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## 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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1 **Modelling mixed crop-livestock farms for supporting farmers' strategic reflections: the CLIFS**  
2 **approach**

3

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

6

7 <sup>1</sup> CIRAD, UMR INNOVATION, F-34398 Montpellier, France

8 <sup>2</sup> Innovation, Univ Montpellier, CIRAD, INRA, Institut Agro, Montpellier, France

9 <sup>3</sup> Université de Toulouse, INPT-ENSAT, F-31326 Castanet Tolosan

10 <sup>4</sup> INRAE, UMR DYNAFOR, F-31326 Castanet Tolosan

11 <sup>5</sup> Institut Agro, UMR SELMET, 2 Place Viala, 34060 Montpellier, France

12 <sup>6</sup> INRAE, UMR SELMET, 2 Place Viala, 34060 Montpellier, France

13 <sup>7</sup> INRAE, UMR AGIR, F-31326 Castanet Tolosan

14 Corresponding author: pierre-yves.le\_gal@cirad.fr

15

16

17 **Abstract**

18

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

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

35

36 **Key words:** design support, simulation, scenario, advisory

37

38

## 39 **1 Introduction**

40

41 The integration of mixed crop and livestock production on farms or within rural territories helps to  
42 improve the sustainability of agricultural production (Herrero et al., 2010; Moraine et al., 2016).  
43 Diversified production enables farmers to secure their incomes to cope with market fluctuations and  
44 climate change while promoting biodiversity in certain modes of management (Kok et al., 2020).  
45 Biomass exchanges between plant and animal enterprises help reduce the purchase of inputs and  
46 increase farm autonomy (Bonaudo et al., 2014). In developed countries where the reintroduction of  
47 these complex production systems is under debate (Schut et al., 2021), the survival of mixed crop-  
48 livestock farms is being challenged by the specialisation of production between regions and a reduced  
49 agricultural labour force (Ryschawy et al., 2013). In emerging and developing countries, some of these  
50 mixed farms are benefiting from booming livestock sectors, particularly dairy and poultry (Sraïri et al.,  
51 2013), but others are facing a decrease in available land, water resources and soil fertility due to  
52 increasing population pressures (Kidron et al., 2010).

53

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

62

63 The use of calculation tools that evaluate *ex ante* the consequences of a given farm configuration on a  
64 farm's technical-economic performance has proven useful in guiding farmers' reflections about future  
65 directions (Semporé et al., 2015; Colnago et al., 2021). Most modelling work related to this activity has  
66 a research objective, both in the design of the models and tools used, and in the intended uses (Le  
67 Gal et al., 2011a). Many tools therefore provide a representation of a farm based on biotechnical  
68 models, coupled with decision modules allowing the advantages of an innovation or a given farm  
69 configuration to be tested (Snow et al., 2014). Optimisation models also are used for this purpose on  
70 typical farms, for example to assess the benefits of conservation agriculture systems (Alary et al.,  
71 2016) or the integration of production activities (Mosnier et al., 2017). Rule-based models aim to  
72 reproduce farmers' decision-making processes (Vayssières et al., 2009), but are often difficult to use,  
73 and do not always capture the complexity of real situations.

74

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

86

87 This article presents an approach that aims to help farmers to think about the future direction of their  
88 farms in terms of introducing or expanding crop and livestock production activities, or of introducing  
89 technical innovations impacting all or part of their farms' operations. It relies on the use of a simulation  
90 tool named CLIFS (Crop Livestock Farm Simulator) which is devoted to mixed crop-livestock farms.  
91 The approach is specifically intended to be used with farmers and transferred to farm advisors. Earlier  
92 versions of CLIFS were tested on samples of 2 to 20 family farms in a range of contexts, and in both

93 tropical and temperate environments (Le Gal et al., 2013; Ryschawy et al., 2014; Semporé et al.  
94 2016). This article presents the current version, developed in Microsoft Excel®, which can be  
95 downloaded freely at the following address: <https://doi.org/10.18167/DVN1/NZHWQQ>. A User Manual  
96 (UM) provides a full description of the software and its equations to which the reader can refer for  
97 additional information (Le Gal, 2021; <https://doi.org/10.18167/agritrop/00577>). The use of the  
98 approach is then illustrated with the case of a dairy farm in Madagascar. In the discussion section, the  
99 approach is assessed from the point of view of researchers and farmers, and its potential use is  
100 explored.

101

## 102 **2 Empirical and methodological background**

103

### 104 **2.1 A set of seven case studies**

105

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

110

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

120

121 These forage crops generally were combined on the farms with food and cash crops, which were more  
122 or less diverse depending on the case study. Apart from the French case, the small family farms met

123 all or part of their cereal needs with their own production (wheat, rice or maize depending on the  
124 case). They also were part of marketing channels through which surplus foodstuffs and specific crops  
125 such as sugar beet in Morocco or cotton in Burkina Faso were sold. The crops could be irrigated or  
126 rain-fed, with different yield potentials and periods of biomass availability. For example, irrigated alfalfa  
127 in Morocco allowed dairy herds to be fed all year round, whereas cultivated rainfed grasslands in  
128 Brazil and France could only be used during the period when grass was growing.

129

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

142 **Table 1.** Main characteristics of the seven case studies.

