe decrease of the turnover (–22%), due to the seasonal variation of lamb prices.

2.4. Discussion about the flow diagram technique

In the first exercise, the flow diagram technique was used as a simple tool to analyse whether or not a combination of decision rules satisfies a given production objective. It is also an interesting tool for problem finding: what parts of the system explain the gap between the flock response and the production objectives? Thus, students are prepared to conceive appropriate rules of management (among those which are designed in the flow diagram) or to identify other possible control variables (which are not designed in the given flow diagram).

In the second exercise, the flow diagram was far more complicated. The objective was to perform both a technical and an economic appraisal of the system with the calculation of ewe flows between the sub-flocks and the financial output. The simulation allowed assessing the sensitivity to hazards of the described management system. This is an essential property of agricultural systems, which have to deal with several sources of variability in an uncertain context of market prices and agricultural policies. It is also a way to point out the hierarchy of factors modifying the economic results of a sheep farm, such as the annual productivity of the ewes or the sale periods of lambs. The last aspect studied was the relevance of such a breeding system in the annual labour organisation.

Ready-made flow diagrams are fairly simple to use in a classroom of undergraduate students. Even if we discuss a lot with students, we have to maintain equilibrium between the numerous simplifications that are proposed and the fact that it remains over-simplified for a practical on-farm use. In particular, teachers insist on the fact that, under farm conditions, mating periods are spread over several oestrus cycles of 17 days.

Table I. Simulation of technical and economic impact of a poor summer mating performance in year 2 (i.e. a reduced fertility rate and litter size) for a flock managed in three mating periods per year during a 4-year period. (Column "*Variation*": ratio of the year n to year 1).

Mating periods	Autumn	Spring	Summer	Total	Variation
Year 1					
Lambing ewes (N)	110	80	213	403	100
Sold lambs (N)	127	67	215	409	100
Turnover (€)	7.240	3.670	14.260	25.170	100
Year 2					
Lambing ewes (N)	110	80	140	330	82
Sold lambs (N)	127	67	215	409	100
Turnover (€)	7.240	3.670	14.260	25.170	100
Year 3					
Lambing ewes (N)	176	86	208	470	117
Sold lambs (N)	201	67	107	375	92
Turnover (€)	11.455	3.670	7.130	22.255	88
Year 4					
Lambing ewes (N)	109	85	210	404	100
Sold lambs (N)	125	74	209	408	100
Turnover (€)	7.125	4.050	13.865	25.040	99

Hence the transfer of ewes between sub-flocks can be even more complicated because some early-lambing ewes can be included into the next mating flock after their drying off. Our aim was to show that such an approach can be included in a spreadsheet assuming that main factors are clearly identified before building the flow diagram. In fact, teachers use spreadsheets as a tool to introduce the initial condition of realistic situations that are subsequently proposed during the training courses.

3. COMPUTER-ASSISTED ANALYSIS OF THE SENSITIVITY OF HERD PRODUCTIVITY TO ENVIRONMENTAL AND MANAGEMENT FACTORS

Here, our goal was to make students analyse cattle breeding systems other than those typical of temperate regions. The chosen context concerned harsh situations where environmental factors are largely unpredictable. Consequently, a stochastic approach was favoured to account for the influence of large climatic variations on herd productivity. Such a modelling approach required computer simulations that can be easily achieved with a spreadsheet.

3.1. Materials and methods

3.1.1. The choice of a tropical cattle production system

During the fourth year of the curriculum, students may choose a course on tropical animal production. For this course, we analyse an agro-pastoral cattle system in West Africa. To parameterise the model, we used performance data and demographic parameters of 10 N'Dama herds studied during 5 years [10] from an on-farm monitoring method developed in Senegal [22].

The size of the herds varied from 10 to more than 200 heads, with a large diversity of objectives and management rules among breeders. Productivity was difficult to evaluate not only because of the variety of end products (e.g., milk, animals for slaughter or sale, work, manure), but also because of the economic value of live animals, since the herd provides a source of capital that may be used if necessary. Furthermore, herd productivity parameters are widely dependent on forage resource availability and thus on climatic conditions. The performance of N'Dama cows differs from those of temperate cattle breeds: mean weight is 250 kg and daily milk production is about 2.7 kg [6]. The age at first calving varies from 50 to 60 months and the annual mean fertility is below 50%. In such a system, long-term analyses are required because of the low reproductive rate and the high inter-annual variability of climatic conditions.

