ADAPT-HERD

Management strategies to improve herd resilience and efficiency by harnessing the adaptive capacities of small ruminants

PRIMA section 2 project

DELIVERABLE 3.2
Herd productivity according to the environmental conditions and feeding limitations

Due date: M42 (02/2023)

Project start date: 18/09/2019 **Duration**: 48 months

Work package concerned: WP3

Concerned work package leader: Margalida JOY (CITA)

Dissemination level: Public

Contents

Preamble

This document is intended as a guide to the advantages of a tool for simulating production (Dynmod) and, by extension, animal productivity at herd level. It is not strictly a report on the results of the productivity surveys carried out during the project by the various national teams involved in the project. We prefer to present a synthesis of the discussions and two workshops held with the Tunisian (12-17 february 2023) and Egyptian teams (24-29 september 2022) to to discover and learn about the demographic projection tool. It should be noted that we did not work on the Spanish example because the Dynmod model is not adapted to small ruminant farming systems for intensified systems where the net offtake rate (sales - purchases) is close to 100%.
We felt that using this simple modelling tool was a good practical introduction to modelling and enabled us to objectivise hypotheses on the impact of herd management interventions on productivity. In this way, we were able to contribute to the discussion on describing and understanding the strategies used by Mediterranean livestock farmers to cope with climate change, which is having an increasingly significant impact on the viability of farming activities. We hope that our partners will continue to use this tool for their prospective work on livestock.

Proposal

The objective of Task 3.2 is to characterize the current productive performance of the small ruminant farming systems that have been selected for the project representing the different productive environments of the Mediterranean PRIMA area.

For this task, the description of productivity is carried out at the herd level and will be used to design and develop a prototype model to simulate the effect of herd management decisions by farmers on the adaptive capacity of small ruminants under climate change scenarios (WP4).

The management of the herd is defined according to the following points:

- Reproduction management,
- feeding strategy (grazing and supplementation)
- herd demography management (replacement and culling strategies).

To help the project partners to identify the levers of productivity variation at the herd level, we propose within the framework of task 3.2 a simple simulation tool (DYNMOD) allowing to quickly evaluate the productivity of a herd (or several herds) according to the demographic parameters which will have been estimated by the partners for the various breeds of sheep and goats.
We therefore propose to the partners a model-based approach to describe the numerical productivity of the different farming systems studied. We believe that this approach will be more useful than a list of demographic and production benchmarks. We also see other advantages.
The model-based approach makes it possible to describe the potential of the systems under different hypotheses based on the herd management practices of the farmers. It is precisely this approach that is used in WP4 activities. The proposal of a simple tool will make it easier to compare the impact of a change on animal production between local breeds or systems.

Lastly, we believe that this proposal could be a good introduction to the use of models for zootechnical partners who have little experience of these approaches or who are often thought to be the preserve of specialists in applied mathematics.

A demographic model to assess herd productivity

Matrix model

We used a matrix model developed by CIRAD's SELMET team and historically used to represent the effect of drought or sanitary interventions on extensive livestock farming in the tropical regions of sub-Saharan Africa, where animal births are not controlled and the lack of demographic data prevented a detailed description of demographic processes (see 'References' section for examples of studies).

This model is based on the life cycle of farm animals (*Fig. 1*), the main indicators of which (fecundity, herd's entry-exit) are the parameters of variability in the number of animals in a herd. We are therefore focusing on decisions concerning reproduction, culling, animal purchases and sales. These type of model enhance all categories (sex and age) of animals (Lesnoff, 2011).

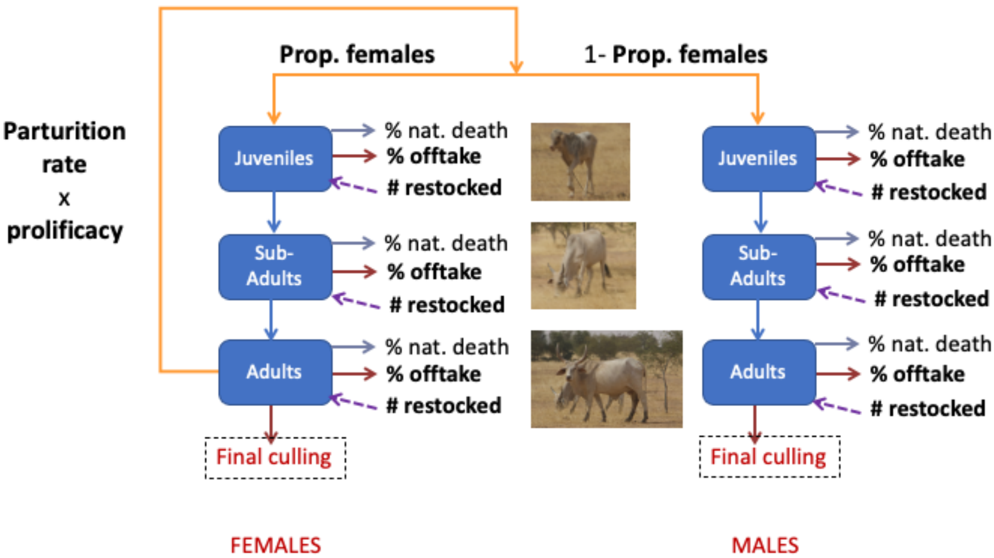

Fig. 1 Simplified animal life cycle defining the structure of the demographic model in DYNMOD.

The model is built from a matrix equation for the projection of livestock numbers over time (Caswell, 2001; Lesnoff, 2000; Lesnoff 2015), which allows the simulation of demographic dynamics and animal production under different scenarios. The model that estimates the size of a herd for the annual time interval [t-t+1 year] is in the following form:

$$X_{(t+1\ year)} = A \times X_{(t)}$$

With :

- X(t) contains the number of animals by age class and sex (animal categories) at time t.

- A contains the demographic parameters (reproduction, mortality and offtake) of the herd for the animal categories.
- $X_{(t+1\ year)}$ contains the result of the distribution of the number of animals in the animal categories at time t + 1 year.

The model is called a matrix model because it is constructed from a series of mathematical equations representing the dynamics of animal categories or compartments defined by sex and age classes. The equations relate the transitions from time t to t+1 of the animals between these compartments.

This model represents a deterministic variable environment. Deterministic because variations in demographic rates are defined on the basis of hypotheses or observations and not randomly (Lesnoff, 2011).

It should be pointed out that the demographic model is a fairly simple version of the demographic mechanisms of herd growth. For example, the model does not take into account seasonal variations in parameters that can influence overall productivity. Environmental variability such as the impact of resource availability, disease or market prices is also not taken into account in the simplified model we propose.

We have two approaches or parameterisations of the model for studying the variability of productivity, which will be detailed in the chapter presenting Dynmod tool.