143

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 <sup>1</sup>	<i>Brachiaria dec.</i> Sugarcane <u>Maize silage</u>	<u>Crop residues</u> (cereals, cowpea) <u>Mucuna pruriens</u> <i>Natural pasture</i>	<i>Cultivated pasture</i> <u>Grass/hay</u> <u>Maize</u>	Brachiaria ruz. <sup>1</sup> Styloxanthès guia. <sup>1</sup> Vetch <sup>1</sup> Wild grass <u>Rice straw</u>	Oat Pennisetum kizosi Ray-grass Forage maize <u>Rice straw</u>	Alfalfa Berseem <u>Silage maize</u> <u>Alfalfa hay</u> <u>Wheat straw</u>	Alfalfa Oat-vetch <u>Maize stems</u>
Main other crops	Maize	Maize	Winter wheat	Irrigated/rainfed	Irrigated/rainfed	Winter wheat	Maize

	Rice	Cotton	Soya	rice	rice	Sugar beet	Potato
	Beans		Sunflower	Maize	Maize+Bean Sweet potato	Vegetables	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

144

<sup>1</sup> Normal font: cut green and provided in troughs

Underline font: stored and provided in troughs

*Italic font*: grazed by herd

145



## 146 **2.2 A generic view of mixed crop-livestock farms**

147

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

161

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

172

173 The management of crop and livestock mobilises the workforce, family and hired labour, which is  
174 allocated by the farm head throughout the year to the various agricultural activities according to needs.  
175 While crop management is determined by crop cycles, seasons and technical practices, livestock

176 farming involves both seasonal work and routine work such as milking reproductive females, tasks that  
177 are repeated every day for all or part of the year (Hostiou and Dedieu, 2012). Mixed crop-livestock  
178 farms therefore represent a complex situation in terms of work organisation.

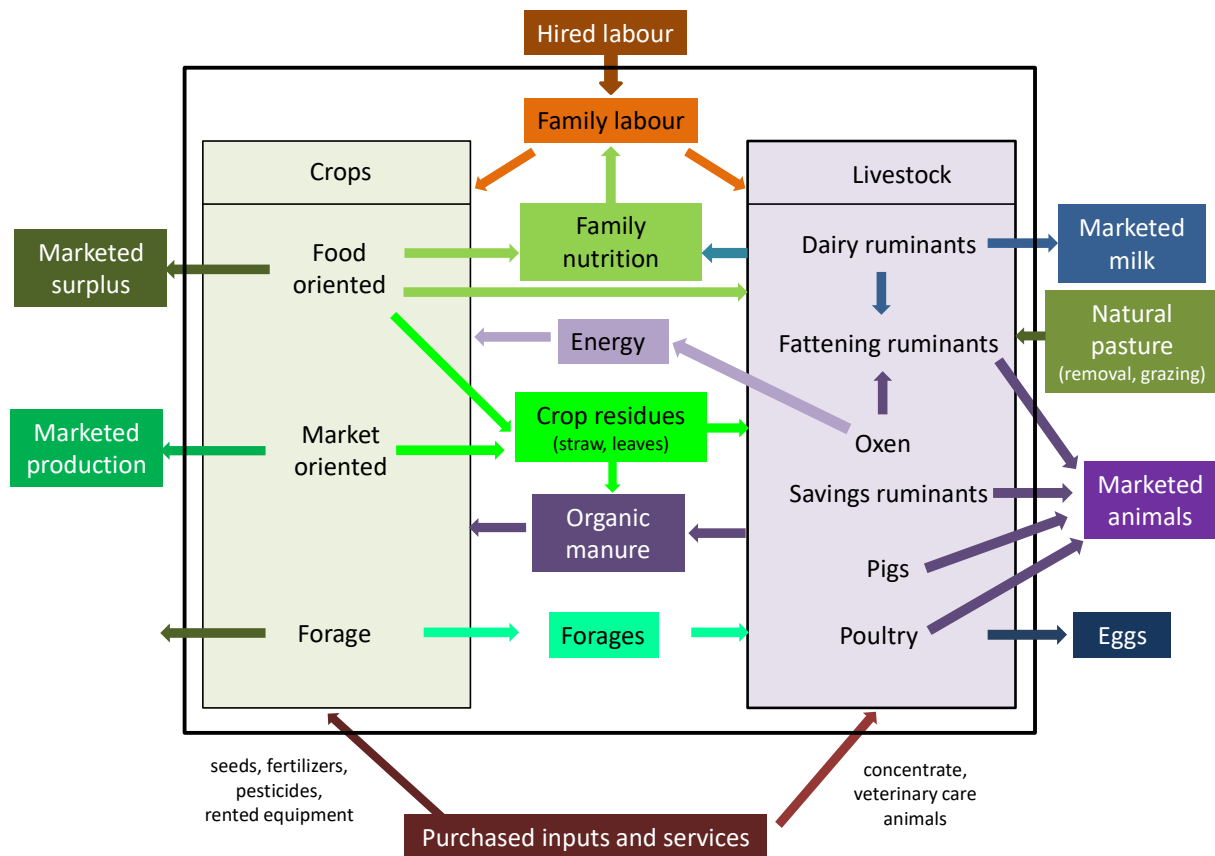
179

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

186

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

199



200

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

203

204 **2.3 A three-step support process**

205

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

214

215 The Initial Scenario (IS) is based on an analysis made with the farmer about the current situation on  
 216 his/her farm. This analysis allows the advisor to better understand the farmer's objectives and

