Modelling mixed crop-livestock farms for supporting farmers' strategic reflections: The CLIFS approach

Pierre-Yves Le Gal, Nadine Andrieu, Guillaume Bruelle, Patrick Dugué, Claude Monteil, Charles-Henri Moulin, Eric A. Penot, Julie J. Ryschawy

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Le Gal P.-Y.[1,2], Andrieu N.[1,2], Bruelle G.[1,2], Dugué P.[1,2], Monteil C.[3,4], Moulin C.-H. [5,6], Penot E.[1,2], Ryschawy J. [3,7]

[1] CIRAD, UMR INNOVATION, F-34398 Montpellier, France
[2] Innovation, Univ Montpellier, CIRAD, INRA, Institut Agro, Montpellier, France
[3] Université de Toulouse, INPT-ENSAT, F-31326 Castanet Tolosan
[4] INRAE, UMR DYNAFOR, F-31326 Castanet Tolosan
[5] Institut Agro, UMR SELMET, 2 Place Viala, 34060 Montpellier, France
[6] INRAE, UMR SELMET, 2 Place Viala, 34060 Montpellier, France
[7] INRAE, UMR AGIR, F-31326 Castanet Tolosan
Corresponding author: pierre-yves.le_gal@cirad.fr

Abstract

Integrated mixed crop-livestock farming systems help improve farm sustainability by securing agricultural incomes through the diversification of productions and by enhancing farm autonomy regarding agricultural inputs. Based on interactions between crop and livestock productions within farms, such systems are complex to manage and to model. A one-to-one support methodology was developed to help farmers in their strategic thinking regarding the future of their farms in a redesign perspective. This methodology includes a three-step scenario process and is based on a spreadsheet simulation tool called CLIFS (Crop LIvestock Farm Simulator). CLIFS makes it possible to build scenarios of the evolution of a farm and assess them *ex-ante* by calculating several balances at the farm level (staple food, forage, manure) and their effects on the farm's economic results. The support process has been tested in several African and South American contexts and with French suckling cattle farms. The diversity of production contexts and issues addressed during the design process led to the development of a generic tool that can be applied easily to a large range of situations. A detailed description of the approach and the tool, with an illustration based on a Malagasy dairy farm, are presented here. Farmers appreciate the support process because it addresses their own questions

within the context of their own farms. The process must now be transferred to advisory structures to assess its relevance in a professional context.

Key words: design support, simulation, scenario, advisory

1 Introduction

The integration of mixed crop and livestock production on farms or within rural territories helps to improve the sustainability of agricultural production (Herrero et al., 2010; Moraine et al., 2016). Diversified production enables farmers to secure their incomes to cope with market fluctuations and climate change while promoting biodiversity in certain modes of management (Kok et al., 2020). Biomass exchanges between plant and animal enterprises help reduce the purchase of inputs and increase farm autonomy (Bonaudo et al., 2014). In developed countries where the reintroduction of these complex production systems is under debate (Schut et al., 2021), the survival of mixed crop-livestock farms is being challenged by the specialisation of production between regions and a reduced agricultural labour force (Ryschawy et al., 2013). In emerging and developing countries, some of these mixed farms are benefiting from booming livestock sectors, particularly dairy and poultry (Sraïri et al., 2013), but others are facing a decrease in available land, water resources and soil fertility due to increasing population pressures (Kidron et al., 2010).

When mixed crop-livestock farmers wish to reconfigure their production systems to overcome certain constraints, strengthen their autonomy with regard to inputs or respond to market demand, they must consider the future interactions of all of their farm's production enterprises. The viability of their projects depends on the balance between the land, forage and organic manure resources available and the needs generated by their production objectives. This reflection may require the support of an agricultural advisor which goes beyond conducting economic assessments (Penot, 2012), drawing comparisons with farm types that are more or less similar to the farmer's specific situation (Titonnell et al., 2009) or using technical management tools such as livestock ration calculators (FAO, 2016).

The use of calculation tools that evaluate *ex ante* the consequences of a given farm configuration on a farm's technical-economic performance has proven useful in guiding farmers' reflections about future directions (Semporé et al., 2015; Colnago et al., 2021). Most modelling work related to this activity has a research objective, both in the design of the models and tools used, and in the intended uses (Le Gal et al., 2011a). Many tools therefore provide a representation of a farm based on biotechnical models, coupled with decision modules allowing the advantages of an innovation or a given farm configuration to be tested (Snow et al., 2014). Optimisation models also are used for this purpose on typical farms, for example to assess the benefits of conservation agriculture systems (Alary et al., 2016) or the integration of production activities (Mosnier et al., 2017). Rule-based models aim to reproduce farmers' decision-making processes (Vayssières et al., 2009), but are often difficult to use, and do not always capture the complexity of real situations.

As these tools are based on a detailed representation of a mixed crop-livestock farm's operations, they are difficult to understand by a farmer and to use for supporting his/her reflections. The use of simulation tools representing these operations in a simplified but realistic way is one way to achieve this objective (Le Gal et al., 2013). In the domain of mixed crop-livestock farming, these tools take various forms, from calculation tools that compare the biomass produced by pastures or crops with the biomass ingested by livestock (Lurette et al., 2013), up to board games that concretely represent forage calendars, sometimes supplemented by spreadsheets (Martin et al., 2011). These tools are often specialised for a certain type of livestock system (Machado et al., 2010; Parsons et al., 2011), or a certain production context (Andrieu and Nogueira, 2010; Lisson et al., 2010). Despite their operational objectives, they often use crop and livestock models that require certain data, the availability of which varies with the work context, to be validated in the specific conditions of a farm.

This article presents an approach that aims to help farmers to think about the future direction of their farms in terms of introducing or expanding crop and livestock production activities, or of introducing technical innovations impacting all or part of their farms' operations. It relies on the use of a simulation tool named CLIFS (Crop LIvestock Farm Simulator) which is devoted to mixed crop-livestock farms. The approach is specifically intended to be used with farmers and transferred to farm advisors. Earlier versions of CLIFS were tested on samples of 2 to 20 family farms in a range of contexts, and in both tropical and temperate environments (Le Gal et al., 2013; Ryschawy et al., 2014; Semporé et al. 2016). This article presents the current version, developed in Microsoft Excel®, which can be downloaded freely at the following address: https://doi.org/10.18167/DVN1/NZHWQQ. A User Manual (UM) provides a full description of the software and its equations to which the reader can refer for additional information (Le Gal, 2021; https://doi.org/10.18167/agritrop/00577). The use of the approach is then illustrated with the case of a dairy farm in Madagascar. In the discussion section, the approach is assessed from the point of view of researchers and farmers, and its potential use is explored.

2 Empirical and methodological background

2.1 A set of seven case studies

The design and development of the CLIFS approach drew from a set of case studies conducted over ten years (from 2004 to 2013) on seven contrasting sites which differed in terms of the mixed crop-livestock farming systems in place and the issues addressed (Table 1). This diversity gives the approach and the application their generic character.

The case studies were distinguished by the type of livestock involved in the farming system: dairy farming (five cases), mixed farming (one case) and suckler farming (one case), possibly combined with a monogastric enterprise (pig, poultry). The size of the farms studied varied greatly, from very small dairy farms in Morocco and Madagascar, to herds and cultivated areas comprising several dozen heads and hectares. The forage systems encountered generally combined several sources of biomass used differently depending on the time of year, including open natural pastures (Burkina Faso, Madagascar), grazed cultivated grasslands (Brazil and France), forage crops cut and distributed green (Morocco, Madagascar, Peru) or stored after silage or haymaking. Crop residues were used widely in Burkina Faso and Peru.

These forage crops generally were combined on the farms with food and cash crops, which were more or less diverse depending on the case study. Apart from the French case, the small family farms met all or part of their cereal needs with their own production (wheat, rice or maize depending on the case). They also were part of marketing channels through which surplus foodstuffs and specific crops such as sugar beet in Morocco or cotton in Burkina Faso were sold. The crops could be irrigated or rain-fed, with different yield potentials and periods of biomass availability. For example, irrigated alfalfa in Morocco allowed dairy herds to be fed all year round, whereas cultivated rainfed grasslands in Brazil and France could only be used during the period when grass was growing.

The issues addressed differed according to the type of livestock sector, the availability of biophysical and socioeconomic resources, and the climate context. On dairy farms that were part of a dynamic sector (Brazil, Morocco, Peru, Madagascar Highlands), most farmers were considering how to increase their production, either by increasing the size of their herd or by increasing the productivity per cow. These questions could be combined with more specific problems, such as reducing the consumption of irrigation water in Morocco and Peru by diversifying forage resources, or improving soil fertility in Burkina Faso and the Lake Alaotra region of Madagascar. In the view of local farmers, crop-livestock integration and the introduction of cover crops combining soil protection and forage use (the Madagascar case) were key to the long-term stability of agricultural production. In the French case, the mixed crop-livestock farms studied were looking for solutions to ensure their sustainability in an economic environment encouraging specialisation, such as reducing production costs through forage autonomy or diversifying livestock sales outlets.