3.1.2. *Principles of the demographic model*

Since the productivity of a herd depends mainly on its age and sex structure, matrix modelling has been chosen. A practical interest of such a method [13] is that it does not require specific mathematical or modelling knowledge. Matrix models are discrete-time, recurrent models, so they can be developed using spreadsheets.

Given an initial herd state and a set of demographic rates (i.e., fecundity, mortality, off-take and input rates), matrix models simulate the future herd structure and size at annual or shorter time intervals. The method was based on the formalism of herd dynamics in tropical livestock systems described by Lesnoff [14]. The state of the herd at time t is described by a vector $x(t)$, in which each component represents the number of animals belonging to a given class of age and sex. In matrix notation, annual models are defined by the recurrent equation $x(t+1year) = Ax(t)$, where A is the annual projection matrix, used to calculate the herd vector for the next year. The A matrix contains the rates that define how the sex-age classes change size over a year. Let $x_{s,i}(t)$, $i \geq 1$ denote the number of animals of sex s ($s = f$ for females or m for males) in age class i at the beginning of the year t. Components $x_{s,1}(t)$ represent the number of living newborns of sex s during the year. For the Leslie annual matrix model, recurrence formulas are:

$$x_{s,1}(t) = \sum_i m_{s,i}\, x_{f,i}(t),$$
$$x_{s,i+1}(t+1) = s_{s,i}\, x_{s,i}(t),\ i \geq 1.$$

The $m_{s,i}$ are the fecundity rates, i.e. the expected number of living newborns of sex s during the year per cow in age class i at the beginning of the year. The $s_{s,i}$ refer to survival rates, including inputs, for animals of sex s in age class i at the beginning of the year:

$$s_{s,i} = 1 - P_{s,i}(death) - P_{s,i}(offtake) + P_{s,i}(input).$$

In the case of large populations, the transition rates correspond to the probabilities of different events (i.e., births, deaths, off-take and inputs). In the case of a small herd, each sex-age class contains a small (integer) number of animals. Thus, the number of animals at t+1 is generated by random draws from a multinomial distribution whose parameters are the former rates.

On the basis of such a matrix model, we built a spreadsheet template that students use without referring to matrix notation.

3.1.3. *Tool utilisation and progress during the training courses*

The training course ran over 2 sessions of 3 hours. During the first session, the students had to build a conceptual model that describes herd productivity. No computer was required for this session. First, the teachers described the agro-pastoral context and the cattle breeding system. The students had to extract the relevant information

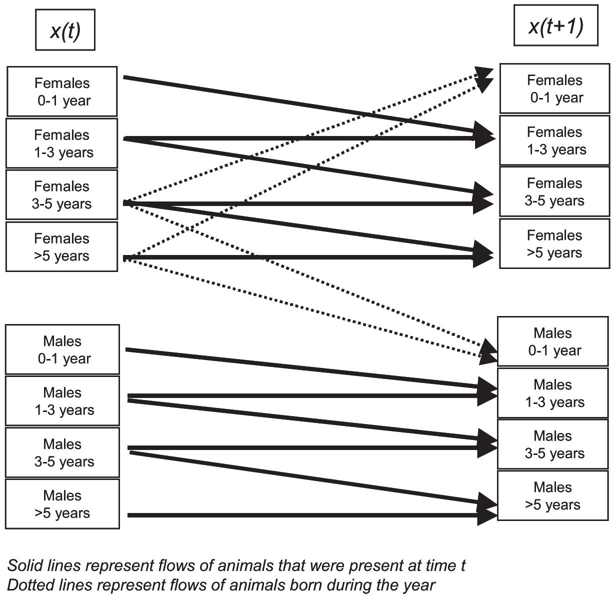

Figure 2. Schematic representation of the contribution of each class present at time t to the sex-age structure of the herd at time t+1.

from this general description in order to build a representation of the system. This step was mainly interactive and allowed to point out the different components of the system (relevant sex-age classes) and their interrelationships and to examine their respective contribution to global productivity (Fig. 2). Then, the students had to consider the system with a dynamic approach, i.e. they had to draw the functioning of the herd from one year to the next (Fig. 2), and to determine the formal projection equations for each sex-age class.

The second session focused on a sensitivity analysis of productivity as influenced by sex-age structure and external factors. This session was computer-assisted, using the spreadsheet template developed by the teachers on the basis of matrix modelling and derived from the conceptual model built by students during the first session. Several simulation exercises were assigned to students, in order to appraise the sensitivity of small herds to environmental factors, as presented below.