217 strategies, to characterise the farm's structure, operations and performance, and to calibrate certain  
218 CLIFS input variables that are difficult to access, such as pasture productivity. Depending on the data  
219 available, it may take several loops to arrive at a representation of the farm that the farmer thinks to be  
220 consistent with reality. This representation is then considered to be valid for the next steps in the  
221 process. This validation stage is important to ensure that the rest of the process is based on  
222 knowledge that is shared by the farmer and the advisor, and to enable the farmer to understand the  
223 structure of CLIFS and the calculations made.

224

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

231

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

239

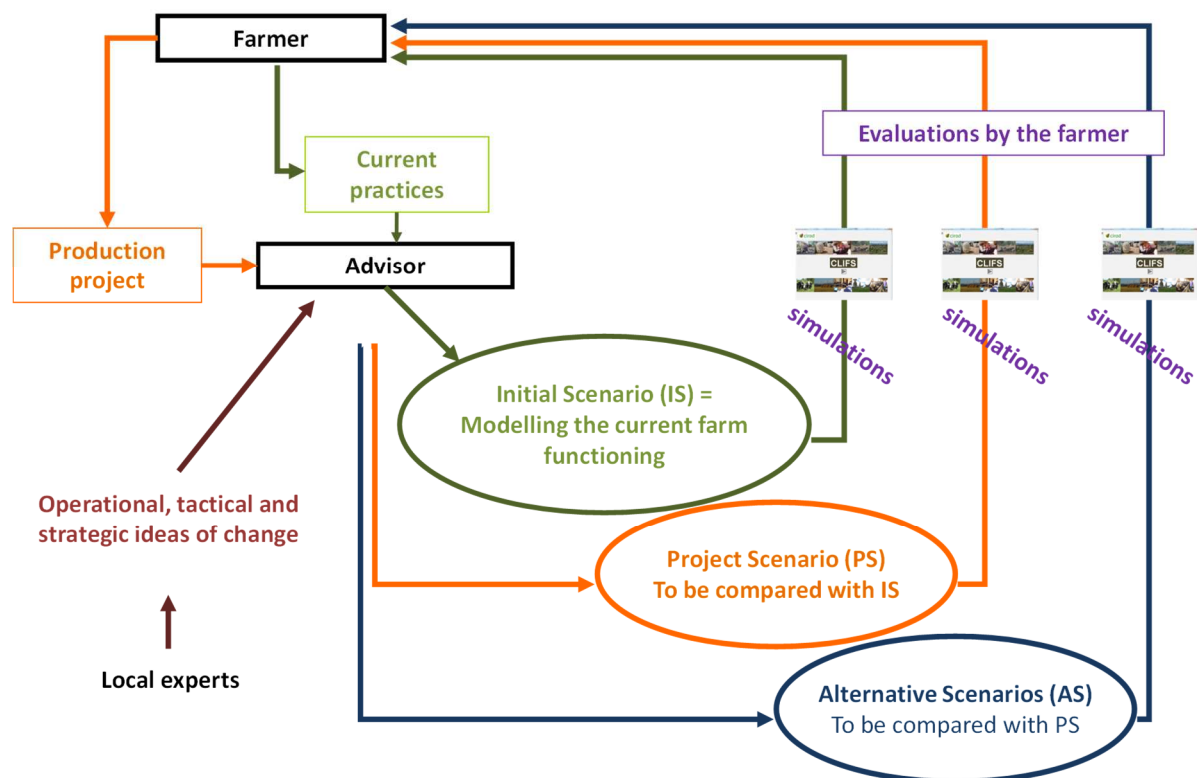
240 The loop may be run through as often as needed to test new ideas or to assess the sensitivity of a  
241 farm configuration to variables such as product and input prices or variations in yields according to the  
242 climate year. As CLIFS is a static tool, these analyses involve multiplying scenarios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

247 returned to the farms a few years later to discuss with the farmers what they finally had achieved, as in  
 248 the case presented in this article.

249

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

254



255

256

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

258

259

260 **3 CLIFS description**

261

262 **3.1 Overview**

263

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

271  
 272 The only equations related to biological processes concern: (i) for all ruminants, excreta production as  
 273 a function of their live weight to calculate the supply of organic manure as a function of herd structure  
 274 and management (Table 5); (ii) for cattle only, energy and nitrogen requirements for animal  
 275 maintenance, gestation of breeding females, and production of milk and meat per head (Table 2) in  
 276 order to link these productions to the rations distributed, with the choice between two calculation  
 277 systems independent of the user's working language: French (INRA, 2007) and American (NRC,  
 278 2001). The user can nevertheless inactivate these calculations of milk and meat production if required  
 279 data are unavailable or another feed system than those proposed is being used. The other  
 280 calculations only use the four mathematical operators.

