A tool for monitoring agricultural policies: modelling farming systems in the Caribbean to build an agricultural supply model

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Abstract

The paper deals with the elaboration of an agricultural supply model that aims at assisting policy makers to monitor the sector.
The choice of the model has been determined by three main factors: 1) the scarcity of information, 2) the need to take into account the variety of farm systems and strategies, and 3) the high instability of the sector. It is, thus, the farmers' rationale resulting in the crop combination, which is modelled through the linear programming techniques.
Given the research context the elaboration of an adequate methodology is crucial. Two main points can be outlined: 1) the building of a conceptual model of the Caribbean farm household leading to the development of a mathematical programming, 2) the setting up of a system of information collection mainly involving a multidisciplinary and multi-institutional network.
The first part of the paper deals with the conceptual model. The second part presents the whole methodology. Finally, the first results of the mathematical modelling are exposed.

Introduction

Most of the policy-makers dealing with agricultural development in the Caribbean region realise the need for monitoring tools which will enable them to assess better the changing trends in the region. Generally, the agricultural economies of the region have become diversified leading to instability in farming systems.
Furthermore the environment of the farms is changing. On the one hand domestic and international demands are becoming more and more unstable and segmented. On the other hand the working rules of the institutional context are also changing dramatically, particularly the market protection and the subsidies system.
Therefore the policy makers have to strengthen the efficiency of the use of the decreasing resources devoted to the agricultural sector.

Because of the multiplicity of the factors to be considered in decision-making, models appear to be relevant for the analysis and policy formulation. But these sector models have to deal with three kinds of obstacles. 1) The complexity of the situation: variety of the types and trajectories of Caribbean farm households in a non-stabilised agriculture; lack of classical cropping patterns; frequency of short cycle crops; occurrence of multiple activity. 2) The rapid changes in underlying economic structure. 3) The scarcity of information, which is particularly the case in Guadeloupe (French West Indies): lack of reliable data on farming systems, on prices and on agricultural supply and demand.
Because of these difficulties a simple production model has been chosen, the socio-economic and biophysical environment taken as exogenous.
A programming model is also more relevant than an econometric one. On the one hand there is the scarcity of data. On the other hand we think with various authors (Boussard et al. 1997; Carles et al. 1998; Hazell and Norton 1986; Lefer and Blaskovic 1994) that the changes in economic structure especially in technologies of production, market opportunities and prices,

can make it unwise to base policy analyses on extrapolations from historically estimated parameters.
Given this research context, the elaboration of an adequate methodology is crucial. Two main points can be outlined: 1) the building of a conceptual model of the Caribbean farm household prior to the mathematical programming, 2) the setting of a system of information collection mainly involving a multidisciplinary and multi-institutional network.
The first part of the paper deals with the conceptual model. The methodology is presented in the second part. Finally, the first results of the mathematical modelling are discussed.

1. The conceptual model

Conceptual models and mathematical models: a double gap

The core of any modelling approach rests in the "rationality" granted by themodel-maker to the system to be modelled. When the phenomenon is simple, e.g. a simple cause-effect situation, a mathematical function that describes as precisely as possible the behaviour of the system can be found and a mathematical model can be developed. This is the case of a prey-predator model. When dealing with more complex systems, as ecosystems or social systems, multiple causalities of various natures referring to a hierarchy of organisation levels are concerned. Here, mathematical modelling remains difficult, sometimes out of reach.

The farm-household is one of these complex systems. The farming system research (FSR) has produced an abundant literature which testifies this complexity (Bory and Paul 1991; Harrington and Winklemann 1982). One of the most obvious manifestations of it is the necessary call for interdisciplinarity required in FSR (Sebillotte 1996). Thus, the farm-household, though fundamentally a socio-economic unit, functions as a result from a wide range of production processes the understanding of which understanding is the concern of agronomy, animal sciences, soil sciences, etc (Bourgeois 1983). Therefore agronomists have long recognised the need to distinguish different levels of organisation within the farm-household, to assign each of them different subsystems with their own "sub-rationality", controlled by the socio-economic rationality of the farm-household but of a different kind. Nevertheless, however various and sophisticated are the conceptual models proposed by the FSR, they remain qualitative and no mathematical formalisation has been proposed yet.