Firstly, modelling the annual dynamics of the herd for up to 20 years. We consider that the effect on productivity of a change in practice is a dynamic process that should be observed over several years. This corresponds well to the use of demographic matrix models, where we have to consider the asymptotic growth rate and structure of the population (i.e. those obtained after a certain number of annual simulations) in order to ensure that population growth depends directly on the demographic parameters (Caswell, 2001).

Secondly, a 1-year steady-state projection model, i.e. a simulation that sets the size and sex-age structure of the herd at a constant level from one year to the next. This condition of stationarity, called steady-state, make it possible to compare herds with different initial demographic characteristics.

It is also important to note that the results of the simulations cannot pretend to be forecasts of the future animal production of the systems studied. The matrix models enable comparisons to be made between different farming systems on the basis of a given demographic situation - for example, the assessment carried out in the farm surveys in WP2 and WP3 of this project - by proposing hypotheses for variations in animal survival and reproduction rates. As a result, these comparisons provide a diagnosis of the current situation rather than a forecast of the future of livestock farming in the Mediterranean area.

Productivity as an indicator of herd management strategies

The main objective of WP3 is to characterise the production environment in order to better understanding the practices of farmers to harness animals adaptive capacities to adverse conditions. Our understanding of Task 3.2 could be seen as a change of scale in the evaluation of animal performance. We propose to characterise the demographic performance of the herd by means of a productivity indicator at herd level, which will make it possible to compare breeding systems. This indicator integrates both the individual performance of the animals and their management by the farmers (Upton, 1989).

Empirical productivity indicators have limitations that make it difficult to understand how they vary as a function of vital demographic rates (reproduction and survival) or beacuse of very different population structures between herds. They are also subject to biases linked to interference between demographic parameters or to imprecise estimates of animal numbers in declarative surveys. The proposal to use a matrix demographic model makes it possible to overcome some of these difficulties by taking into account the entire life cycle of animals, animal flows and variations in animal stock. Matrix population models provide a link between individuals and the population (Caswell, 2001). Demographic projection provides a framework for comparatively simulating the outputs of a herd, making it possible to describe productive environments (Fig. 2).

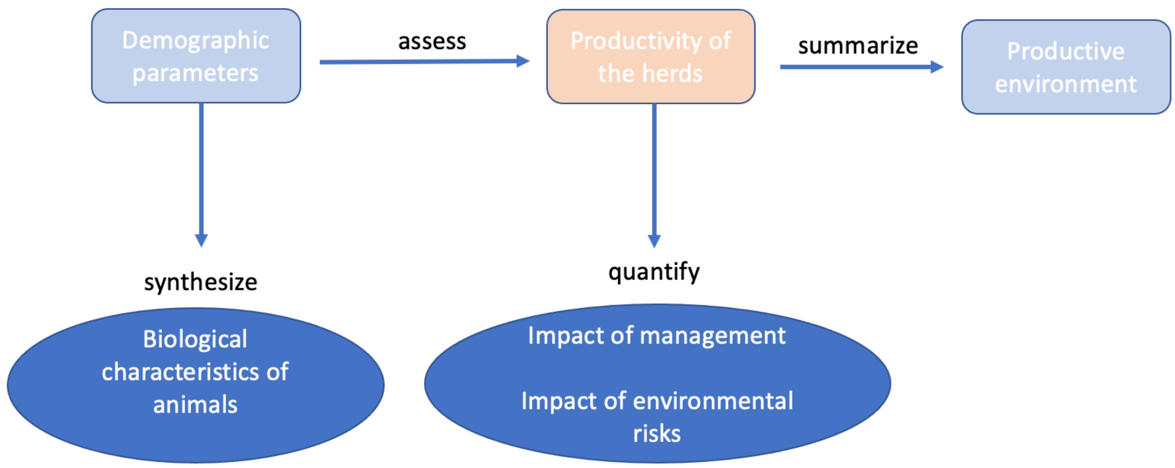

Fig. 2. The links between demographic parameters, herd productivity and the productive environment.

The method is based on a set of hypotheses built according to relevant scenarios in the PRIMA context which attempts to evaluate the effect of climate change on production, It will be possible to carry out prospectives based on questions such as:

- What is the effect of a massive slaughter or sale of animals on the annual productivity of the herd ?
- What is the effect of a decrease in fertility rate (parturition rate) on annual productivity ?
- Which demographic parameters have the greatest impact on annual productivity ?

- What is the effect of the age-sex structure on annual productivity ?
- If a shock occurs (e.g., a drastic decrease in the number of animals in the herd), how long does it take to rebuild the herd ?

These examples of herd management strategies can help the partners to characterize specifically the actions and rules of the herd model developed in task 4.2 (WP4).

Herd productivity as a unit of comparison between livestock systems

There are many indicators to describe the productivity of a herd and many definitions of the productivity rate, but a general definition can be given (see Lesnoff 2011 for a summary): the ratio between an production and the means used to obtain it. We have chosen a measure of the herd's numerical productivity that integrates the processes inherent in the entire life cycle of the animals, animal flows and variations in the animal stock (Jalvingh, 1997). More specifically, this numerical productivity, which is derived from the sex-age composition of herds and demographic rates (reproduction, mortality and exploitation), is used by farmers in terms of stock variation and offtakes (slaughter, sales, gifts, etc.). It should also be noted that this production can be expressed according to other equivalence units such as live or carcass weight, milk production, or even the dry matter feed requirements of the animals.

We define the potential production as an indicator of herd productivity using the equation below for the general demographic projection between year t and year t+1. It is shown that the annual balance between births and deaths is the sum of the variation in the number of animals present in the herd between the beginning and end of the year and the difference between the offtakes (slaughtering, sales, gifts) and animals imported into the herd (purchases, gifts).

$$\mathrm{n}\,(t{+}1\ \mathrm{year}) = n\,(t) + b - d - o + i$$

Herd size (end of the year) — Herd size (start of the year) — Births — Deaths — Offtake — Intake

$$\Delta n = n\,(t{+}1) - n\,(t)$$

$$\Rightarrow b - d = (o - i) + \Delta n$$

Total production ("Potential offtake") — Net offtake ("Effective offtake") — Stock Variation (Herd dynamics)

We obtain a measure of productivity or potential production in the form of a rate by dividing by the average number of animals ($\bar{n}$) for the period *t* - *t+1* (Lesnoff, 2011) :

$$\frac{b-d}{\bar{n}} = \frac{o-i}{\bar{n}} + \frac{\Delta n}{\bar{n}}$$

$$P = O + SV$$

Potential of production rate — net Offtake rate — Stock Variation rate

For example, a rate *P* = 0.12 means that the herd produces 12% of its size each year, which the farmer may or may not use as offtakes.

if we express the above equation in terms of stock variation, we obtain:

$$SV = P - O$$

We can see that if the production potential *P* is lower than the net offtake (*O*), then the size of the herd decreases and vice versa.