281

282 **Table 2.** Equations of energy and protein requirements for a lactating cow according to the feed value  
 283 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 1 liter of milk	Energy	0.44	0.699
	Protein	48	0.05

284 With:

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

286  $CBW_b$ : Calf Birth Weight for batch  $b$  (kg)

287  $g$ : Month after fertilization [1,9]

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

289

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

303

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

307

## 308 **3.2 Structure and operation**

309

### 310 *3.2.1 General structure*

311

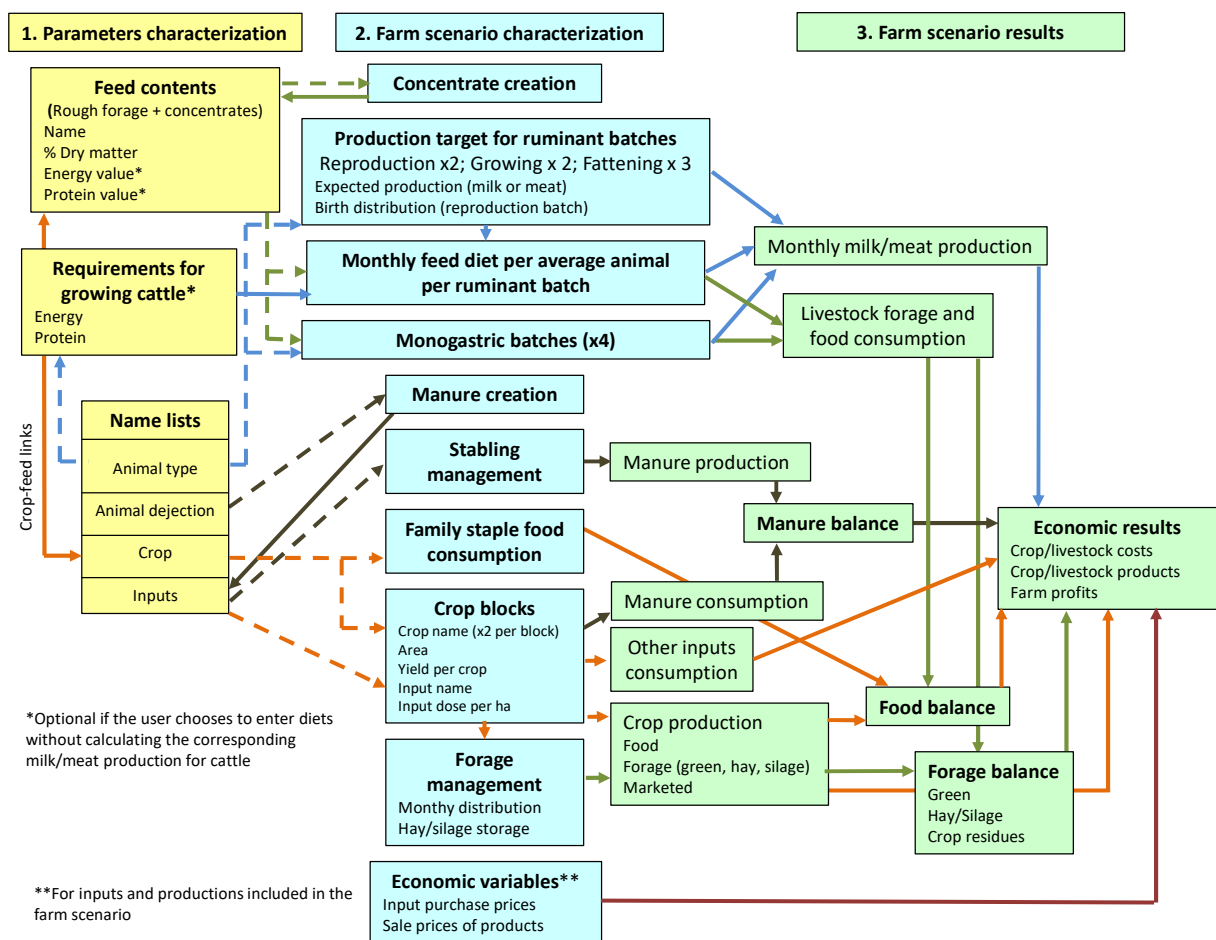
312 CLIFS consists of a series of Excel® sheets grouped into three linked modules (Figure 3, and UM C.  
313 for a full list of the sheets):

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

316 (ii) Input variables, specific to each farm, with an "animal" sub-module of 16 sheets characterising the  
317 dairy, growth and fattening ruminant enterprises and the batches of monogastric animals (UM E.1 to  
318 E.8); and a "crop" sub-module of six sheets characterising the crop blocks making up the farm. Each  
319 block is defined by the combination of one to two food, cash or forage crops, the technical practices

320 applied and the associated yields. It may or may not correspond to physical crop fields (UM E.9 to  
 321 E.14). Also included is an economic sub-module of four sheets to enter prices of inputs and services,  
 322 and prices of marketed products (UM E.15 to E.18);  
 323 (iii) Output variables, grouping all of the balances and economic calculations resulting from the farm's  
 324 sizing, technical choices and performance (UM F.) in 14 sheets;  
 325 Input and output variables are linked through a set of calculations included in sheets not visible to the  
 326 user (UM Eq.1 to Eq.22).