Table 1. Main characteristics of the seven case studies.

Country	Brazil	Burkina-Faso	France	Madagascar	Madagascar	Morocco	Peru
Location	Cerrados	Cotton belt	South-West	Lake Alaotra	Highlands	Tadla plain	Andean valley
Period of study	2009-2011	2007-2011	2013	2009-2013	2012	2004-2008	2011-2013
Involved farm number	6	24	2 + one group of 15 farmers	6	8	12	10
Production system	Rainfed crops Dairy cattle	Mixed crop-livestock	Rainfed crops Suckler cattle	Irrigated/rainfed crops x Dairy cattle	Irrigated/rainfed crops x Dairy cattle	Irrigated crops Dairy cattle	Irrigated crops Dairy cattle
Farm size	10-30 cows over 15-30 ha	1-3 cows 4 – 25 ha	43-50 cows over 85-130 ha	1-3 cows over 3-8 ha	2-11 cows over 1-24 ha	5-6 cows over 2-30 ha	3-65 cows over 1-60 ha
Livestock	Dairy cows	Oxen Suckler cows Fattening cattle Fattening sheep	Suckler cows Fattening cattle	Dairy cows Pigs, poultry	Dairy cows Pigs, poultry	Dairy cows	Dairy cows
Forage system[1]	*Brachiaria dec.* Sugarcane Maize silage	Crop residues (cereals, cowpea) Mucuna pruriens *Natural pasture*	*Cultivated pasture* Grass/hay Maize	Brachiaria ruz.[1] Styloxanthès guia.[1] Vetch[1] Wild grass Rice straw	Oat Penissetum kizozi Ray-grass Forage maize Rice straw	Alfalfa Berseem Silage maize Alfalfa hay Wheat straw	Alfalfa Oat-vetch Maize stems
Main other crops	Maize	Maize	Winter wheat	Irrigated/rainfed	Irrigated/rainfed	Winter wheat	Maize

	Rice Beans	Cotton	Soya Sunflower	rice Maize	rice Maize+Bean Sweet potato	Sugar beet Vegetables	Potato Vegetables
Raised issues	Milk production increase	Crop-livestock integration	Forage autonomy Diversification of livestock product	Cover crop introduction	Increase of forage availability	Milk production increase Water consumption reduction	Milk production increase Forage diversification
References	Le Gal et al., 2013	Semporé et al., 2016	Ryschawy et al., 2014	Douhard, 2010 Foussat, 2011	Mouret, 2012	Le Gal et al., 2011b	Bienz and Le Gal, 2012

[1] Normal font: cut green and provided in troughs Underline font: stored and provided in troughs *Italic font*: grazed by herd

2.2 A generic view of mixed crop-livestock farms

The design of CLIFS is based on a generic representation of mixed crop-livestock farms (Figure 1) that was derived from observations made in the seven study areas. This representation is organised around exchanges between crop activities, which produce biomass on the farm, and livestock activities, which consume biomass and produce organic manure that can be used on the crops. The herd can be composed of ruminant and monogastric animals. For ruminants, a distinction is made between (i) breeding females producing milk that is sold or consumed by their young, (ii) animals kept for renewal, savings, traction, and reproduction, and (iii) animals that are fattened and sold. Monogastrics are distinguished by their function: breeder or producer of meat and eggs. All of these animals produce manure, either directly on the fields while they are consuming the biomass available there, or while stabled in livestock buildings or pens. In the latter case, the manure can be mixed with litter from crop residues to form organic fertiliser. This can then be spread on the cultivated fields. This process provides more control over the quantity and quality of the organic manure than the practice of keeping animals on the fields (Blanchard et al., 2014).

The crops potentially present on the farm are grouped into three categories: (i) crops to feed the farmer's family, the surplus of which can be marketed once family needs have been met. Some crops such as grain maize also can be fed to animals, both as the main feed for monogastric animals or as a supplement for ruminants; (ii) crops intended solely or mainly to be sold, such as cotton and groundnuts, but which could contribute to the family's diet; (iii) grassland and forage crops directly intended to feed ruminants; when there is a surplus in relation to the herd's needs, these may be marketed. This biomass can be distributed in three forms: green, hay or silage. This on-farm forage resource is supplemented by crop residues from food crops, such as cereal straw, and from marketed crops, such as groundnut leaves. All of these crops can potentially receive organic manure produced by the farm's herd.

The management of crop and livestock mobilises the workforce, family and hired labour, which is allocated by the farm head throughout the year to the various agricultural activities according to needs. While crop management is determined by crop cycles, seasons and technical practices, livestock farming involves both seasonal work and routine work such as milking reproductive females, tasks that are repeated every day for all or part of the year (Hostiou and Dedieu, 2012). Mixed crop-livestock farms therefore represent a complex situation in terms of work organisation.

The farm is open to its environment, with which it interacts to (i) generate income from the sale of its products according to its marketing strategy, and (ii) obtain goods and services for the farm: inputs for crop (seeds, fertilisers, pesticides, mechanised services) and livestock activities (fattening animals, food supplements, veterinary interventions); seasonal labour to supplement the permanent labour force at certain times of the year; pastures and natural biomass outside the farm on which animals can be fed directly or after mowing and distribution.

Mixed crop-livestock farmers must therefore make strategic and tactical choices concerning (i) the nature of the crop and livestock production they wish to develop in relation to the desired degree of specialisation *vs* diversification, (ii) the coordinated sizing of the crop and livestock enterprises with regard to the desired degree of autonomy in terms of animal feed and crop fertilizers from outside the farm, (iii) the way in which the crops and the herd will be managed in order to attain a given production objective. The timing of biological cycles is an important element to consider in these choices, including crop cycles according to the seasons and irrigation options, which determine in particular the moment when biomass is available for animals and whether or not it must be stored as hay or silage for later use, and animal breeding cycles which may or may not be synchronised with previous ones. The internal degree of integration between crops and livestock, considered as one of the levers leading towards more agroecological production systems (Ryschawy et al, 2017), depends on this set of interlocking decisions.

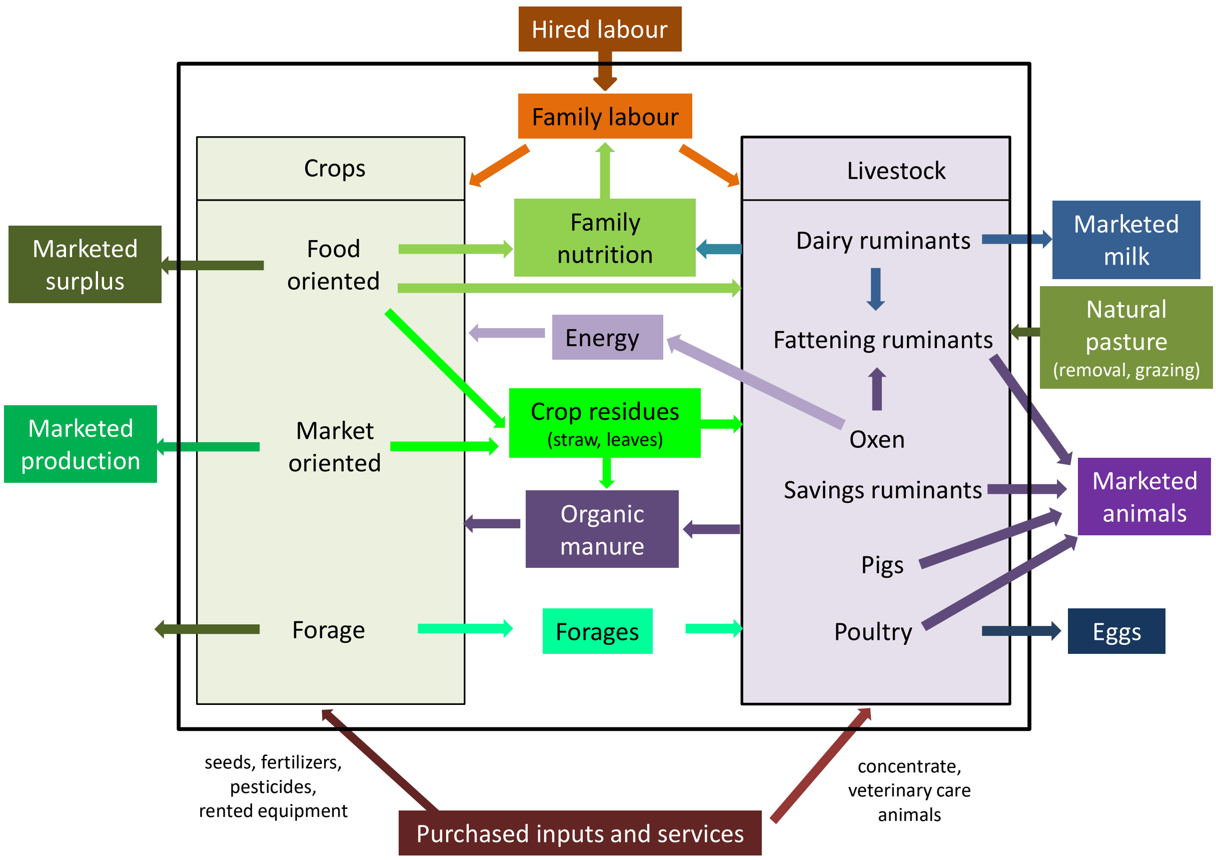


Figure 1. Generic representation of the components and flows between components of mixed crop-livestock farms.