3.2. The effect of food availability on productivity and growth of small herds

In West Africa, one of the breeders' objectives is to own a large herd, above 100 heads. After receiving a few cows from their fathers, not all young stockbreeders succeed in increasing the herd size. The students had to analyse the growth mechanism of a small initial herd in order to understand some of the reasons for this failure. They simulated the growth of 50 herds with the same initial structure (20 cows and 4 bulls). The input and off-take rates were fixed (Tab. II). Fecundity and mortality were assumed to be linked to food availability, strongly dependent on climatic conditions. Years were qualified as good, bad or catastrophic, according to the impact of food availability on the demographic parameters (Tab. II). Because of the small size of each sex-age class, a stochastic process was applied to calculate the number of animals dying, calving or being taken off the herd. The succession of good,

Table II. Parameters of the matrix model for small herds (< 50 heads).

Initial number of reproductive animals				
Females	3–5 yrs	0		
	> 5 yrs	20		
Males	3–5 yrs	0		
	> 5 yrs	4		
Demographic parameters (related to the year type and defined for partially milked cows)				
	Age	Good year	Bad year	Catastrophic year
Mortality	0–1 yr	0.15	0.30	0.60
	1–3 yrs	0.10	0.10	0.20
	Adult	0.01	0.02	0.05
Females fecundity	3–5 yrs	0.30	0.15	0.07
	≥ 5 yrs	0.30	0.25	0.20
Sex ratio	0.50			
Off-take rates per sex-age class (whatever the year type)				
Females	1–3 yrs	0.10		
	3–5 yrs	0.10		
	≥ 5 yrs	0.15		
Males	1–3 yrs	0.15		
	3–5 yrs	0.30		
	≥ 5 yrs	0.35		
Input rates per sex-age class (related to global herd size, whatever the year type)				
Females	> 1 yr	0.02		
Males	1–3 yrs	0.10		
	> 3 yrs	0.02		

bad and catastrophic years was also stochastic, with an average occurrence of 1 good year for 1 bad year, and an average occurrence of 1 catastrophic year out of 10 bad years. The students had to draw and comment the graph obtained for the 50 simulated herds (Fig. 3).

The fixed off-take rate was sometimes too high to allow any herd increase. The cases of decrease in herd size were related to the stochastic effects of mortality and fecundity on sex-age classes with small size. During a catastrophic year, all the calves born may die even if the death probability is lower than 1. This high sensitivity to environmental factors may contribute to explain why one of the breeders' main objectives was to increase the size of their herds. On the contrary, under the same initial conditions (herd size and structure) and management (input and off-take rates), the size of some simulated herds increased over 350 heads, because of favourable successions of good years within the 50 years of the simulation. In the field, herds never reach such a size, mainly because food, pastures and labour are limiting in this agro-pastoral system. Comparing observations and simulation outcomes, the students critically examined the model and concluded that breeders may change the way they manage their herds when they become large enough. Hence, the assumption of fixed off-take and input rates cannot be kept. The conclusion was that the proposed model has to

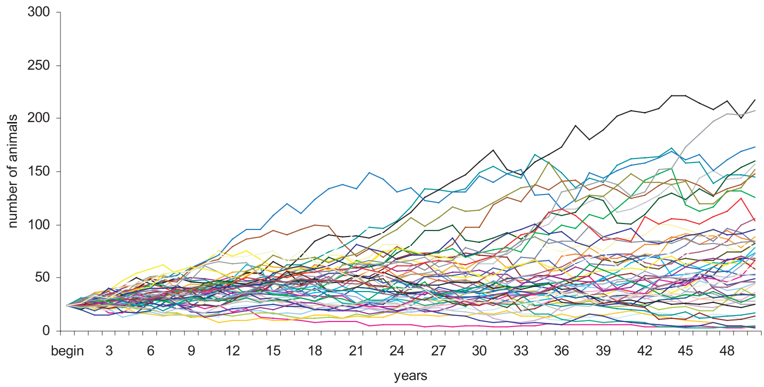

Figure 3. Simulations of the evolution of a small herd size under stochastic successions of good, bad or catastrophic annual climatic conditions.

be improved by accounting for the changes of management rules according to the current herd size. Hence, the students were asked to identify which parameters of the model have a strong impact on the herd growth and should be considered size dependent. A simple modification of the model, such as a change of the off-take of reproductive cows, is sufficient to regulate the herd size and to give more realistic results.