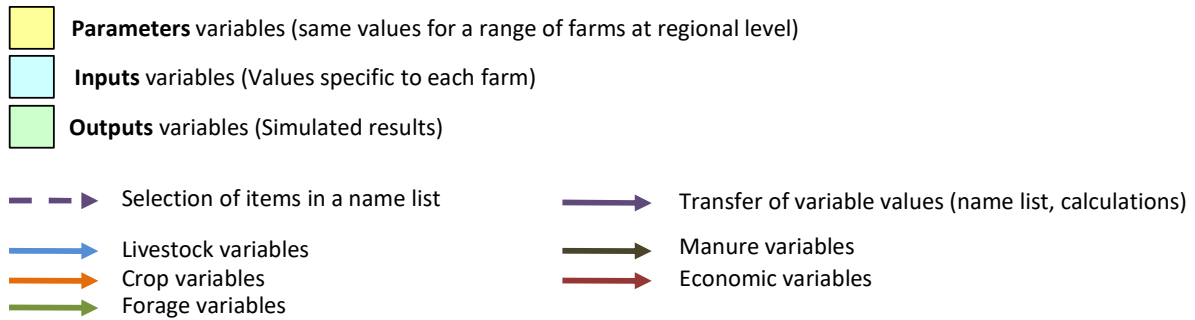
327  
 328



329



## Legend



330

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

332

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

342

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

348

349 CLIFS uses different time steps depending on the process represented (Table 3). These time steps  
350 are those used by farmers to manage their production activities while being aggregated to limit the  
351 amount of data needed to be entered. For example, diets are entered in kg per day, which can be  
352 modified each month, i.e., 12 values to be entered per feed. Similarly, the units used vary according to  
353 the variables (UM B.2). They are either specified in the row and column headings (e.g., kg/ha for crop

354 yields), or left to the user's choice (e.g., quantities of all crop inputs except organic fertilisers given in  
 355 kg/ha). The monetary unit related to the economic variables is also left to the user's choice.

356

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

Modelled item	Time step	Comments
<b>Input variables</b>		
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
<b>Result variables</b>		
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	

358

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

368

### 369 *3.2.2 Calculation of food-market crop balance*

370

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

376

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

384

### 385 *3.2.3 Forage balance*

386

387 The forage balance makes it possible to assess the degree of a farm's forage self-sufficiency for each  
388 scenario designed. Each forage is the subject of a calculation that subtracts the herd's total

389 consumption according to the diets applied in the different enterprises from the supply produced by  
 390 the farm (see Table 4 with the example of green forage). For each forage crop, this supply  
 391 corresponds to the sum of the {area x yield} of the blocks where it is grown pure or in association.  
 392 Yields are entered in gross weight and not in dry matter to be consistent with farmers' practices  
 393 regarding the quantification of diets distributed. The annual quantity produced is then distributed on a  
 394 monthly basis using a percentage of the yield depending on the production dynamics of the different  
 395 forage crops (growing all or part of the year like grassland or alfalfa, or without regrowth like forage  
 396 maize). The user then specifies for each crop and each month how it is used: green (grazing on the  
 397 field or distribution synchronised with the harvest), stored as hay, or silage.

398

399 **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 $f$	$\sum_{m=1}^{12} Bal\_GF_{f,m} \text{ with } Bal\_GF_{f,m} < 0$

400 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

401

402 The demand is calculated monthly for each forage based on the diets distributed in each enterprise,  
 403 multiplied by the size of the enterprise (Fig.4 for an example of a diet in a dairy unit). A monthly  
 404 balance is then calculated by comparing the supply and demand from January to December. For  
 405 green forage, no carry-over from one month to the next is possible. For hay and silage, the monthly  
 406 evolution of the stock is calculated, which makes it possible to pinpoint the date when a shortage is

407 possible. A positive balance, monthly for green forage or at the end of the annual cycle for stocks,  
 408 reflects an imbalance between production and needs. However, surplus stocks can be sold if a market  
 409 price exists. A negative balance triggers the purchase of forage, whatever its type, which is added to  
 410 the farm's expenses if a market price exists. In the absence of a market, the scenario highlights a  
 411 structural forage imbalance that must be corrected by reconfiguring demand (nature and size of the  
 412 herd, diets) or supply (cropping pattern and yields). The user then has to evaluate these changes,  
 413 including the choices and management of animal diets, by designing and simulating additional  
 414 scenarios since CLIFS does not provide any optimisation algorithm to define a relevant farm  
 415 configuration.

416  
 417 Crop residues (straw, stover, tops) stored dry by the farm at harvest and then incorporated into diets  
 418 are subject to a supply-demand balance only on an annual basis. The supply is calculated from the  
 419 crop production to which a grain/residue ratio based on raw material is applied. The demand includes  
 420 the quantities consumed by the ruminants and those incorporated into organic manure.