2.3 A three-step support process

CLIFS is first and foremost an individual support tool that aims to provide farmers elements to consider and assess when considering a medium to long-term development project for their farms. Its main objective consists of supporting farmers' reflections in an exploratory and iterative way rather than defining precisely the project content and how it will be implemented. Indeed, the strategic evolution of a farm includes many interacting elements that are difficult to comprehensively address, especially since the future of some of these elements remains uncertain. This approach has three steps based on the (i) design, (ii) simulation and (iii) assessment of successive scenarios (Figure 2). Each scenario corresponds to a configuration of the farm that is simulated over one year.

The Initial Scenario (IS) is based on an analysis made with the farmer about the current situation on his/her farm. This analysis allows the advisor to better understand the farmer's objectives and strategies, to characterise the farm’s structure, operations and performance, and to calibrate certain CLIFS input variables that are difficult to access, such as pasture productivity. Depending on the data available, it may take several loops to arrive at a representation of the farm that the farmer thinks to be consistent with reality. This representation is then considered to be valid for the next steps in the process. This validation stage is important to ensure that the rest of the process is based on knowledge that is shared by the farmer and the advisor, and to enable the farmer to understand the structure of CLIFS and the calculations made.

The next step is to build a coherent and balanced Project Scenario (PS) corresponding to choices as to how the farm might evolve. CLIFS highlights possible imbalances between supply and demand for resources, for example between the size and productivity of a dairy herd and the forage resources generated by the cropping pattern planned. At the end of this step, which may include several intermediate scenarios if necessary, farmers have a more precise and concrete idea of their project and the consequences on their production and economic results.

During the third step, Alternative Scenarios (AS) are developed by the farmer and the advisor based on the results of the PS and proposed changes or technical innovations considered to be potentially interesting. If the farmer is satisfied with the PS, this last step is optional. Nonetheless, it opens up the field of possibilities and enriches the thinking of both participants, as the farmer may ultimately prefer one of these AS. It also makes it possible to assess *ex ante* the relevance of an innovation at the level of a given farm, and to evaluate the variability of scenario results according to changes in prices or yields, for instance.

The loop may be run through as often as needed to test new ideas or to assess the sensitivity of a farm configuration to variables such as product and input prices or variations in yields according to the climate year. As CLIFS is a static tool, these analyses involve multiplying scenarios that vary the values given to these variables. This procedure allows the user to maintain control over the changes made during the support process. Once completed, the process can be evaluated with the farmer to assess what the user has learned from it (Matthews et al., 2010). The approach does not include support for the eventual implementation of the preferred scenario. In some cases, however, we returned to the farms a few years later to discuss with the farmers what they finally had achieved, as in the case presented in this article.

CLIFS can be used to address a wide range of farm issues and projects, such as the choice and resizing of livestock enterprises to increase milk production, the choice of a forage system for self-sufficiency, the introduction of innovations such as catch crops or the partial use of cover crop biomass, and the analysis of a farm's sensitivity to climatic and economic shocks.

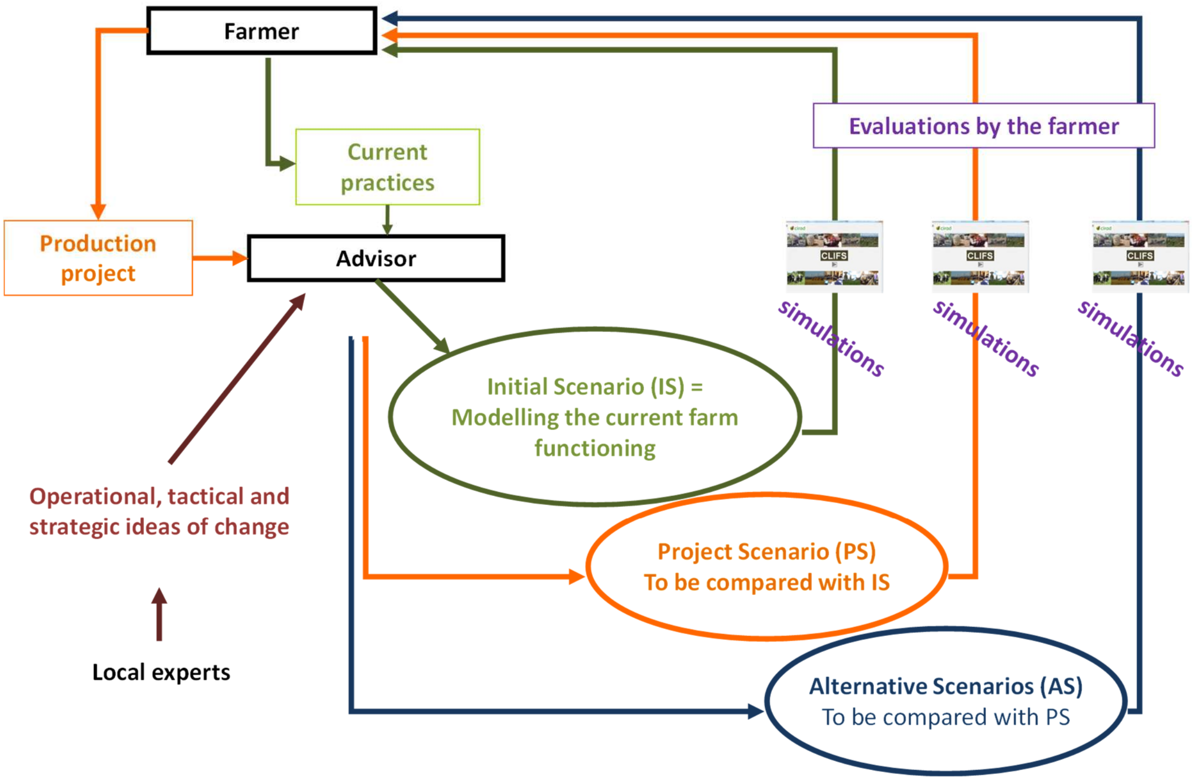


Figure 2. Organization of the farmer support approach in three main loops.

3 CLIFS description

3.1 Overview

CLIFS translates the generic representation of a mixed crop-livestock farm (Figure 1) into a spreadsheet-based simulation tool (Microsoft Excel®). The format makes it usable and accessible to a wide range of users. The overall structure of the tool, along with its calculation procedures and output variables, have been designed so that the farmers involved can understand them while also providing a representation that closely matches the farms which the farmers can validate. This led to limiting the number of variables to be characterized on each farm and to excluding the integration of crop and livestock models, which are furthermore often unavailable in many contexts.

The only equations related to biological processes concern: (i) for all ruminants, excreta production as a function of their live weight to calculate the supply of organic manure as a function of herd structure and management (Table 5); (ii) for cattle only, energy and nitrogen requirements for animal maintenance, gestation of breeding females, and production of milk and meat per head (Table 2) in order to link these productions to the rations distributed, with the choice between two calculation systems independent of the user's working language: French (INRA, 2007) and American (NRC, 2001). The user can nevertheless inactivate these calculations of milk and meat production if required data are unavailable or another feed system than those proposed is being used. The other calculations only use the four mathematical operators.