A quick description of DYNMOD

Dynmod is a simplified ruminant herd productivity simulation tool that is presented in the form of Excel spreadsheets. The tool is built around a model that simulates population growth in order to estimate the size of the population and the number of animals produced annually. DYNMOD operates a model with user-defined sex-age compartments. Only females in the adult group are considered reproductive.

These outputs are also automatically translated into meat and milk production or feed requirements of the animals produced. Several studies have shown how this tool can be used to easily forecast the animal load per area unit of the rangelands in a region (Sounon et al., 2019) or to perform a sensitivity analysis of demographic parameters on the productivity of cattle herds in Mali (Ba et al. 2009).

DYNMOD offers two types of simulations (Table 1). An annual simulation of productivity using steady-state demographic models and a multi-year simulation over the long term (until 20 years). Materials (manual, STEADY1, STEADY2 and PROJ Microsoft Excel spreadsheet of DYNMOD) are available here : https://gitlab.cirad.fr/selmet/livtools/dynmod

Table 1. DYNMOD: a what-if simulation tool. Input and output parameters.

	INPUT	OUTPUT
STEADY 1-year projection	population size reproduction rate mortality rate offtake rate	number of animals sex-age structure growth rate
PROJ Up to 20-year projection	population size reproduction rate mortality rate offtake rate Optionally, animals purchased (intake).	number of animals sex-age structure growth rate

Steady-stade model

Steady-state models are used to simulate the productivity of a herd for one year. These models are based on the assumption of demographic steady-state. This means that from one year to the next the annual growth rate and the sex-age structure of the herd are considered stable. This stability (the number of animals can nevertheless increase or decrease) of the distribution of the numbers of animals from one year to the next allows the prediction of the numbers from a common base, which makes it possible to easily compare the productivity of several herds with contrasting demographic characteristics. This common framework ensures that projections of animal numbers are not linked to the initial demographic situations of the herds to be compared (Upton, 1989).

It should also be noted that steady state models can be used to assess the productivity of a herd even when the demographic parameters are uncertain, thanks in particular to the calibration stage. This is particularly true of offtake parameters, which can also be estimated using this type of model.

Two versions of the steady-state model are proposed in DYNMOD:

STEADY 1 simulates the annual productivity of a herd based on its size and the demographic parameters of reproduction and offtake (offtake = sales + slaughter - purchases). The module calculates the number of animals, the sex-age structure and the growth rate corresponding to the "stable" state of the population.

STEADY 2 simulates the annual productivity of a herd based on the demographic rates of reproduction, mortality, offtake and the number of adult animals given as input. The module calculates the number of animals produced in order to maintain a zero annual growth rate of the population corresponding to a stable and equilibrated state of the population. The demographic state of a population in equilibrium means that the growth rate is zero.

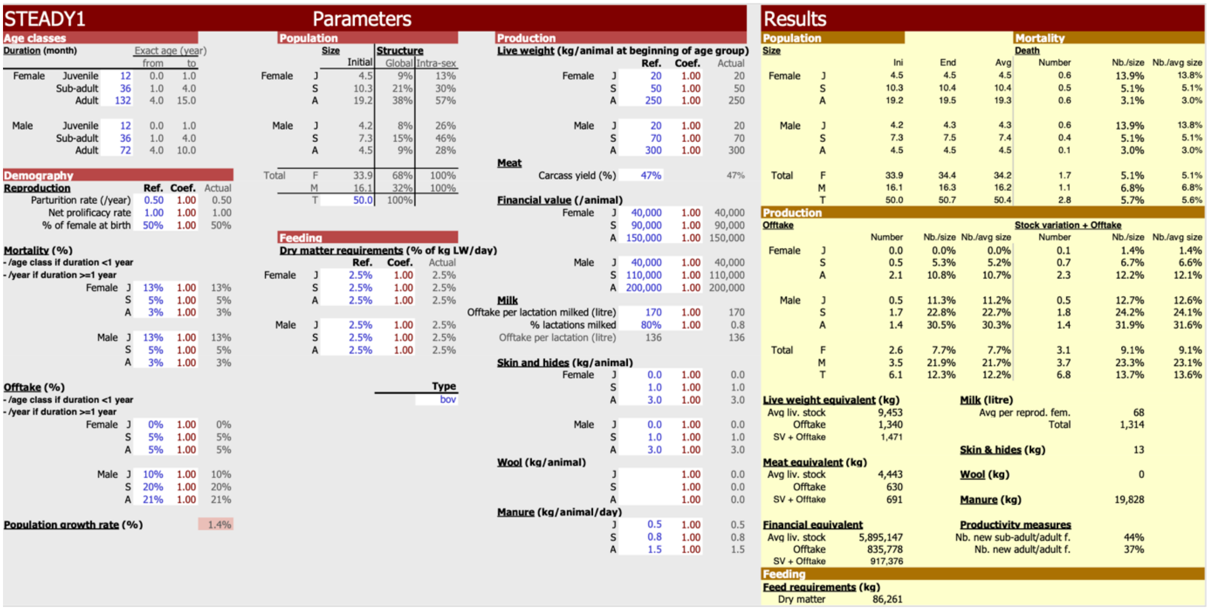

Fig. 3. Example of a simulation of a cattle herd of 50 animals with the STEADY1 spreadsheet of DYNMOD under Microsoft Excel. The input parameters are in blue color and automatically multiplied by the value of the Coef. (in red) which facilitates comparative analyses.

An example of a STEADY 1 simulation interface is shown in (Fig. 3). In order to calculate the number of animals produced annually, the user enters the number of animals in the herd (50 animals), the longevity[1] (in months) of the 3 age categories (J: Juveniles; S: sub-adults; A: adults), the reproduction parameters, the natural mortality and offtake probabilities by age class.

In the 'Results' section, we read:

- The annual offtake or production (6.1 animals).
- The total annual production (stock variation + offtake[2]) is 6.8 animals, which can be related to the average number of animals in the herd: 13.6% (productivity rate in animal numbers).
- The annual growth of the herd is 1.4% (population growth rate).

The numerical yield is automatically converted by DYNMOD into meat, milk or financial values if the user has entered the conversion references.

Multi-year simulation model : PROJ

The long-term projection model (PROJ) can be parameterized from one year to the next, so that a favorable or unfavorable production environment can be represented for each year of simulation and its impact on the productive dynamics of the herd can be observed for up to 20 years. PROJ can be used for instance to make long-term forecasts or to simulate the resilience of a herd after a shock such as a drought. Another possible application of this type

[1] For the DYNMOD simulation, animals that exceed the maximum age set are considered slaughtered and are counted in the production (offtake).