421

#### 422 3.2.4 Manure balance

423

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

432

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

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

---


$$\frac{QY\_Exc_{x,a,b}}{Prod\_Manure_{u,b}} = \frac{QY\_Exc_{x,a,b} \times n\_man_{a,b} \times Conv\_Exc_{x,b} \times ((100 - Loss\_Exc_{u,b}) \div 100) \div ((100 - \%Exc_{x,u}) \div 100)}{Prod\_Manure_{u,b}}$$


---

434 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  $b$ <sup>2</sup>

$Loss\_Exc_{u,b}$  Loss rate (%) of manure  $u$  in batch  $b$

$\%Exc_{x,u}$  Proportion of excreta  $x$  in manure  $u$  (%)<sup>3</sup>

435 <sup>1</sup>The coefficient '0.01' is based on the following assumptions:

436 - A ruminant eats 2.5% DM of its live weight

437 - The diet has an average digestibility of 60%

438 - The dried excreted quantities =  $LW_{a,b} \times 0.025 \times (1 - 0.60)$

439 <sup>2</sup>When excreta are processed before their use as fertilizer.

440 <sup>3</sup>Considering that a given manure can consist of a mix of excreta and crop residue.

441

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

448

### 449 3.2.5 Milk and meat production for the ruminant batches

450

451 Milk production is calculated monthly for each batch of breeding females by first defining with the  
 452 farmer a production target based on the genetics of the herd, or depending on what the farmer  
 453 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  
 454 detailed presentation of the procedure, the variables and the equations used). This objective is  
 455 translated into a simplified lactation curve applied to all of the breeders in the batch according to their  
 456 calving months. For cows only, the production linked to the diet ingested each month is then  
 457 calculated from the feed values of the forage and concentrates concerned (Figure 4). Concentrate  
 458 quantities are entered according to the lactation stage of the breeders and not the calendar month.  
 459 This practice is in fact widely used in most of the dairy farms observed. The final production

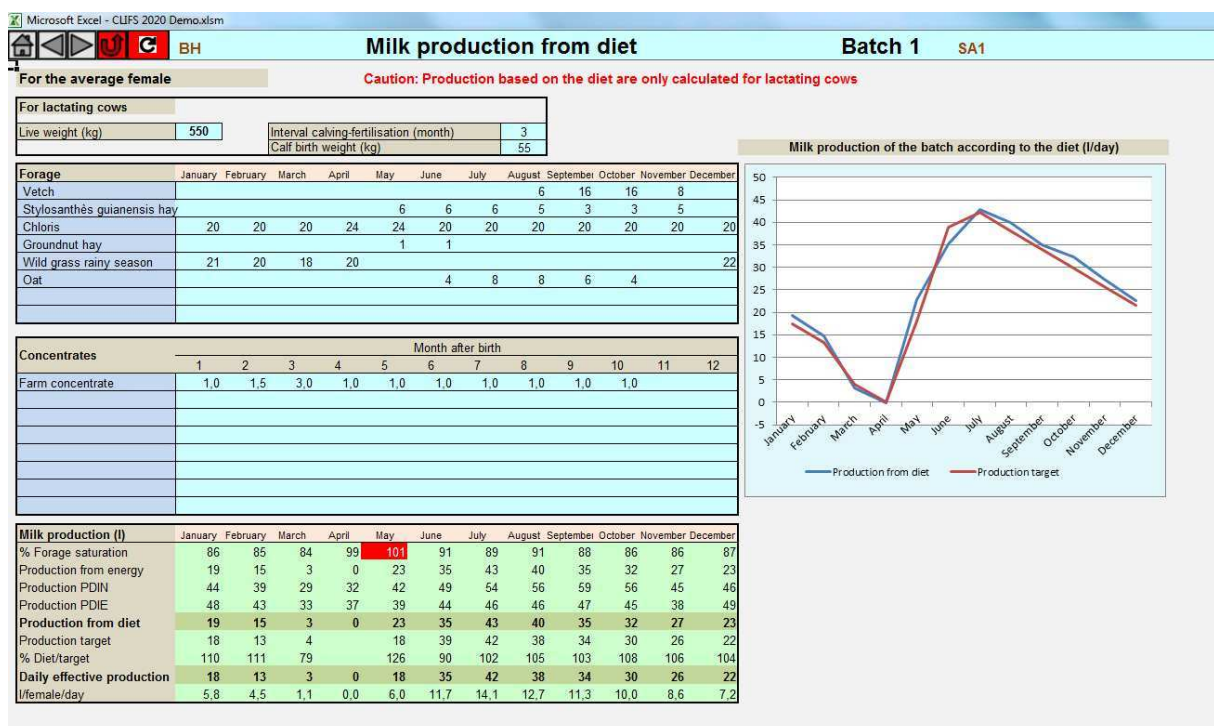
460 considered each month is equal to the minimum of the production target and the productions linked to  
 461 the diet's protein and energy content.

462

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

468

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



475

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

478

### 479 3.2.6 Economic results

480

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

488

## 489 **4 Example of CLIFS implementation on a Malagasy dairy farm**

490

491 The use of CLIFS is illustrated with the case of a real dairy farm located in the Lake Alaotra area in  
492 Madagascar. Support was given to this farm in 2011 under a research project aiming to develop  
493 mulch-based cropping systems (MCS) combining a crop of interest such as maize with permanent  
494 plant cover. This innovation is being promoted by local development and research structures for its  
495 expected effects on soil fertility and in reducing the risk of erosion on sloping fields (Corbeels et al.,  
496 2013). This example was chosen because the entire process was carried out with the farmer, with  
497 scenarios assessing the benefits of this innovation on the farm's dairy performance by making the  
498 most of the cover plants' forage potential.