Table 2. Equations of energy and protein requirements for a lactating cow according to the feed value system

		INRA	NRC
Daily maintenance	Energy	$5 + ((LW_b - 600) \div 100) \times 0.6$	$0.079 \times {LW_b}^{0.75}$
	Protein ($NIMR_b$)	$395 + ((LW_b - 600) \div 100) \times 50$	$3.8 \times {LW_b}^{0.75}$
Pregnancy	Energy	$0.00072 \times CBW_b \times e^{(0.116 \times g \times 4.33)}$	*g*<7 : 0 *g*>6 : $(0.00318 \times DAF_g - 0.0352) \times (CBW_b \div 45) \div 0.218$
	Protein	*g*<7: 0 *g* =7: $0.18 \times NIMR_b$ *g*=8: $0.33 \times NIMR_b$ *g*=9: $0.50 \times NIMR_b$	*g*<8: 0 *g*>7: $((0.69 \times DAF_g) - 69.2) \times (CBW_b \div 45) \div 0.33$
Production of 1liter of milk	Energy	0.44	0.699
	Protein	48	0.05

With:

LW_b: Live weight of the average cow of batch *b* (kg; considered as constant throughout the year)

CBW_b: Calf Birth Weight for batch *b* (kg)

g: Month after fertilization [1,9]

DAF_g: Day after fertilization [from g=1 to g=9: 15; 45; 75;105; 135; 165; 200; 230; 260]

For each farm configuration simulated, CLIFS calculates the resource supply-demand balances of three key components of mixed crop-livestock farms, namely: (i) the annual balance of food and cash production, between the supply per crop linked to its area and yield and its consumption by the family and livestock (UM F.6); (ii) the monthly forage balance between the supply linked to the forage system (area and yield per forage crop, crop residues) and the demand linked to the ruminants, which itself depends on herd structure (numbers per type of animal), the diet over the 12 months of the year and the reproductive strategy for female breeders (distribution of births over the 12 months of the year) (UM F.3, F.4 and F.5 for green forage, hay and silage, and crop residues, respectively); (iii) the annual balance of organic fertiliser based on the manure produced by stabled animals and the use of the organic fertiliser on crop fields (UM F.7). In addition to these three balance sheets, the economic results (variable and fixed costs, gross and net margins) corresponding to each farm configuration are calculated (UM F.8). However, CLIFS does not include a labour balance sheet due to the time required to estimate labour supply and demand with a precision that makes sense to farmers.

CLIFS is available in English, French, Spanish and Portuguese for names and titles that cannot be modified by the user. However, users can enter in their own language the contents of the choice lists linked to certain variables.

3.2 Structure and operation

3.2.1 General structure

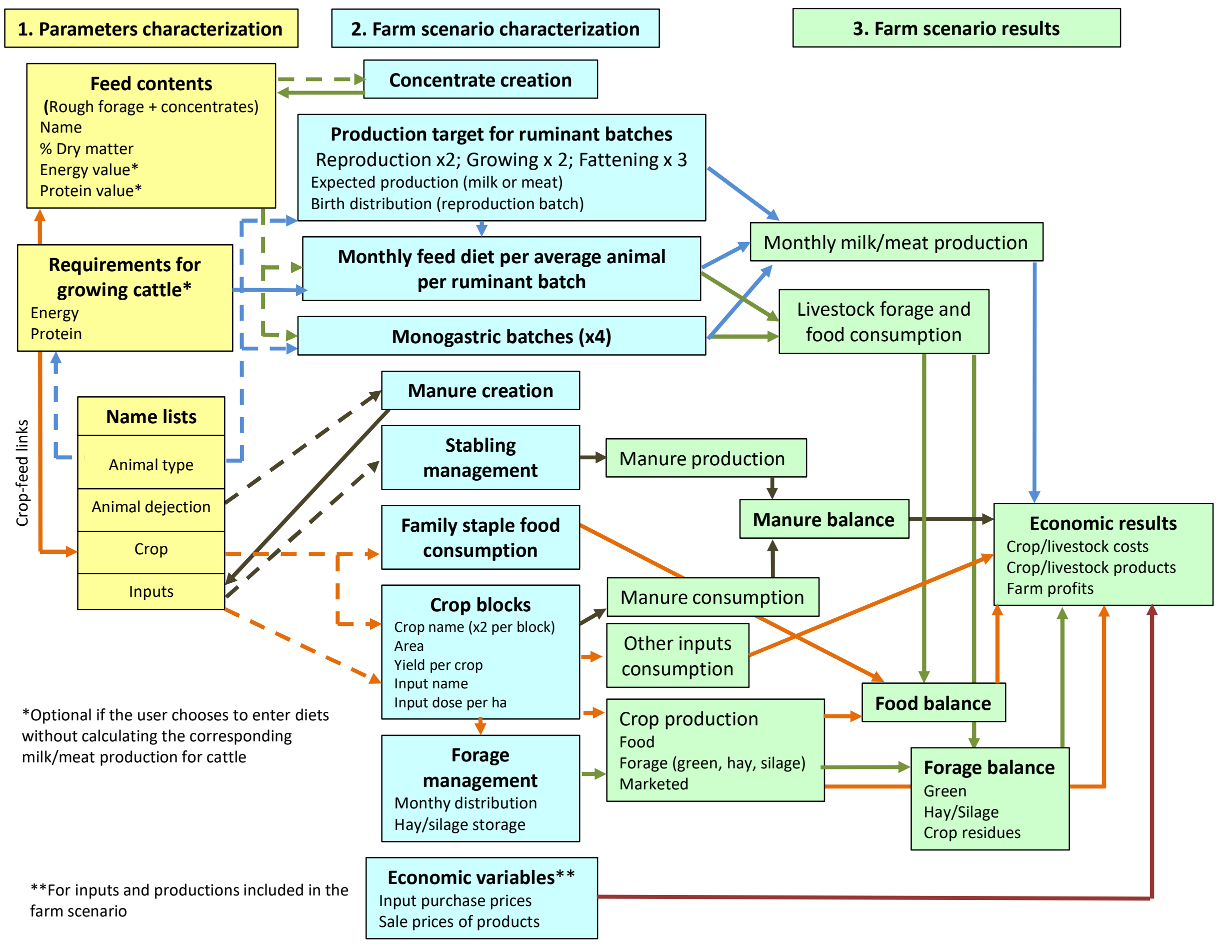
CLIFS consists of a series of Excel® sheets grouped into three linked modules (Figure 3, and UM C. for a full list of the sheets):

(i) Parameters (UM D.) with seven sheets grouping variables whose values are identical for a set of farms, such as the characterisation of animals' feed and requirements;

(ii) Input variables, specific to each farm, with an "animal" sub-module of 16 sheets characterising the dairy, growth and fattening ruminant enterprises and the batches of monogastric animals (UM E.1 to E.8); and a "crop" sub-module of six sheets characterising the crop blocks making up the farm. Each block is defined by the combination of one to two food, cash or forage crops, the technical practices applied and the associated yields. It may or may not correspond to physical crop fields (UM E.9 to E.14). Also included is an economic sub-module of four sheets to enter prices of inputs and services, and prices of marketed products (UM E.15 to E.18);

(iii) Output variables, grouping all of the balances and economic calculations resulting from the farm's sizing, technical choices and performance (UM F.) in 14 sheets;

Input and output variables are linked through a set of calculations included in sheets not visible to the user (UM Eq.1 to Eq.22).



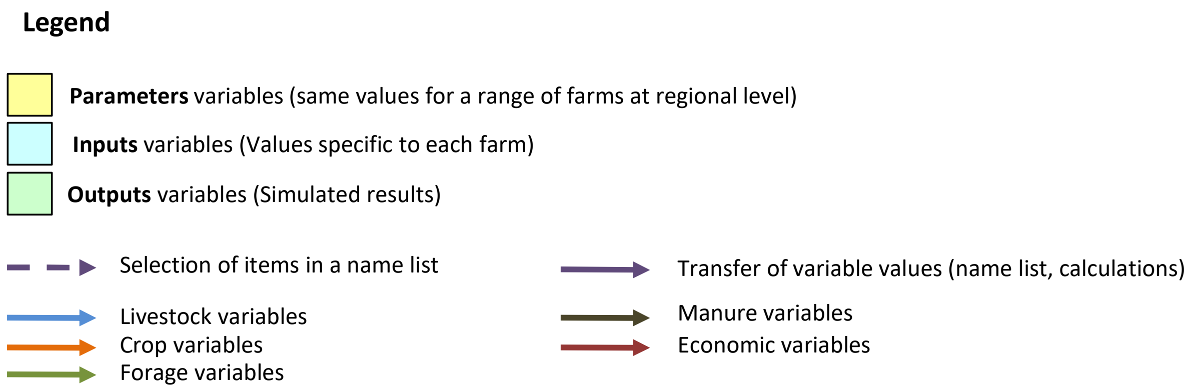


Figure 3. CLIFS structure into three modules and links between modules.

Each batch of ruminants is represented as a sum of individuals homogeneous in weight, and female breeders by a lactation curve. Each animal receives the same daily diet comprising a forage component, which can be modified each month from January to December for breeding and growing animals, and a concentrates component, distributed to breeding animals according to their monthly stage of lactation (Figure 4). Fattening enterprises are defined by their duration and position in the year, the number of animals concerned and a uniform daily forage+concentrates diet for each period considered. CLIFS considers that the feed distributed or grazed is ingested completely by the average animal per batch as long as the animal's intake capacity is not saturated. The user must decrease the distributed quantities when the calculated forage saturation exceeds this capacity.

The structure of Excel® in sheets and tables limits the number of elements that can be characterised per activity (UM B.3). The sizing was determined to (i) make it easier to read the tables on the screen, and (ii) represent many different production systems, combining cattle, small ruminants and monogastrics for livestock, and food, cash and forage crops (including permanent grasslands) in pure, associated or catch crop form for crops.