[2] Stock variation = difference between the population sizes at end and beginning of the year; offtake is the annual net exploitation, i.e.: sales + slaughterings - purchases.

of model is to study the dynamics of the herd over a certain period in order to understand how demographic equilibrium (steady state) is achieved.

- Total number of animals in the herd;
- Parturition rate and prolificacy of females
- Mortality rates by sex and age group;
- Offtake rates (sales + slaughter - purchases) by sex and age group.
- Optionally, animals purchased (intake).

Study case : example of Saidi goats herds in Assuit (Upper Egypt)

We present an example of simulating the production potential of goat herds located in several villages of the Assuit area in the Nile Valley in Upper Egypt. We reported in Table 2 the parameter estimates obtained from a retrospective demographic survey conducted in 2018 among 19 flocks representing a total of 167 animals.

The year 2018 was particularly dry and the high offtake rates reflect strategies to reduce herd size in order to cope with food limitations and attempt to maintain a sufficient production level for family needs.

A first simulation with STEADY1 shows that the very high sales of males and young females results in a high productivity rate (41%) but at the same time a decrease in herd size of -17%. This observed decrease in herd size is not sustainable in the short term and is certainly also linked to the particularly high mortality rates of the young (63% and 34% respectively for females and males) for the year 2018. Moreover, we know that these rates are highly variable from year to year.

We propose to study the sensitivity of the offtake rate of females, which are particularly high for young animals, in order to estimate the equilibrium point that would allow to maintain a constant population size (zero growth rate). To do this, we will vary successively and independently the offtake rates of young, sub-adult and adult females (see Table 2) in order to simulate the variation of the number of animals produced annually and the annual growth rate of the herd.

Table 2. Demographic input parameters used in the STEADY1 model. Age categories (J: 0-6 months; S: 6-12 months; A: >12 months).

Parameter	Sex	Age class	Estimation	Range of variation
Parturition rate (/year)			0.82	-
Net Prolificacy rate[3]			1.48	-
% of female			50	-
Mortality rate (%)	F	J	63	-
		S	1	-
		A	1	-
	M	J	34	-
		S	0	-
		A	0	-
Offtake rate (%)	F	J	50	0-50
		S	13	0-50
		A	13	0-50
	M	J	53	-
		S	40	-
		A	40	-

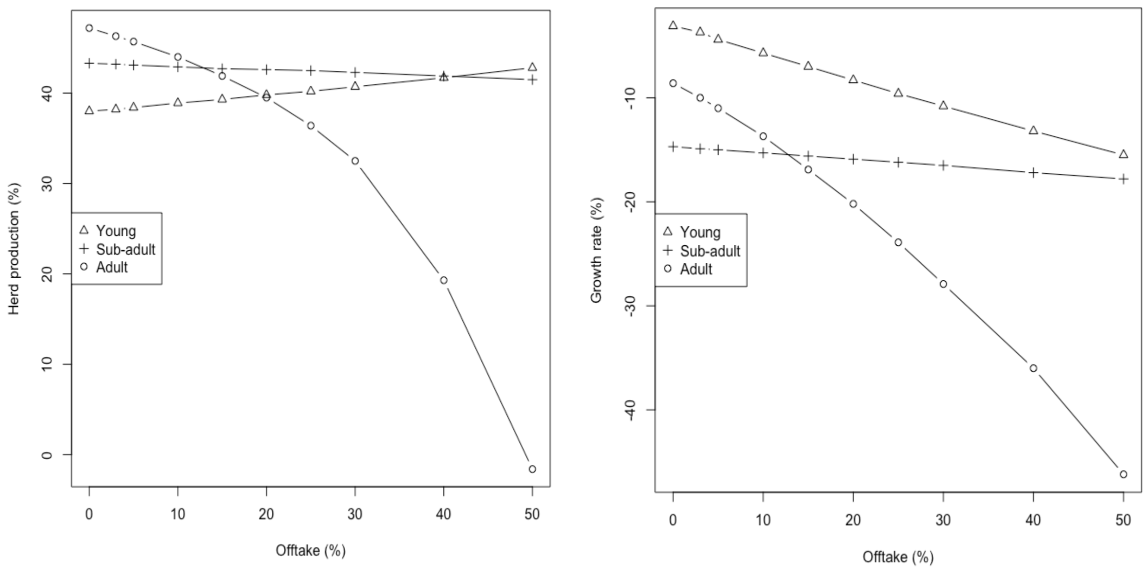

Fig. 4. Variation of total annual production or productivity rate (% of average herd size) and herd growth rate (%) with female offtake rate (%).

This small example shows how the variation in sales and slaughter (offtake) of females according to their age can impact the annual production of animals. The results for the year 2018 are presented in Fig. 4. The simulation shows that the offtake of adult females (> 1 year old) can potentially drastically decrease the growth rate of the herd and at the same time significantly reduce the productivity (herd production). The levels of decrease in production

[3] Net prolificacy rate = average number of offspring born alive per parturition.

and growth rate are much less if one considers the option of selling young female animals first, all other demographic parameters being equal.

Comparative description of the productivity of small ruminant farming systems in Tunisia and Egypt

Comparison of productivity at the "average" farm level

It should be remembered that the main benefit of demographic projection models is the possibility of comparing different demographic situations on the basis of a common framework. We will define this framework later in this chapter. We have chosen to compare the livestock production systems of Tunisia and Egypt on the basis of 'average' livestock production, i.e. where the parameters used as input to the DYNMOD model are averages of the information available to us (surveys, literatutre, expert). We have not taken into account the stochastic nature of the parameters, which is generally simulated to study the sensitivity of the model's outputs.

Table 3 shows some of the demographic parameters compiled in Task 3.1 of the project and used for the proposed simulations.

Table 3. List of demographic parameters used for the simulation of herd productivity. Field survey data compiled in task 3.1.

	herd size	ewes/hh	rams/hh	replac. ewes/hh	lambs born/hh	lamb mortality (%)	offtake lamb (%)	Partur. rate	prolificacy
Egypt									
extensive	314	211	10	30	215	10	61	1.05	1.09
intensive	38	22	2	8	26	37	45	0.89	1.48
semi-intensive	25	13	1	5	18	18	53	0.94	1.38
Spain									
Dryland	3045	1115	25	153	2045	6	100	1.15	1.70
Irrigated	6367	2360	63	276	3669	10	97	1.33	1.54
Mountain	1611	554	16	84	956	8	99	1.21	1.45
Tunisia									
Agro-pastoral	266	121	5	20	120	8	85	0.90	1.19
Agro-pastoral irrigated	146	64	6	8	67	10	75	0.87	1.23
Agro-sylvo-pastoral	238	112	5	13	108	10	71	0.85	1.10

hh : household

Steps for simulating herd productivity

Productivity simulations are performed in 3 steps:

- Identify an initial situation or baseline or unchanged situation that will serve as the starting point for the annual or multi-year productivity simulation.