499

### 500 **4.1 Farm structure and production**

501

502 BH's farm, located on the shores of Lake Alaotra (17°41'S; 48°27'E), combines rice and dairy  
503 production on about six hectares. Irrigated rice fields with high yield potential (5.5 t/ha of paddy) cover  
504 80% of the area. The harvest covers the family's rice needs and provides two-thirds of the farm's  
505 income. The remaining 20% of the farm consists of a lowland field (0.20 ha) producing green forage  
506 throughout the year (*Chloris gayana*), and two rainfed plots (0.20 ha in total) cultivated as pure forage  
507 (*Bracharia ruziziensis* and *Stylosanthes guianensis*). A rainfed area of 0.80 ha has been left to lie  
508 fallow as it is too degraded to be productive (Table 6). The dairy herd consists of three improved breed



509 cows, the target production estimated by BH is 2800 l/cow/lactation. Calving takes place in November-  
510 December with peak production in January-February (Figure 5). The cows are fed from the forage  
511 plots, supplemented throughout the year with natural grasses that are grazed or collected. This  
512 collection of biomass requires the employment of five permanent paid employees, who also are  
513 responsible for milking the cows, processing the milk into yoghurt, and marketing. The cows are  
514 permanently stalled all year round, which allows an abundant production of manure (a mixture of dung  
515 and rice straw produced on the rice fields) that generally is spread on the rice fields.

516

#### 517 **4.2 Building the scenarios**

518

519 After introducing BH to the support process and the general structure of CLIFS, an IS was built based  
520 on his current situation. This step revealed that the cows' diet did not allow them to reach the expected  
521 peak production in the rainy season because the energy content of the forage was insufficient (Figure  
522 5). The focus then turned to redesigning the forage system in relation to the herd feeding system by  
523 integrating three objectives expressed by BH: (i) produce more milk in the dry season (May-  
524 September) because this would earn a better return (1,200 Ar<sup>1</sup>/l instead of 1,000 Ar/l the rest of the  
525 year); (ii) reduce the manpower devoted to the collection of natural grasses by feeding the cows with  
526 on-farm cultivated forage; (iii) improve degraded soils to increase forage production and diversify food  
527 production. To achieve these objectives, BH considered (i) shifting calving to May and June, (ii) setting  
528 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  
529 crop sequence consisting of a maize/*Stylosanthes* combination for one year, followed by three years  
530 of *Stylosanthes* alone, and (iv) diversifying food production with a plot of groundnuts (0.20 ha) and  
531 cassava (0.10 ha) in rainfed conditions on soils improved by MCS. The tops of groundnut plants also  
532 can be fed to dairy cows.

533

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

---

<sup>1</sup> 2800 Ariary = 1 € in 2011 when the study was conducted.

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

540

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

549

### 550 **4.3 Evaluation**

551

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

563

564 From an economic point of view, each scenario increased the net margin of the farm compared to the  
565 initial situation, with the milk enterprise accounting for a higher share of income while nonetheless  
566 remaining less than that of rice. The existence of potential forage surpluses, especially in the

567 alternative scenarios, raised the possibility of increasing the herd size, but this was not modelled  
 568 during the support process with BH due to time constraints. In view of these results, BH was interested  
 569 in the alternative scenarios, especially as he already had a building in which he could store hay.  
 570 Discussions also focused on the benefits and feasibility of the MCS modelled, which are presented  
 571 here under steady state conditions but which require an installation time of one year to establish the  
 572 cover crop. This installation time was a constraint for BH because it meant that he would have to adapt  
 573 how he fed his herd due to the lack of forage.

574

#### 575 **4.4 Outcomes**

576

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

586

587

588 **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 <sup>2</sup>		0.25	0.25
Rice+Oat <sup>2</sup>			0.25
Chloris gayana <sup>1</sup>	0.20	0.20	0.20

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

589 Crop objectives:

590 <sup>1</sup> provide balanced green forage throughout the year

591 <sup>2</sup> provide nitrogen-rich green forage in the dry season (August-November)

592 <sup>3</sup> provide green forage in the rainy season and at the beginning of the dry season

593 <sup>4</sup> provide green forage in the dry season (June-November)

594 <sup>5</sup> provide nitrogen-rich dry forage (peanut tops)