However, agro-economists have developed mathematical models of farmers' decision-making process for long. They are based on linear programming (LP) (Bonneviale, Jussiau, and Marshall 1989). Step by step, these models have reached a high degree of sophistication, using the up-to-date mathematical advances in microeconomics (CGPRT Centre and CIRAD 1997; Collectif 1997; Hazell and Norton 1986; Howitt 1995). But one might be surprised by the double gap on the one hand between the complexity and the variety of the FS conceptual models and the poor microeconomic conceptual models, on the other hand between these poor micro-economic conceptual models and the highly sophisticated mathematical tools used to feed them. These models are generally based on economic theory describing the rationality of the farm-household by an exogenous utility cardinal function often reflecting an objective of income or profit maximisation. Although risk aversion is nowadays often taken into account, these conceptual models remain very sketchy when compared to the reality of tropical farm-households and hardly explain their behaviour. Furthermore, not only are the conceptual premises weak, they are rarely explicit. But one must acknowledge that though a much more complex set of rationalities is embedded in the farming system conceptual models, it unfortunately has not given birth to any mathematical model.

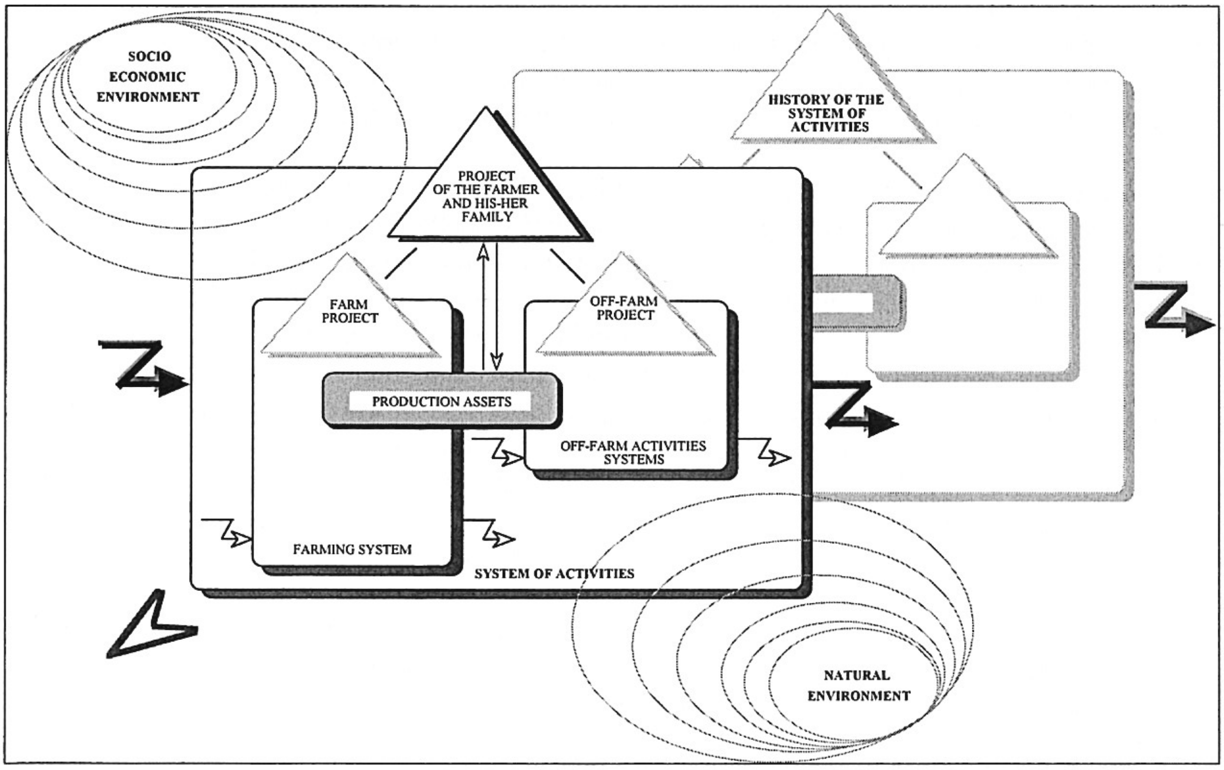
Our team has been working on farming systems in different parts of the Caribbean (French West Indies, Haiti, Cuba, Windward Islands, French Guyana) and in Brazil. Many models of farm-household of good heuristic value have been proposed (Bory and Paul 1991; Fabri et al. 1989; Paul et al. 1994) but as many conceptual models, their use by the decision-makers has been limited. Our hypothesis is that a more formal model would ease the transfer of our research results to the agricultural development decision-makers. We have therefore started with the use of linear programming as a basis for building an appropriate FS model.