- Define the demographic situation that will serve as the basis for comparing outputs for the different systems. This involves calibrating the initial situation according to a demographic context defined by the user on the basis of 2 main criteria: the growth rate of the small ruminant population and the structure of the population according to sex and age categories. This situation must more or less conform to an observable reality. It should be noted that to calibrate the model in a specific demographic context, it is generally chosen to adjust the growth rate and the sex-age structure by making assumptions about the offtake rate for different categories of animal. In many countries, offtake rate is considered difficult to estimate from farmers for many reasons and varies from year to year. We override these difficulties by using this parameter as an adjustment variable.

- Simulate the situation with change. The user can then test the modification of a set of demographic parameters corresponding to the effect of a practice or a change in the environment on productivity.

The method for comparing the productivity of livestock production systems consists of developing scenarios based on the knowledge acquired about the herd, the growth rate and average demographic performance. To compare productivity in the different Tunisian and Egyptian systems, characterised mainly by their level of intensification, we chose 2 main scenarios (Fig. 5).

The first scenario explores the consequences of the combined effect of an increase in young sheep mortality and a decrease in ewe fertility. The second scenario uses as an indicator the time taken to reconstitute the flock after a destocking of productive females against an improvement in the performance of the best ewes.

We propose to examine the results of 3 case studies:

- modelling a decrease in available food (Tunisia and Egypt),
- modelling intensification (Tunisia and Egypt),
- modelling viability of householders (Egypt).

In this document, we just provide a brief review of selected results because the purpose of these simulations is to test hypotheses whose results can be discussed by researchers and, more generally, by stakeholders involved in livestock farming. It should be remembered that the aim is not to predict the performance of flocks, but to use prospective studies to better assess current viability of family farming systems.

Comparison of annual herd productivity	
STEADY	
Situation without change	Situation with change
Target growth rate = 0%	
Average values of demographic parameters and herd size	↗ lambs mortality ↘ fecundity
Target growth rate = +3%	
Average values of demographic parameters and herd size	↗ lambs mortality ↘ fecundity
Target growth rate = -3%	
Average values of demographic parameters and herd size	↗ lambs mortality ↘ fecundity

Comparison of the time needed to recover the initial stock	
PROJ	
Situation without change each year	Situation with change
Target growth rate = +1%	
Average values of demographic parameters and herd size Parameters remain **constant** each year	↗ destocking ewes ↗ fecundity during 3 years
target growth rate = +3%	
Average values of demographic parameters and herd size Parameters remain **constant** each year	↗ destocking ewes ↗ fecundity during 3 years

Fig. 5. Scenarios for simulating herd productivity. Application to sheep farming systems in Egypt and Tunisia.

Modelling a decrease in available food

System comparisons

Table 4. Results of simulations of annual productivity for the 3 sheep farming systems in Tunisia. Comparison of the initial situation according to 3 demographic contexts (growth rate 0%, +3% and -3%) and the situation with change, which includes a decrease in food availability translated into demographic parameters: partirution rate: -5%; prolificacy rate: 1; lamb mortality: +25%.

Tunisia

Comparison of annual herd productivity			
	without change	with change	diff
	growth rate = 0%		
agro-pastoral	66%	55%	11
agro-pastoral irrigated	61%	49%	12
agro-sylvo-pastoral	53%	46%	7
	growth rate = +3%		
agro-pastoral	67%	55%	12
agro-pastoral irrigated	62%	49%	13
agro-sylvo-pastoral	54%	47%	7
	growth rate = -3%		
agro-pastoral	66%	54%	12
agro-pastoral irrigated	60%	48%	12
agro-sylvo-pastoral	52%	46%	6

Table 4 shows that in Tunisia, agro-pastoral and irrigated agro-pastoral have quite the same response to change. Agro-sylvo pastoral system seems to be the more resilient under all livestock growth scenarios.

Table 5. Results of simulations of annual productivity for the 3 sheep farming systems in Egypt. Comparison of the initial situation according to 3 demographic contexts (growth rate 0%, +3% and -3%) and the situation with change, which includes a decrease in food availability translated into demographic parameters: partirution rate: -5%; prolificacy rate: 1; lamb mortality: +25%.

Egypt

Comparison of annual herd productivity			
	without change	**with change**	**diff**
	growth rate = 0%		
extensive	51%	44%	7
intensive	48%	33%	15
semi-intensive	52%	38%	14
	growth rate = +3%		
extensive	52%	47%	5
intensive	49%	34%	15
semi-intensive	54%	40%	13
	growth rate = -3%		
extensive	50%	45%	5
intensive	46%	32%	14
semi-intensive	50%	37%	13

Table 5 shows that in Egypt, the 3 systems are quite similar in terms of productivity regardless of the herd growth scenario. The extensive pastoral system is the most resilient, with a significantly smaller gap in productivity after the crisis than other systems (5-7% vs 13-15%).

Comparisons of sheep breeds in Tunisian systems

We wanted to compare the impact of sheep breed on productivity. We used the general scenario of a decrease in food availability at 2 levels of intensity (low change : partirution rate = -5%; prolificacy rate = 1; lamb mortality = +25%. High change : partirution rate = -20%; prolificacy rate = 1; lamb mortality = +50%) and simulated the productivity of the different systems according to 3 demographic regimes (growth rates : 0%, -3%, +3%) as a baseline. Table 6, Table 7, Table 8 present the results of comparisons between systems with each of the breeds studied.

Other simulations (not presented in this document) repeated within each system in order to compare the productivity of the different breeds showed very similar results, showing that the potential differences in productivity were certainly more related to the systems than to the breeds.

The main result is that the agro-sylvo-pastoral system with the Queue Fine de l'Ouest and Noire de Thibar breeds appear to be more resilient to a fall in food availability, with a smaller productivity gap than the other systems x breed.

Table 6. Results of simulations of annual productivity of Queue Fine de l'Ouest sheep for the 3 sheep farming systems in Tunisia. Comparison of the initial situation according to 3 demographic contexts (growth rate 0%, +3% and -3%) and the situation with change, which includes a decrease in food availability translated into demographic parameters. Low change : partirution rate: -5%; prolificacy rate: 1; lamb mortality: +25%. High change : partirution rate: -20%; prolificacy rate: 1; lamb mortality: +50%.