595 <sup>6</sup> provide usable hay in the dry season

596 <sup>7</sup> provide the ingredients of the self-produced concentrate

597 <sup>8</sup> diversify food crops

598 <sup>9</sup> improve degraded soils

599

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

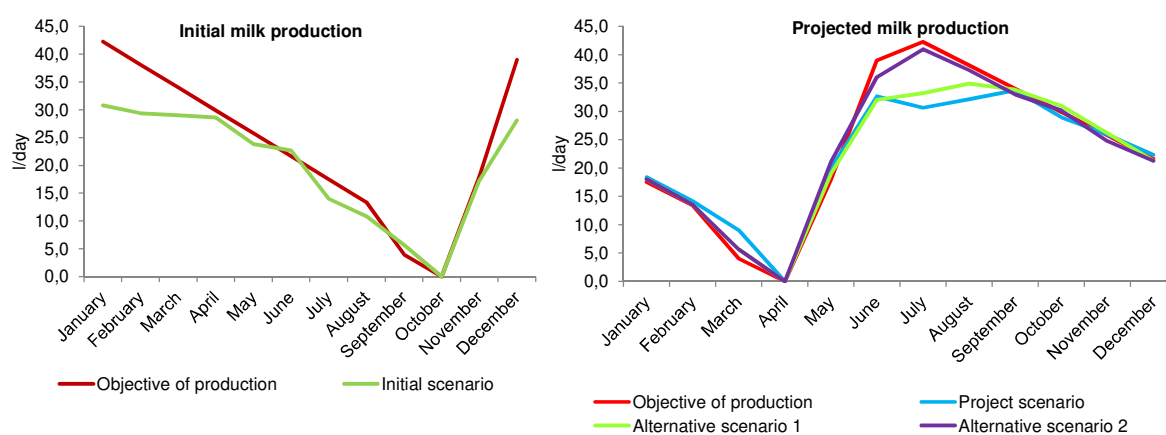
	IS	PS	AS1 (without concentrate)	AS2 (with concentrate)
Marketable milk production (l)	6380	7050	7220	7760
% production in dry season	36	52	53	56
Average sale price (Ar/l)	1071	1104	1105	1113
Total natural grasses (t)	23.2	11.1	9.2	9.2

Of which dry season	10.2	6.5	0	0
% dry season	44	59	0	0
<b>Excess green forage (t/year)</b>				
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			
<b>Expenses (1000 Ar)</b>				
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
<b>Total net margin (1000 Ar)</b>				
	19740	20880	21090	21720
% livestock <sup>1</sup>	35	37	38	39

601

602 <sup>1</sup> 100\* Livestock Gross Margin / Total Net Margin

603



604

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

606

607

608 **5 Discussion**

609

## 610 **5.1 Characterizing scenarios**

611

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

619

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

627

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

636

637 The second point concerns how to determine the performance of crop and livestock enterprises as a  
638 function of respectively crop and feed management sequences when equations linking them are

639 absent. These values have a direct impact on the balance sheets calculated and the resulting  
640 economic results. They need to be considered for each technical change in a scenario, either with the  
641 farmer concerned or with experts in the field, in order not to lead to outliers. These considerations can  
642 include the effects of adverse climatic and health events to assess the capacity of the simulated  
643 configurations to absorb such shocks.

644

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

651

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

663

664

## 665 **5.2 Contributions and limitations for farmers and advisors**

666

667 The individual farmer support approach was implemented in a similar way on all of the sites where it  
668 was tested. A number of points emerged that were remarkably consistent across the farms

669 participating in the study. First, farmers particularly appreciate the fact that the work is carried out on  
670 their own farms and not on a virtual case (Ryschawy et al., 2014). This point, which is related to the  
671 individual nature of the support, is due to the unique character of each farm which follows its own  
672 development trajectory, even if certain objectives or issues which arise are shared by others (Rose et  
673 al., 2016). Nonetheless, the outcomes of individual cases can be used to fuel collective reflection, as  
674 long as the group is used to working collectively and uses real farms in the discussions (Ryschawy et  
675 al., 2014).

676

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

685

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

693

694 However, as demonstrated by the case presented here, the projects discussed are not necessarily  
695 implemented. This may be because this step involves questions of feasibility that the approach did not  
696 address (McCown, 2002), or because farmers encounter opportunities or hazards that lead them to  
697 reconsider their choices. Discussions and simulations may consider some of these points, such as the  
698 occurrence of an extreme weather event, potential market opportunities and price dynamics, but the



699 reality encountered later may be quite different. The added value of the approach thus lies rather in  
700 the capacity to transfer and increase the knowledge of both farmers and advisors about possible future  
701 options (Martin et al., 2011).

702

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

712

### 713 **5.3 From the tool to its use**

714

715 CLIFS was designed with the explicit aim of transferring the approach and the tool to non-researchers.  
716 To achieve this objective, a compromise had to be reached between over simplifying, which would  
717 make the tool ineffective with regard to the reflections to be conducted on strategic issues, and over  
718 complicating, which would make the tool unusable in a professional advisory context (Rose et al.,  
719 2016). This compromise led to the structural choices concerning the static nature of the simulations  
720 and the calculation of balances.

721

722 The different case studies have shown that the tool appeals to farmers because it is relevant to their  
723 questions, helps them understand scenario outputs and is useful for their reflections (Matthews et al.,  
724 2008). However, the inclusion of new actors, such as agricultural advisors, and the structures in which  
725 they are part have not yet been tested. Such an inclusion raises new questions regarding the skills of  
726 those involved, both technically and in terms of their ability to analyse, make proposals and interact  
727 with farmers in order to carry out the process. These skills are not common in advisory structures,  
728 even in well-staffed contexts such as France, where strategic farm advice remains rare (Capitaine et

729 al., 2013). This situation stems in part from the need to focus on individual farms due to their specific  
730 features, which is both time-consuming and costly. Mixed crop-livestock farming adds to the difficulty,  
731 as agricultural advisors are often specialised by production sector, with a distinct separation between  
732 the crop and livestock worlds (Garrett et al., 2020).

733

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

742

## 743 **6 Conclusion**

744

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

755

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757

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767

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