3.3. Discussion about the demographic model

The modelling and simulation approaches developed in this exercise present major pedagogical interests. Whereas the flow diagram only allows studying the impact of one factor on the reproductive performances, simulations on a spreadsheet make students appraise the complex interactions between demographic parameters, and their relationships to environmental factors (climate and food resources) and breeders' practices (off-take, input of live animals). Students are able to develop a critical analysis of the simulator, because they previously built a conceptual model of herd functioning. This phase implies that relevant choices are to be made in accordance with the objectives of the study. Students become aware of what part of the reality the model represents. For instance, they discuss the choice of an annual time scale. Students frequently propose to divide the annual cycle into several periods to represent the seasonal variations in the demographic rates. This has been shown to be relevant at a fortnight scale for sheep [14] and a monthly scale for cattle [11]. Nevertheless, for this training course, an annual time-step is chosen and students know that, for instance, the impact of the duration of the dry season [10] cannot be studied with such a model. In the same way, when simulated data do not fit observations, students may assess what components of the model have to be improved. At last, this training course offers the possibility to the students to handle quite unfamiliar parameter values, which are, however, relevant in tropical conditions. They understand how modelling can be complementary to on-farm monitoring. The former requires field data in order to parameterise and validate the model; the latter is an expensive procedure, which cannot be applied to investigate alternative management decisions. They can also see the interest of formalising a new situation into a framework (conceptual diagram) and testing it rapidly with a very common tool such as a spreadsheet. The initial presentation is of particular importance: students are then able to point out the pertinent assumptions that have to be tested.

4. GENERAL DISCUSSION AND CONCLUSION

Both teachers and students are users of animal science models. Teachers resort to modelling to reach pedagogical objectives. Students use the modelling process to formalise the biological laws and mechanisms, and the simulations to explore the behaviour of the system. To achieve our pedagogic objectives, we could have used existing models, such as research models or decision support tools. Instead, we preferred to build new models that could be named teaching support tools. The reasons for this choice are discussed below.

Some research models deal with livestock on a farm setting. The herd is only a sub-system that is poorly or not really modelled; even if the animal is the basic component of the model, the main outputs are the economic results [8]. In other models, the animal is the system modelled; the accumulation of animals in classes makes up the simulated flock [3, 5]. Because the herd is not clearly described, these models do not fit our teaching objectives. Other research models are specially designed to represent herd functioning [7, 11, 14]. They are not, however, shaped for an interactive use by inexperienced people. In addition, they have been developed with software languages mostly unknown to undergraduate students. These are the main reasons why such models cannot be used in short training courses. Moreover, these models are complicated because of many feedback loops added to better represent reality. They are too complex for teaching purposes, given that our main pedagogical goal is to highlight the sensitivity of the system to direct external factors.

Decision support tools for herd management, often based on research models, may be used for teaching purposes. For example, GRAZPLAN [9] has been chosen by teachers of the University of New England for a 4-year curriculum. Students become very familiar with this software and could easily use it, as long as this software can solve the problems they will encounter during their professional careers. Another type of decision tool, as spreadsheet templates, is available for flock management decisions [1]. Such a tool could have been used during training courses but, since its main objective is an economic optimisation, it is not directly adaptable to flock functioning simulations.

As a consequence, none of these modelling approaches was convenient for our teaching goals. Another argument that plays in favour of developing our own models for teaching is that students could take part in the elaboration of the model and thus learn to be critical when encountering unrealistic behaviour of the system. Indeed, in such extreme cases, students are to criticise the conceptual model (which is their view of the real system) and/or the hypotheses developed during the formalisation step. All these points are of main interest as part of the students' own experience. This is why models for teaching have to be flexible and simple, making a top-bottom approach easier (from the results back to the hypotheses and inversely). In such a context, teacher-cum-researchers rely on their research experiences to deliberately simplify the research models in order to achieve the formerly described objectives.

The two techniques described in this paper illustrate how modelling can originally be used in livestock dynamics teaching. This pedagogical approach emphasises the usefulness of modelling in teaching, as already experienced in other animal science courses such as animal nutrition [18]. Moreover, because our approach is progressive and interactive, we are confident that, in the long-term, students will be well-informed users of more elaborated models such as decision support tools.

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