CLIFS uses different time steps depending on the process represented (Table 3). These time steps are those used by farmers to manage their production activities while being aggregated to limit the amount of data needed to be entered. For example, diets are entered in kg per day, which can be modified each month, i.e., 12 values to be entered per feed. Similarly, the units used vary according to the variables (UM B.2). They are either specified in the row and column headings (e.g., kg/ha for crop yields), or left to the user's choice (e.g., quantities of all crop inputs except organic fertilisers given in kg/ha). The monetary unit related to the economic variables is also left to the user's choice.

Table 3. Time steps used in CLIFS according to the modelled item.

Modelled item	Time step	Comments
Input variables		
Lactation curve (l/day)	Daily	One value entered every month over 12 months
Birth distribution	Monthly	From January to December
Diet		
Ruminants (kg/day)	Daily	
Lactating females		One value entered every calendar month for forage and every month after parturition for concentrates
Growing animals		One value entered every calendar month for forage and for concentrates
Fattening animals		Uniform for the whole fattening period
Monogastrics (kg/year)	Annual	Total quantity of concentrates distributed per batch
Manure production		
Total duration of stabling	Day	Between 1 and 365 days over the year
Daily duration of stabling	Hour	Between 1 and 24 h
Technical sequence per crop block	Crop cycle	From land preparation to harvest over the year
Forage yields (%)	Month	From January to December
Forage type (hay/silage)	Month	From January to December
Fixed costs	Annual	Total amount per cost
Result variables		
Milk production	Month	+ annual total
Green forage balance	Month	+ annual balance
Hay/Silage stock balance	Month	+ annual balance
Crop residue balance	Annual	
Food/Market balance	Annual	
Organic fertilizer balance	Annual	
Economic results	Annual	

For each change introduced into a scenario, the internal consistency of the data entered must be verified since the mechanistic links between variables are limited to cattle feed, if the user wishes to use this functionality, and to excreta production for ruminants. This vigilance is required in particular to ensure consistency between technical practices and corresponding yields per crop block, and between livestock diets and milk and meat production in the absence of equations (in the case of small ruminants) or when the proposed equations (Table 2) are considered unsuitable for the case studied. This alignment may be based on expert knowledge, whether provided by the farmers themselves, the users of the tool or specialists in the field, or from crop models and rationing tools that are not part of CLIFS as long as their area of validity covers the situation under study.

3.2.2 Calculation of food-market crop balance

On farms combining self-consumption, sales and herd feeding for certain crops such as maize, farmers must reconcile different objectives: to cover family food needs, meet production targets related to the herd, and generate a certain income. CLIFS therefore calculates the family's food needs for up to two crops from the list defined by the user, based on the structure of the family and the annual quantities needed to cover the needs of one person.

The food balance for the two selected crops corresponds to the difference between their total production on the farm and the amount consumed by the family over the year. A negative value generates an expense based on the market purchase price entered by the user. These amounts are not deducted from the net margin of the scenario but their total is provided as an indicator of non-achievement of the food self-sufficiency objective. A positive value leads to the calculation of a second balance, which subtracts the total quantities consumed by the animals from this value. A negative balance generates a purchase, a positive one, proceeds.

3.2.3 Forage balance

The forage balance makes it possible to assess the degree of a farm’s forage self-sufficiency for each scenario designed. Each forage is the subject of a calculation that subtracts the herd’s total consumption according to the diets applied in the different enterprises from the supply produced by the farm (see Table 4 with the example of green forage). For each forage crop, this supply corresponds to the sum of the {area x yield} of the blocks where it is grown pure or in association. Yields are entered in gross weight and not in dry matter to be consistent with farmers' practices regarding the quantification of diets distributed. The annual quantity produced is then distributed on a monthly basis using a percentage of the yield depending on the production dynamics of the different forage crops (growing all or part of the year like grassland or alfalfa, or without regrowth like forage maize). The user then specifies for each crop and each month how it is used: green (grazing on the field or distribution synchronised with the harvest), stored as hay, or silage.

Table 4. Equations used for calculating green forage balance

Balance component	Equation
Supply for forage *f* month *m* $Prod\_GF_{f,m}$	$\sum_{l} Surf\_GF_{f,l} \times Yield_{f,l} \times \%Yield_{f,m} \div \sum_{m=1}^{12} \%Yield_{f,m}$
Annual supply for forage *f* $Prod\_GF_{f}$	$\sum_{m=1}^{12} Prod\_GF_{f,m}$
Consumption of forage *f* month *m* $Q\_GF_{f,m}$	$\sum_{b} Q_{f,m,b} \times Day_{m} \times n_{b}$
Annual consumption of forage *f* Q_GF_{f}	$\sum_{m=1}^{12} Q\_GF_{f,m}$
Balance for forage *f* month *m* $Bal\_GF_{f,m}$	$Q\_GF_{f,m} - Prod\_GF_{f,m}$
Annual balance of forage *f*	$Q\_GF_{f} - Prod\_GF_{f}$
Total annual deficit of forage *f*	$\sum_{m=1}^{12} Bal\_GF_{f,m}$ with $Bal\_GF_{f,m} < 0$

With:

$Surf\_GF_{f,l}$ Area of green forage crop *f* block *l* (these blocks can bear up to two forage crops *f*)

$Yield_{f,l}$ Total gross yield of green forage *f* on crop block *l* (kg/ha)

$\%Yield_{f,m}$ Percentage of the total gross yield of forage *f* for month *m*

$Q_{f,m,b}$ Quantity of forage *f* provided daily per ruminant head during month *m* for batch *b* (kg green matter)

Day_{m} number of days of month *m* during which animals are fed

n_{b} Number of heads in each of the seven ruminant batches

The demand is calculated monthly for each forage based on the diets distributed in each enterprise, multiplied by the size of the enterprise (Fig.4 for an example of a diet in a dairy unit). A monthly balance is then calculated by comparing the supply and demand from January to December. For green forage, no carry-over from one month to the next is possible. For hay and silage, the monthly evolution of the stock is calculated, which makes it possible to pinpoint the date when a shortage is possible. A positive balance, monthly for green forage or at the end of the annual cycle for stocks, reflects an imbalance between production and needs. However, surplus stocks can be sold if a market price exists. A negative balance triggers the purchase of forage, whatever its type, which is added to the farm's expenses if a market price exists. In the absence of a market, the scenario highlights a structural forage imbalance that must be corrected by reconfiguring demand (nature and size of the herd, diets) or supply (cropping pattern and yields). The user then has to evaluate these changes, including the choices and management of animal diets, by designing and simulating additional scenarios since CLIFS does not provide any optimisation algorithm to define a relevant farm configuration.

Crop residues (straw, stover, tops) stored dry by the farm at harvest and then incorporated into diets are subject to a supply-demand balance only on an annual basis. The supply is calculated from the crop production to which a grain/residue ratio based on raw material is applied. The demand includes the quantities consumed by the ruminants and those incorporated into organic manure.

3.2.4 Manure balance

With CLIFS, it is possible to define up to 10 types of organic manure combining, in proportions chosen by the user, a type of excreta based on the animals present on the farm and a crop residue (e.g., rice or wheat straw) used as litter. The supply in gross weight of each type of manure is then calculated as a function of the time spent in stable stalls by each group of animals and the size of each group (Table 5). Only the organic manure produced is considered to be available for return to the plots via crop fertilisation. The contribution of excrement deposited while animals are grazing on fields, which is still frequent in certain regions such as Burkina Faso, is not included in the quantities of manure provided because it is difficult for farmers to control.

Table 5. Equations used for calculating manure production by ruminant batches

Production component	Equation
Daily production of excreta by one animal of type *a* in batch b[1] $QD\_Exc_{x,a,b}$	$LW_{a,b} \times 0.01 / DM\_Exc_x$
Annual production of excreta x by one animal *a* in batch *b*	$QD\_Exc_{x,a,b} \times Dur\_Stab_{a,b} \times (HD\_Stab_{a,b} \div 24)$

$QY\_Exc_{x,a,b}$	
Annual production of manure u of batch b $Prod\_Manure_{u,b}$	$QY\_Exc_{x,a,b} \times n\_man_{a,b} \times Conv\_Exc_{x,b} \times ((100 - Loss\_Exc_{u,b}) \div 100) \div ((100 - \%Exc_{x,u}) \div 100)$

With:

$LW_{a,b}$	Live weight of the average animal *a* of batch *b* (kg)
DM_Exc_x	Dry matter of excreta *x* (g/kg)
$Dur\_Stab_{a,b}$	Duration of stabling (days) of animal *a* in batch *b*
$HD\_Stab_{a,b}$	Daily duration of stabling (hours) animal *a* in batch *b*
$n\_man_{a,b}$	Number of heads of animal *a* in batch *b*
$Conv\_Exc_{x,b}$	Conversion rate for excreta *x* in batch *b*[2]
$Loss\_Exc_{u,b}$	Loss rate (%) of manure *u* in batch *b*
$\%Exc_{x,u}$	Proportion of excreta *x* in manure *u* (%)[3]

[1]The coefficient '0.01' is based on the following assumptions:

- A ruminant eats 2.5% DM of its live weight
- The diet has an average digestibility of 60%
- The dried excreted quantities = $LW_{a,b} \times 0.025 \times (1 - 0.60)$

[2]When excreta are processed before their use as fertilizer.