Comparison of annual herd productivity (%) By system for Queue Fine de l'Ouest						
	without change (baseline)	with change low	With change high	Diff. low – high	Diff. base - low	Diff. base-high
growth rate = 0%						
Agro pastoral irrigated	61	48	41	7	13	20
Agro sylvo pastoral	50	43	36	7	7	14
Agro pastoral	64	52	45	7	12	19
growth rate = -3%						
Agro pastoral irrigated	60	48	41	7	12	19
Agro sylvo pastoral	50	42	36	6	8	14
Agro pastoral	64	52	44	8	12	20
growth rate = +3%						
Agro pastoral irrigated	62	49	42	7	13	20
Agro sylvo pastoral	50	43	37	6	7	13
Agro pastoral	65	52	45	7	11	18

Table 7. Results of simulations of annual productivity of Barbarine for the 2 sheep farming systems in Tunisia. Comparison of the initial situation according to 3 demographic contexts (growth rate 0%, +3% and -3%) and the situation with change, which includes a decrease in food availability translated into demographic parameters. Low change : partirution rate: -5%; prolificacy rate: 1; lamb mortality: +25%. High change : partirution rate: -20%; prolificacy rate: 1; lamb mortality: +50%.

Comparison of annual herd productivity (%) By system for Barbarine						
	without change (baseline)	with change low	with change high	diff. low – high	diff. baseline - low	diff. baseline-high
growth rate = 0%						
Agro sylvo pastoral	51	45	38	7	6	13
Agro pastoral	60	54	46	8	6	14
growth rate = -3%						
Agro sylvo pastoral	50	44	38	6	6	12
Agro pastoral	59	53	46	7	6	13
growth rate = +3%						
Agro sylvo pastoral	51	45	38	7	6	13
Agro pastoral	60	54	46	8	6	14

Table 8. Results of simulations of annual productivity of Noire de Thibar sheep for the 2 sheep farming systems in Tunisia. Comparison of the initial situation according to 3 demographic contexts (growth rate 0%, +3% and -3%) and the situation with change, which includes a decrease in food availability translated into demographic parameters. Low change : partirution rate: -5%; prolificacy rate: 1; lamb mortality: +25%. High change : partirution rate: -20%; prolificacy rate: 1; lamb mortality: +50%.

Comparison of annual herd productivity (%) By system for Noire de Thibar						
	without change (baseline)	with change low	with change high	diff. low-high	diff. baseline-low	diff. baseline-high
growth rate = 0%						
Agro sylvo pastoral	52	46	40	6	6	12
Agro pastoral	64	55	47	8	9	17
growth rate = -3%						
Agro sylvo pastoral	51	46	39	6	5	12
Agro pastoral	63	54	47	7	9	16
growth rate = +3%						
Agro sylvo pastoral	52	47	40	7	5	12
Agro pastoral	64	55	47	8	9	17

Modelling intensification

Table 9 shows that in Tunisia, the effect of destocking adult females is quite the same between systems regardless scenario. The importance of individual animal performance in coping with crises is illustrated here, where in a favourable demographic context (growth rate = +3%), the improvement of of the herd. reproduction makes it possible to gain 10 years in the reconstitution of the flock.

Table 9. Results of simulations of the number of years required to recover the number of sheep after destocking in Tunisia. Destocking is characterised by a reduction in the number of ewes per flock (ewes offtake rate: + 33%) and an improvement in the feeding of ewes that have been kept, resulting in an improvement in the parturition rate of 5% each year for 3 years.

Tunisia

Comparison of the time needed to recover the initial stock			
	without change	**with change**	**diff**
	growth rate = 1%		
agro-pastoral	13 years	8 years	5 years
agro-pastoral irrigated	15 years	11 years	4 years
agro-sylvo-pastoral	15 years	12 years	3 years
	growth rate = +3%		
agro-pastoral	3 years	2 years	1 year
agro-pastoral irrigated	4 years	3 years	1 year
agro-sylvo-pastoral	5 years	4 years	1 year

Table 10 shows that in Egypt, the effect of destocking adult females is more contrasted between systems if herd growth is low (+ 1%). In a favourable context of flock growth (+3%), the impact of destocking ewes (33%) is reduced by 70% and the impact of an improvement in reproduction is multiplied by 3 (1 year vs 3 years).

Table 10. Results of simulations of the number of years required to recover the number of sheep after destocking in Egypt. Destocking is characterised by a reduction in the number of ewes per flock (ewes offtake rate: + 33%) and an improvement in the feeding of ewes that have been kept, resulting in an improvement in the parturition rate of 5% each year for 3 years.

Egypt

Comparison of the time needed to recover the initial stock			
	without change	**with change**	**diff**
	growth rate = 1%		
extensive	10 years	7 years	3 years
intensive	14 years	11 years	3 years
semi-intensive	8 years	5 years	3 years
	growth rate = +3%		
extensive	3 years	2 years	1 years
intensive	4 years	3 years	1 years
semi-intensive	3 years	2 years	1 years

Modelling herd productivity to assess the socio-economic viability of householders in Egypt

We have chosen to present one of the results of the thesis of Taha Abdel-Sabour (APRI, Egypt). The main objective is to assess and discuss the contribution of small ruminant farming to farm resilience in several livestock farming regions in Egypt with contrasting agro-climatic environments. Livestock production is considered to be a livelihood asset for farm viability. The main hypothesis is that the economic resilience of the farm is partly linked to the performance or productivity of the herd. The aim of the study is to assess the contribution of livestock activities to the farm's ability to cope with increasingly difficult situations, particularly climatic ones. We considered that this work was fully in line with task 3.2 of the ADAPT-HERD project and we therefore paid particular attention to improving our knowledge of the productivity of Barki and Saidi breed sheep and goat flocks adapted to local conditions.

We carried out comparative simulations of the productivity of the herds of 4 farms or households that were representative of the systems studied, covering the major farm typologies in Egypt: the Rainfed zone, the zone irrigated by the River Nile and the Oases (Table 11). The demographic performance of the herds was estimated using 3 successive retrospective surveys (Table 12) from 2018 to 2020 (Abdelsabour et al. 2019, 2023).

Table 11. Egyptian farming systems.

Agro-ecological zone	Rainfed zone		Irrigated zone	
Cluster represented	Mixed farming system	Mixed farming system	Limited land and livestock resources	Diverse livestock, employee famers
Livestock oriented	sheep	goat	sheep	goat
id. number of representative householder	53	171	4	418

Table 12. Estimated demographic parameters for 2018 to 2020 for farms representing systems in the rainfed and irrigated zones used to simulate productivity. Parameter estimates for farm 418 are not shown and have been estimated from other surveys.