The conceptual model

It is not useful in such a short presentation to recall all the main features of the farming system approach. We will therefore focus on the more original points of our model. The key words are "hierarchical structuring" and "structure of objectives".

The farm-household is considered as a system whose projects are chosen by the family (Figure 1). In order to reach these objectives, the family will mobilise its labour, the assets it owns (land, equipment, buildings, capital...) and possibly buy or rent complementary factors of production. The family will then set a system of activities within which the farming system is included. It is important to outline that in the Caribbean, as in many tropical countries, farming is rarely the only economic activity of the family. Crafts, fishing, wage labour, etc., are often as important as farming. Since there is competition for the factors of production (including family labour) between the different activities (farming and transport or crafts for example) these secondary activities must be taken into account even if we remain primarily interested in the farming system study. Naturally, relationships with the socio-economic environment must be considered both in the decision-making process and in its implementation. The influence of the history of the farming system from which the present situation results should not be forgotten.

<u>Figure 1: The system of activities</u>



At the level of the system of activities, the objectives belong to the socio-economic sphere: income, work schedule, social recognition, etc. The idea is to classify all the subsystems included in the system of activities of objectives and sub-objectives, starting from a pure socio-economic standpoint to a pure bio-technical one (Table 1).

Table 1: Simplified structure of objectives associated to the different systems and sub-systems of the system of activities

Systems and subsystems	Nature of the associated objectives
• System of activities	• socio-economic
• Farming system	• socio-economic
• Cropping and livestock systems	• technico-economic
• Technical itineraries	• technico-economic
• Technical operations	• bio-technical