[3]Considering that a given manure can consist of a mix of excreta and crop residue.

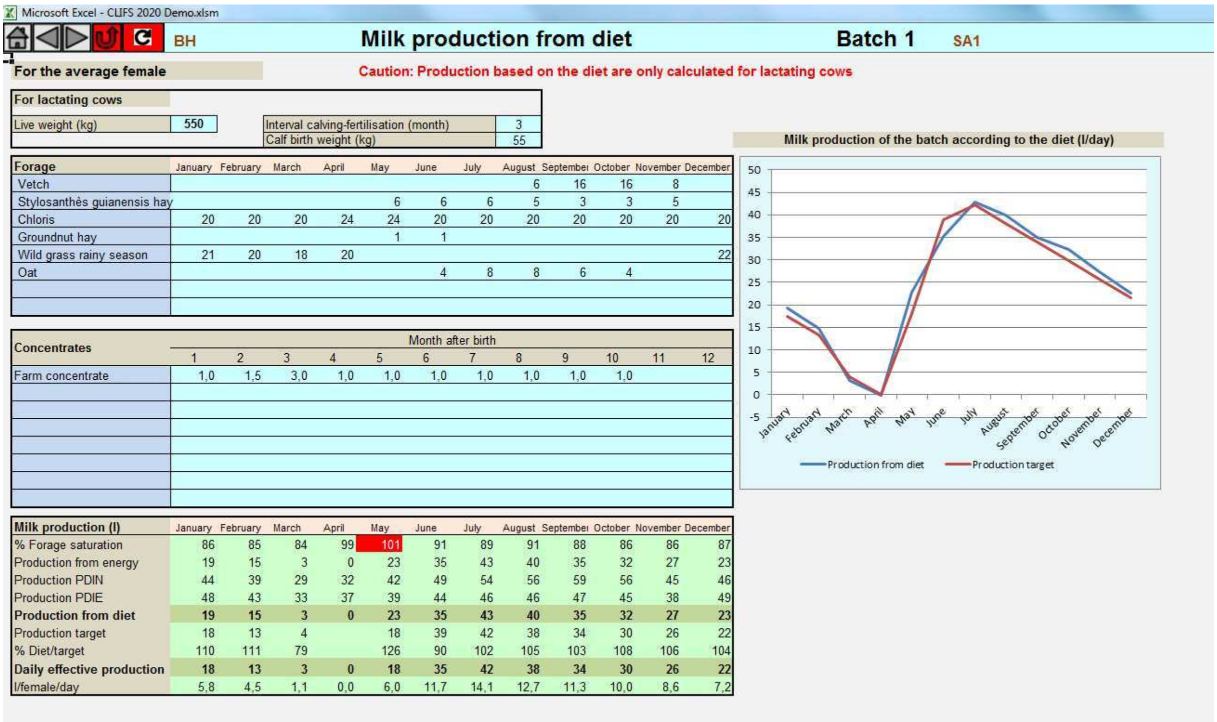
The quantities applied per hectare by type of organic manure are entered with all of the technical practices used on each crop block. These quantities come from farmer declarations, local standards, or research results. The balance is calculated for each type by subtracting the sum of the quantities applied to the blocks from the total quantity produced. A negative balance indicates too much demand for manure while a positive one indicates a surplus. If a market exists for the corresponding manures and prices have been entered these values trigger respectively a purchase or a sale.

3.2.5 Milk and meat production for the ruminant batches

Milk production is calculated monthly for each batch of breeding females by first defining with the farmer a production target based on the genetics of the herd, or depending on what the farmer believes he/she is able to produce from the farm's feed resources (UM E.4 and UM Eq.5 to Eq.13 for a detailed presentation of the procedure, the variables and the equations used). This objective is translated into a simplified lactation curve applied to all of the breeders in the batch according to their calving months. For cows only, the production linked to the diet ingested each month is then calculated from the feed values of the forage and concentrates concerned (Figure 4). Concentrate quantities are entered according to the lactation stage of the breeders and not the calendar month. This practice is in fact widely used in most of the dairy farms observed. The final production considered each month is equal to the minimum of the production target and the productions linked to the diet’s protein and energy content.

A graph is provided showing the production curves related to the target and those to the diet. In cattle, the comparison of these curves makes it possible to detect, month by month, phenomena of over or under-feeding that may have multiple causes. During IS characterization these include poor knowledge of the animals' requirements and of the dietary values of the inputs, an underestimation of the genetic potential of the herd, or a poor quantitative estimate of the diets actually provided.

The increase in live weight of fattening and growing cattle such as replacement heifers is calculated by looking up, in the tables entered, the average daily gain (ADG) corresponding to the total energy and nitrogen input of the diet as a function of the average live weight of the animal over the fattening period. The user can inactivate all the calculations linking diet and production in cattle by not filling in certain variables at the level of parameters or enterprises. The productions linked to targets are then used for the rest of the calculations, as in the case of sheep and goats.



For lactating cows			
Live weight (kg)	550	Interval calving-fertilisation (month)	3
		Calf birth weight (kg)	55

Forage	January	February	March	April	May	June	July	August	September	October	November	December
Vetch								6	16	16	8	
Stylosanthès guianensis hay					6	6	6	5	3	3	5	
Chloris	20	20	20	24	24	20	20	20	20	20	20	20
Groundnut hay					1	1						
Wild grass rainy season	21	20	18	20								22
Oat						4	8	8	6	4		

Concentrates	Month after birth											
	1	2	3	4	5	6	7	8	9	10	11	12
Farm concentrate	1,0	1,5	3,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0		

Milk production (l)	January	February	March	April	May	June	July	August	September	October	November	December
% Forage saturation	86	85	84	99	101	91	89	91	88	86	86	87
Production from energy	19	15	3	0	23	35	43	40	35	32	27	23
Production PDIN	44	39	29	32	42	49	54	56	59	56	45	46
Production PDIE	48	43	33	37	39	44	46	46	47	45	38	49
Production from diet	**19**	**15**	**3**	**0**	**23**	**35**	**43**	**40**	**35**	**32**	**27**	**23**
Production target	18	13	4		18	39	42	38	34	30	26	22
% Diet/target	110	111	79		126	90	102	105	103	108	106	104
Daily effective production	**18**	**13**	**3**	**0**	**18**	**35**	**42**	**38**	**34**	**30**	**26**	**22**
l/female/day	5,8	4,5	1,1	0,0	6,0	11,7	14,1	12,7	11,3	10,0	8,6	7,2

Figure 4. Example of graphic user interface (entry of daily diets and calculation of milk production for the average lactating cow of batch 1).

3.2.6 Economic results

The calculations of the above balances and of milk and meat production provide the quantities of crop and livestock products that can be sold or need to be purchased, as well as forage and concentrates. Added to this are the other inputs needed for the crop blocks. These different quantities are valued economically by multiplying them by the unit purchase and sale prices entered by the user. On this basis, and after entering the amounts of fixed costs for the entire farm, CLIFS calculates the following economic variables, both in total and per hectare: expenses, gross proceeds, total gross margins (in total and per crop and livestock component), and net profits.

4 Example of CLIFS implementation on a Malagasy dairy farm

The use of CLIFS is illustrated with the case of a real dairy farm located in the Lake Alaotra area in Madagascar. Support was given to this farm in 2011 under a research project aiming to develop mulch-based cropping systems (MCS) combining a crop of interest such as maize with permanent plant cover. This innovation is being promoted by local development and research structures for its expected effects on soil fertility and in reducing the risk of erosion on sloping fields (Corbeels et al., 2013). This example was chosen because the entire process was carried out with the farmer, with scenarios assessing the benefits of this innovation on the farm’s dairy performance by making the most of the cover plants’ forage potential.