Householder/Type	53 Rainfed zone sheep			4 Irrigated zone sheep			171 Rainfed zone goat		
Year	2018	2019	2020	2018	2019	2020	2018	2019	2020
Parturition rate	0.62	0.57	0.61	0.53	0.53	0.52	0.61	0.56	0.6
Prolificacy rate	1.08	1.16	1.16	1.39	1.31	1.39	1.28	1.44	1.71
Young female (n)	7	10	4	16	14	16	7	8	7
Mortality rate (%)	0.20	0.08	0.03	0.36	0.08	0.12	0.1	0.1	0.03
Offtake rate (%)	0.83	0.6	0.58	0.56	0.45	0.38	0.83	0.48	0.65
Ewes/does (n)	31	31	38	35	20	22	6	4	8
Mortality rate (%)	0.06	0.04	0.03	0.06	0.02	0.03	0.03	0.02	0.04
Offtake rate (%)	0.14	0.05	0.08	0.08	0.11	0.14	0.08	0.06	0.02
Young male (n)	2	7	4	3	5	5	1	0	2
Mortality rate (%)	0.32	0.18	0.09	0.37	0.23	0.14	0.19	0.09	0.18
Offtake rate (%)	0.94	0.87	0.85	0.86	0.77	0.77	0.94	0.88	0.89
Ram/Buck (n)	2	2	2	2	1	1	1	0	1
Mortality rate (%)*	0	0.05	0.05	0.03	0	0.05	0	0	0
Offtake rate (%)*	0.15	0.58	0.68	0.47	0.54	0.7	0	0.51	0.7
Total sheep/goat	42	50	48	56	40	44	15	12	18

* Mortality and offtake rates (h) were converted into probability (p), $p = 1 - \exp(-h)$

We considered the evaluation of productivity by comparing the response over time of these different systems to different changes in herd management by the farmer. The initial situations are summarised in the
Table 13.

Table 13. Initial situations or situation without interventions (baseline) for each houselhold.

Household/Type/Species	Hypothesis for baseline
53 Rainfed zone sheep	Repeat the parameters of the cycle of five years over the 20 years : - The first 3 years are dry years - The following 2 years are restocking years
171 Rainfed zone goat	Repeat the estimated parameters for the years 2018-2010 over a 20-year period.
4 Irrigated zone (Nile valley) sheep	High incidence of abortions in 2018 and 2019 (very dry years). The parameters for 2020 are repeated over 20 years to reflect the impact of abortions over the long term.
418 Irrigated area (New Valley) goat	Survey in 2019 was used with keeping the same parameters over the 20-years.

In order to carry out these comparative analyses of the productivity of these farms, we have chosen to make forecasts based on different choices of intervention by the farm managers (Table 14) without any major intervention by the public authorities. Only vaccination campaigns are subject to state intervention, which would cover part of the cost of veterinary interventions.

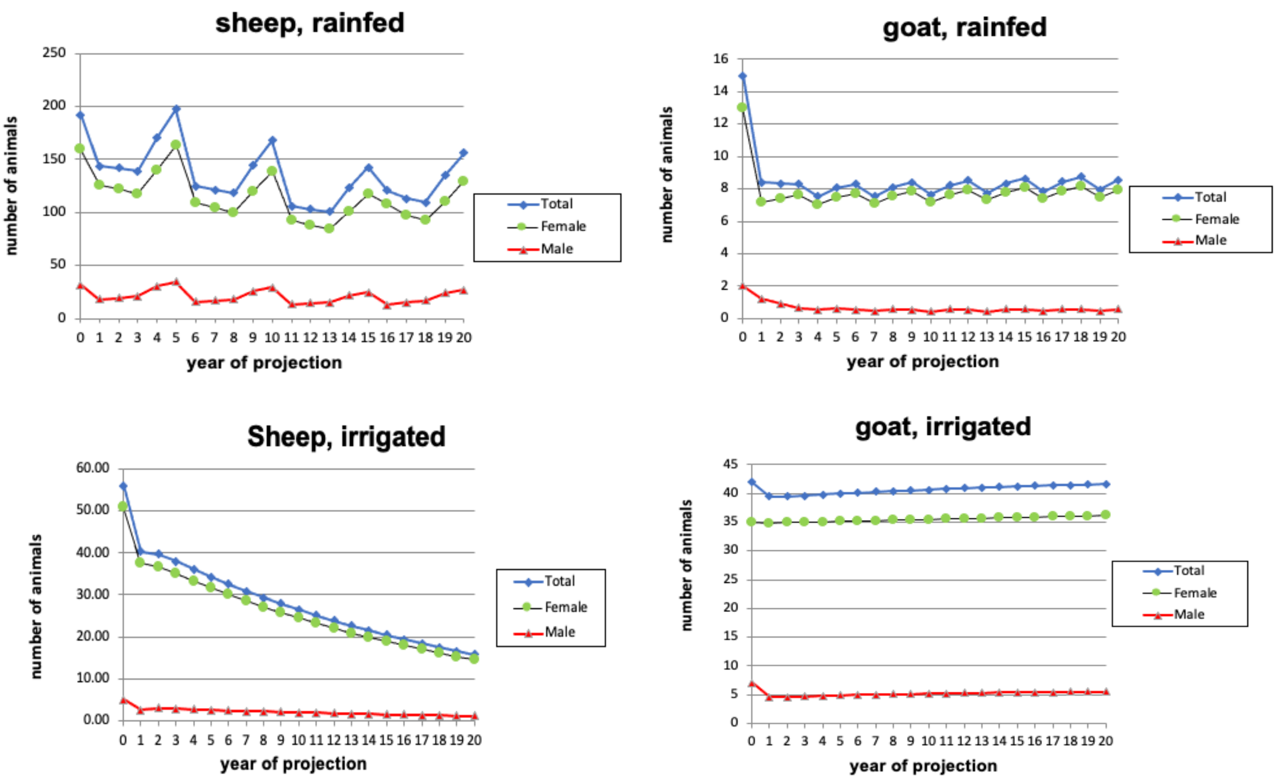

Fig. 6. Result of a 20-year simulation of the initial situation (baseline) for the four households over the 20 years (2018-2037) (a) for sheep in rainfed, b) goat in rainfed, c) sheep in irrigated (Nile Valley) and d) goat in irrigated (New Valley).

It should be noted in Fig. 6 that the very sharp falls observed either after the first year or after a cycle are due to the response of the model, which may be in non-stationary demographic conditions and provide a growth rate subject to strong variations (negative in this case) which are not necessarily proportional to the real impact of demographic rates. As indicated in this document on the use we make of the model's outputs, we prefer to interpret long-term trends.

With the exception of the goat system in the New Valley, the overall animal population growth rate was negative between -1% and -2.8 %. The effect of cyclically simulated drought for sheep and goats in the rainfed zone is shown in these simulations. For the sheep farm in the irrigated area, which records the highest negative growth rate (-6.1%), this decrease is linked to the abortion rate, which, if kept constant over time, has a significant impact on the viability of the flock.

Table 14. Situation with intervention for each houselhold. Levers used by farmers and hypothesis about demographic parameters.