4.1 Farm structure and production

BH's farm, located on the shores of Lake Alaotra (17°41'S; 48°27'E), combines rice and dairy production on about six hectares. Irrigated rice fields with high yield potential (5.5 t/ha of paddy) cover 80% of the area. The harvest covers the family's rice needs and provides two-thirds of the farm's income. The remaining 20% of the farm consists of a lowland field (0.20 ha) producing green forage throughout the year (*Chloris gayana*), and two rainfed plots (0.20 ha in total) cultivated as pure forage (*Bracharia ruziziensis* and *Stylosanthès guianensis*). A rainfed area of 0.80 ha has been left to lie fallow as it is too degraded to be productive (Table 6). The dairy herd consists of three improved breed cows, the target production estimated by BH is 2800 l/cow/lactation. Calving takes place in November-December with peak production in January-February (Figure 5). The cows are fed from the forage plots, supplemented throughout the year with natural grasses that are grazed or collected. This collection of biomass requires the employment of five permanent paid employees, who also are responsible for milking the cows, processing the milk into yoghurt, and marketing. The cows are permanently stalled all year round, which allows an abundant production of manure (a mixture of dung and rice straw produced on the rice fields) that generally is spread on the rice fields.

4.2 Building the scenarios

After introducing BH to the support process and the general structure of CLIFS, an IS was built based on his current situation. This step revealed that the cows' diet did not allow them to reach the expected peak production in the rainy season because the energy content of the forage was insufficient (Figure 5). The focus then turned to redesigning the forage system in relation to the herd feeding system by integrating three objectives expressed by BH: (i) produce more milk in the dry season (May-September) because this would earn a better return (1,200 Ar[1]/l instead of 1,000 Ar/l the rest of the year); (ii) reduce the manpower devoted to the collection of natural grasses by feeding the cows with on-farm cultivated forage; (iii) improve degraded soils to increase forage production and diversify food production. To achieve these objectives, BH considered (i) shifting calving to May and June, (ii) setting up a 0.25 ha plot of vetch as a catch crop after irrigated rice, (iii) setting up on 0.60 ha of rainfed land a crop sequence consisting of a maize/*Stylosanthes* combination for one year, followed by three years of *Stylosanthes* alone, and (iv) diversifying food production with a plot of groundnuts (0.20 ha) and cassava (0.10 ha) in rainfed conditions on soils improved by MCS. The tops of groundnut plants also can be fed to dairy cows.

The project scenario (PS) was developed on this basis by seeking technical references on MCS from local experts in the field (Husson et al., 2013). The biomass of *Stylosanthes* exportable each year for the herd was estimated in such a way that a minimum of vegetation would be maintained on the

[1] 2800 Ariary = 1 € in 2011 when the study was conducted.

ground in order to manage fertility and control erosion (Naudin et al., 2015). The maize-*Stylosanthes* system, practically divided into four equal subparts in rotation, was modelled to produce the same amount of maize and forage each year.

After simulating the PS, a first alternative scenario AS1 was built to reach BH's objectives of forage autonomy and increased production during the dry season. This scenario expanded the type of MCS introduced on the farm to diversify the forage available for the herd, and transformed the entire production of *Stylosanthes* into hay starting from May. This technique, which BH was not practicing but did know, represented an additional innovation in relation to the farm's current system and its planned evolution. A second alternative scenario, AS2, added to AS1 the distribution of a concentrate to the dairy cows, composed of raw materials directly available on the farm (grain maize, cassava) or after processing (rice bran and groundnut cake).

4.3 Evaluation

This first stage of the process confirmed BH's observation that there was a milk production deficit in the dry season in the initial situation (IS). It also enabled him to verify that the model was able to represent his current situation before moving on to represent his project. The PS shows a reduction in the volume of natural grasses collected in the dry season, while the cows' demand for forage increases due to the higher proportion of milk produced in the dry season (Table 7; Figure 5). However, the permanent labour force could only be decreased by one person due to the volumes that continue to be needed. Furthermore, the target milk production could not be reached at peak production in June-July. AS1 made it possible to forgo natural grasses in the dry season, saving an additional permanent labour position. However, peak production still did not reach the target because the diet remained too low in energy content. Only AS2 allowed both objectives to be achieved through the use of concentrates produced on the farm.

From an economic point of view, each scenario increased the net margin of the farm compared to the initial situation, with the milk enterprise accounting for a higher share of income while nonetheless remaining less than that of rice. The existence of potential forage surpluses, especially in the alternative scenarios, raised the possibility of increasing the herd size, but this was not modelled during the support process with BH due to time constraints. In view of these results, BH was interested in the alternative scenarios, especially as he already had a building in which he could store hay. Discussions also focused on the benefits and feasibility of the MCS modelled, which are presented here under steady state conditions but which require an installation time of one year to establish the cover crop. This installation time was a constraint for BH because it meant that he would have to adapt how he fed his herd due to the lack of forage.

4.4 Outcomes

Two years after this intervention, a visit was made to BH to learn about the developments on his farm related or not to what had been discussed. The farm's rice orientation had been accentuated with the opportunity to acquire a new plot of land with good control of irrigation water. BH also had reduced his herd to two dairy cows, which were better fed than before thanks to the increased production of groundnut tops and the addition of concentrates, and had shifted calving to the dry season as planned. However, he had not implemented the MCS tested in the scenarios because he considered that they were too complicated and not well adapted to his production conditions. Natural grasses therefore continued to provide much of the forage biomass, supplemented by green *Bracharia r.* grown in rotation with maize and cassava.

Table 6. Characteristics of the four scenarios simulated with CLIFS on the BH case.

	BS	PS	AS1 & AS2
Permanent staff (n)	5	4	3
Lowland cropping pattern (ha)			
Monocropped Rice paddy	4.75	4.50	4.25
Rice+Vetch[2]		0.25	0.25
Rice+Oat[2]			0.25
Chloris gayana[1]	0.20	0.20	0.20

Rainfall cropping pattern (ha)			
Groundnut[5,8]		0.20	0.10
Cassava[7,8]		0.10	
Maïze[7,8]			0.10
Maïze//Stylosanthes[3,5,6,8,9]		0.60	
Groundnut//Stylosanthes[3,5,6,7,8,9]			0.40
Cassava//Stylosanthes[3,6,7,8,9]			0.30
Stylosanthes guianensis.[3,9]	0.10		
Bracharia ruziziensis[3,9]	0.10		
Fallow	0.70		
Total (ha)	5.85	5.85	5.85
% Total forage area	6.8	10.7	13.7

Crop objectives:

[1] provide balanced green forage throughout the year

[2] provide nitrogen-rich green forage in the dry season (August-November)

[3] provide green forage in the rainy season and at the beginning of the dry season

[4] provide green forage in the dry season (June-November)

[5] provide nitrogen-rich dry forage (peanut tops)

[6] provide usable hay in the dry season

[7] provide the ingredients of the self-produced concentrate

[8] diversify food crops

[9] improve degraded soils

Table 7. Technical-economic outcomes of the four scenarios simulated.

	IS	PS	AS1 (without concentrate)	AS2 (with concentrate)
Marketable milk production (l)	6380	7050	7220	7760
% production in dry season	36	52	53	56
Average sale price (Ar/l)	1071	1104	1105	1113
Total natural grasses (t)	23.2	11.1	9.2	9.2

Of which dry season	10.2	6.5	0	0
% dry season	44	59	0	0
Excess green forage (t/year)				
Chloris g.	0.7	1.2	0.7	0.7
Vetch		0.0	0.8	0.8
Oat			2.2	2.2
Stylosanthes g.	0.3	0.9	0.0	0.0
Bracharia r.	0.2			
Expenses (1000 Ar)				
Permanent work force	1375	1100	825	825
Seasonal work force (harvest)	1730	1870	1880	1880
Intermediate consumption	660	1190	1450	1450
Concentrates	-	-	-	97
Total	3765	4160	4345	4442
Total net margin (1000 Ar)	19740	20880	21090	21720
% livestock[1]	35	37	38	39

[1] 100*Livestock Gross Margin / Total Net Margin

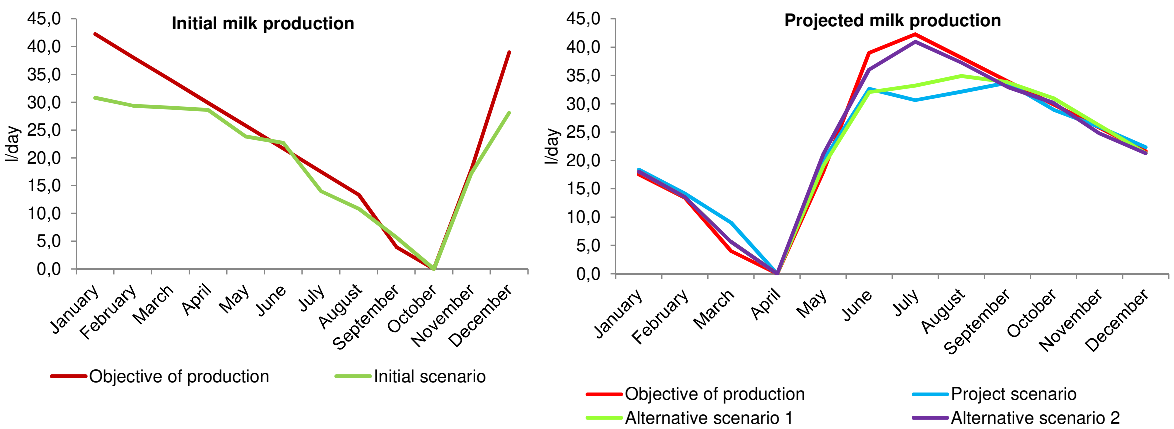


Figure 5. Monthly milk yields as a function of the production target and diet distributed.

5 Discussion

5.1 Characterizing scenarios

CLIFS limits the use of mechanistic equations to excreta production for ruminants, and to the relationship between feed and production for cattle. The latter equations are assumed to be valid for any type of context where animals have a live weight of between 400 and 800 kg (INRA, 2007), and to be sufficient for farm-level estimates that do not require the same degree of precision as a feed rationing tool. Aside from these situations, or when the data needed for the calculations are unavailable, users can switch to a simplified use of the simulator where the link between diet and production is based on their own expertise and not on calculations.

This option, and the fact that CLIFS essentially only mobilizes data describing the farm's resources and how these are used, provides sufficient flexibility for the software to be used in many contexts. Users are thus freed from the constraints encountered by whole-farm models integrating biophysical models which require data that are not systematically available or validated, which limits their use and utility in supporting farmers (Jones et al., 2017). This flexibility appears well suited to non-research contexts with real farms, in individual or group situations (Ryschawy et al., 2014), and not just typical farms reconstructed for the purposes of a research study (Tittonell et al., 2009; Smith et al., 2020).

However, this flexibility calls for vigilance with regard to three points. The first concerns the quality of the data describing the farm in the initial scenario, which may not be available or entirely accurate on all of the farms likely to benefit from the approach. The construction of this scenario can therefore be time-consuming when extensive discussions with the farmer are needed to arrive at a plausible representation of his/her situation. The interactions between the components of the production system and the technical and economic performances, which often are known or even recorded (e.g., milk production marketed), make it possible to arrive at a result that farmers themselves can evaluate and validate within a participatory modelling approach (Voinov and Bousquet, 2010).

The second point concerns how to determine the performance of crop and livestock enterprises as a function of respectively crop and feed management sequences when equations linking them are absent. These values have a direct impact on the balance sheets calculated and the resulting economic results. They need to be considered for each technical change in a scenario, either with the farmer concerned or with experts in the field, in order not to lead to outliers. These considerations can include the effects of adverse climatic and health events to assess the capacity of the simulated configurations to absorb such shocks.

The third point concerns the characterisation of the technical innovations integrated into the prospective scenarios when the farmer is unfamiliar with them. The data needed to describe the innovations are then obtained from scientists and experts in the field. However, their validity in the case under study cannot be guaranteed. In such situations, it is useful to develop a set of scenarios in which yields are varied within a range considered plausible in the context studied to assess the variability of the resulting technical and economic results.

Unlike other whole-farm models (Pissonnier et al., 2017; McDonald et al., 2019), the balance between supply and demand for labour has not been integrated into CLIFS due to the complexity of calculating this at the scale of a farm where there are a multitude of tasks, some seasonal, some routine, multiple possibilities of division of labour within the farm (Davison, 2019), and multiple viewpoints on this question depending on the farmer involved. When faced with an increasing demand for labour, some farmers may be willing to work more, while others may prefer to hire labour from outside the farm (Hostiou et al., 2015). These contexts lead to the establishment of individual balances per worker within the farm, requiring a large amount of data. This is why, rather than embarking on such calculations, it is preferred to assess with the farmer the additional costs generated by a given configuration involving significant changes in labour demand (hiring temporary workers or employment of permanent staff) (Ryschawy et al., 2014).

5.2 Contributions and limitations for farmers and advisors

The individual farmer support approach was implemented in a similar way on all of the sites where it was tested. A number of points emerged that were remarkably consistent across the farms participating in the study. First, farmers particularly appreciate the fact that the work is carried out on their own farms and not on a virtual case (Ryschawy et al., 2014). This point, which is related to the individual nature of the support, is due to the unique character of each farm which follows its own development trajectory, even if certain objectives or issues which arise are shared by others (Rose et al., 2016). Nonetheless, the outcomes of individual cases can be used to fuel collective reflection, as long as the group is used to working collectively and uses real farms in the discussions (Ryschawy et al., 2014).

Farmers also appreciate the ability to integrate the different components of the farm in a holistic approach which they can understand, and the realistic and concrete character of the simulated scenarios. This last point is the result of both the individual nature of the support and the attention paid to the validation of the scenarios by the farmers themselves. From this perspective, the transparent structure of CLIFS is an advantage. As with any support process based on the analysis of scenarios (Martin et al., 2011), the farmers emphasise the capacity of the process to compare different options and their impacts in terms of the management of production factors and performance, which can go as far as reorienting their initial project.

They also highlight the knowledge gained in certain technical areas, such as dairy cow diets or forage quality, through discussions about the scenarios (Semporé et al., 2016), and an increased awareness of the value of collecting data on farm activities and planning these activities, as proposed by certain advisory methods (Faure et al., 2018). The existence of quantified data about their farms known by the farmers facilitates the implementation of the approach. When such is not the case, the advisor must spend more time characterising the initial scenario, but in so doing gains a deeper understanding of the farm.

However, as demonstrated by the case presented here, the projects discussed are not necessarily implemented. This may be because this step involves questions of feasibility that the approach did not address (McCown, 2002), or because farmers encounter opportunities or hazards that lead them to reconsider their choices. Discussions and simulations may consider some of these points, such as the occurrence of an extreme weather event, potential market opportunities and price dynamics, but the reality encountered later may be quite different. The added value of the approach thus lies rather in the capacity to transfer and increase the knowledge of both farmers and advisors about possible future options (Martin et al., 2011).

For the advisors, who to date have mainly consisted of researchers and students, this participatory approach provides a framework that goes beyond qualitative approaches, with the quantified outputs of the simulations feeding into discussions with the farmer(s) on a concrete basis. By placing farmers in a position to react and reflect on the questions they are asked and the results they are presented, they are led to a better understanding of their own objectives, strategies, constraints and knowledge. The advisor is required to seek biotechnical references from experts, researchers and technicians, both to configure CLIFS under local conditions and to define the scenarios. This presents opportunities to discuss possible technical innovations in a given case, and to point out knowledge gaps in certain areas. A lack of local references indeed may limit the range of possible scenarios.

5.3 From the tool to its use

CLIFS was designed with the explicit aim of transferring the approach and the tool to non-researchers. To achieve this objective, a compromise had to be reached between over simplifying, which would make the tool ineffective with regard to the reflections to be conducted on strategic issues, and over complicating, which would make the tool unusable in a professional advisory context (Rose et al., 2016). This compromise led to the structural choices concerning the static nature of the simulations and the calculation of balances.

The different case studies have shown that the tool appeals to farmers because it is relevant to their questions, helps them understand scenario outputs and is useful for their reflections (Matthews et al., 2008). However, the inclusion of new actors, such as agricultural advisors, and the structures in which they are part have not yet been tested. Such an inclusion raises new questions regarding the skills of those involved, both technically and in terms of their ability to analyse, make proposals and interact with farmers in order to carry out the process. These skills are not common in advisory structures, even in well-staffed contexts such as France, where strategic farm advice remains rare (Capitaine et al., 2013). This situation stems in part from the need to focus on individual farms due to their specific features, which is both time-consuming and costly. Mixed crop-livestock farming adds to the difficulty, as agricultural advisors are often specialised by production sector, with a distinct separation between the crop and livestock worlds (Garrett et al., 2020).

However, given the challenges of transforming farms facing environmental issues and economic uncertainties in the agricultural and food sectors, such advisory services are needed. Consequently, the goal now is to test the use of the approach by agricultural advisors in their own work contexts and in various forms, ranging from individual support to advising producer groups. It also can be used in frameworks involving research, development structures and farmers in the co-design of innovative mixed crop-livestock systems (Berthet et al., 2016). In the academic sector, this type of tool makes it possible to assess *in silico* highly innovative production system configurations (Pissonnier et al., 2019) and to make students aware of the complexity of these systems and how to think about their evolution.

6 Conclusion

The farmer support approach built around CLIFS software is specifically dedicated to the strategic questions that mixed crop-livestock farmers ask themselves about their future. The various experiments conducted with family farms in the tropics and in France show that the tool meets the expectations of farmers and enables them to better understand possible changes in their production systems. CLIFS was designed to adapt to a wide range of situations and geographical contexts while remaining simple to use, particularly with regard to the variables to be filled in on each farm. Its transfer to advisory structures remains to be tested, but this simplicity should be an asset in this effort. The use of the tool also could evolve towards being linked with environmental assessment methods in order to think about crop-livestock combinations on farms that limit environmental impacts and improve certain components such as biodiversity.

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