Household/Type	Intervention	Hypothesis on parameters
53 Rainfed zone Sheep	- improve the rate of parturition of ewes - increasing offtake of ewes - decreasing offtake of young females (to replace old ewes)	farmer will continue to sell the majority of adult females over the period 2023-2032 and keep only the most performing females. Therefore, the rate of parturition will vary from 0.75 to 0.89 compared to 0.52 to 0.89 in the first 5 years cycle. Theoretically, the feed quantity will decrease due to the reduction of the permanent stock of adult females.
171 Rainfed zone Goat	- improve the parturition rate of adult females - increasing offtake of old and non-reproductive does.	the farmer will increase the sale of adult females over the period 2021-2023 from 2% to 5% and keep only the most performing females. Therefore, the rate of parturition will vary from 0.70 to 0.9 compared to 0.56 to 0.61 in the first 5 years cycle.
4 Irrigated zone (Nile area) Sheep	- Reducing abortion rate for adult females by vaccination.	It was proposed to organize regular campaign of vaccination against abortions. Reduction the offtake rate of ewes from 14% to 8%.
418 Irrigated zone (New valley) Goat	- Increase the prolificacy rate due to selection of adult females with high twining rates.	By increasing disposal rate of single kidding does from 10 to 20% for first three years, it is expected a gradual increase of the prolificacy rate from 1 to 1.3 over the period of three years and then stabilization at 1.3 over the rest of the planning period.

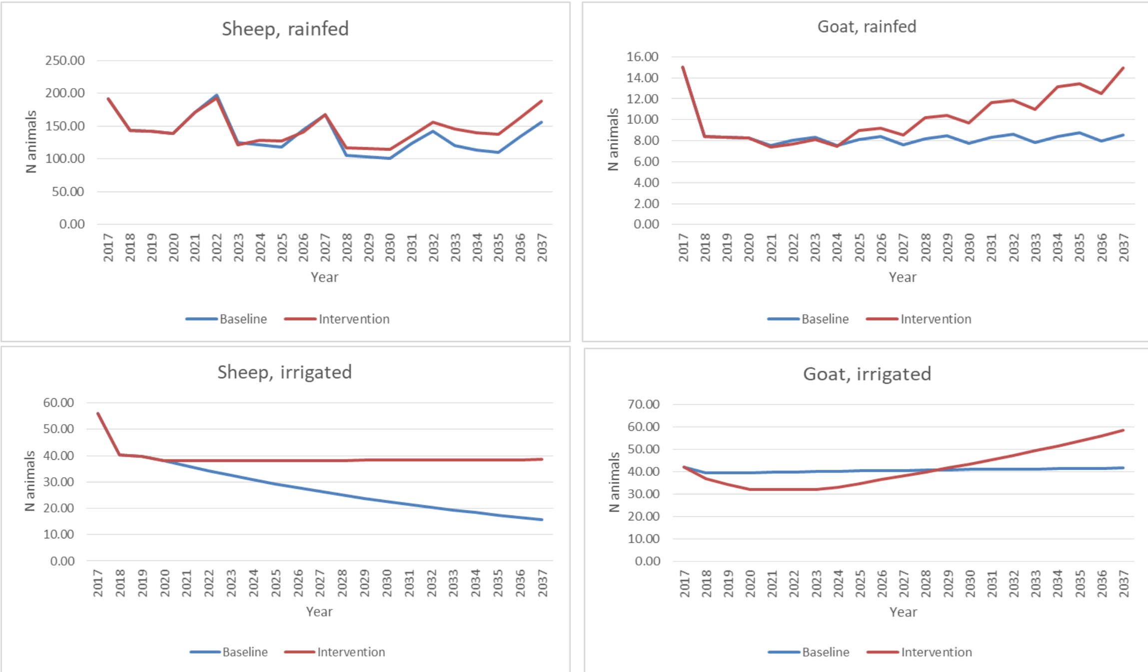

Fig. 7. Total population trend without (in blue) and with (in red) intervention for the four households over the 20 years (2018-2037) (a) for sheep in rainfed, b) goat in rainfed, c) sheep in irrigated (Nile Valley) and d) goat in irrigated (New Valley).

Fig. 7 shows the change in herd size with and without intervention. The intervention scenarios are presented in Table 14. Overall in the four case studies, the intervention allows the preservation of the animal capital over the 20 years.

In the raifed zone, the sheep farmer controls the size of the breeding ewe population in order to limit pressure on feed. This strategy of improving the individual productivity of the females and increasing the parturition and so the valorisation of young male on the market seems to be able to maintain the size of the flock over the medium term and even increase it after about ten years.

In the irrigated zone, the strategy of vaccinating ewes enables the size of the herd to be maintained, while the goat farmer in the Oasis zone (New Valley) increases his herd after ten years of selecting the most prolific does.

The intervention hypotheses chosen for the simulation correspond to the potential strategies of farmers depending on their location and the species of herd. Table 15 compares the gains or losses in productivity (also translated into income) and thus provides indicators of the viability of the types of livestock farming studied according to the intervention scenarios.

Table 15. Productivity and income results between the baseline and intervention scenarios (average over the 20 years)

Household/Type	53 rainfed sheep		171 rainfed goat		4 Irrigated sheep		418 Irrigated goat	
	Baseline	Inter-vention	Baseline	Inter-vention	Baseline	Inter-vention	Baseline	Inter-vention
Rate of productivity in numbers (%)	71	65	66	70	61	66	42	59
Net income from livestock production per animal (EGP)	706	843	1287	1921	1100	1359	587	905
Net income from livestock system/Total household income (%)	35	65	29	31	27	63	5	5

EGP : Egyptian pound

Conclusion

We are aware that the proposal may seem insufficient because it may be too simple, but we are convinced of the advantages of proposing a simulation tool to initiate and develop discussions and thoughts between researchers and also with other livestock farming stakeholders on the technical levers that can be mobilised by farmers to enhance the value of local breeds of small ruminants in order to cope with the increasingly prevalent environmental changes in the Mediterranean area.
Below are the advantages of this approach, which were presented and validated by the partners during the workshops.

- More than a simple succession of demographic and productive performance benchmarks per country that better understand the link between demography and productivity.
- Good introduction to simulating approach with a deterministic model.
- Facilitate herd productivity comparisons between local breeds, livestock systems.
- Help characterize herd productivity potential under different assumptions (farm's management practises) and will be useful for the design of the herd model planned in WP4.

Acknowledgements

In alphabetical order, my sincere thanks to the following people who contributed in one way or another to this document.

Adel Aboul-Naga, Taha Abdel-Sabour, Mehrez Ameur, Nazhia Atti, Christian Corniaux, Margalida Joy, Lionel Julien, Matthieu Lesnoff, Sandra Lobon, Mokhtar Mahouachi, Aziza Mohamed, Massara Nasraoui, Samir Smeti, Laurence Puillet, Yathtreb Yagoubi.

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