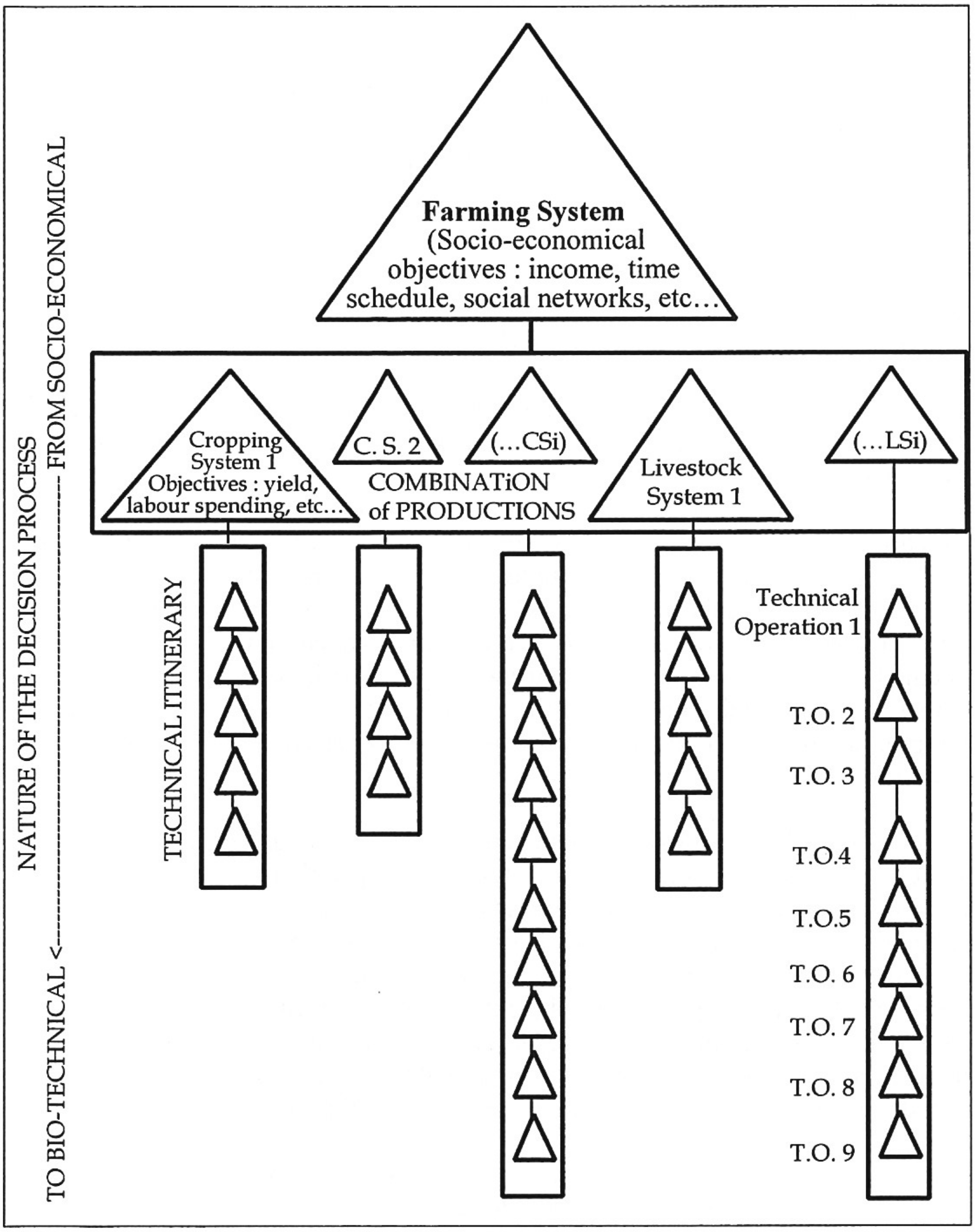
The farming system includes all the agricultural activities, from production to marketing[1]. Within the farming system, when a crop or a livestock is chosen, the associated decision-making and production processes constitute a given cropping or livestock system. There are as many such sub-systems as crops or livestock under a unified decision process and a homogeneous production process. One may observe, for example, a rainy season tomato cropping system, a dry season one, a maize-bean (multiple) cropping system, etc. Each of these sub-system is associated with particular objectives which, although of an economic nature again, are more precise and more technical than those of the farming system. For example, if a given cropping system should produce a given part of the income, this is now directly linked to a yield level. In short, the general objectives of the farming system are reached through a programme. This programme is a combination of sub-objectives referring to a combination of cropping and livestock systems.

In the same way, there is a programme associated with, say, a given cropping system. This programme is a logical sequence of technical operations starting from the land preparation to the harvest. It is called "technical itinerary" (Sebillotte 1977). Objectives of this programme are of a technico-economic nature, for example: maintaining a low level of weed development with a minimum use of labour. Each technical operation can be also regarded as associated with a particular objective and a given programme. In this case objectives are purely technical: land preparation is a technical operation, it is made of several manual and/or mechanical interventions with the aim of obtaining a given soil structure and a given level of weed control. Figure 2 shows the conceptual model.

One of the most important advantages of the model is that once the objectives and decision process of a given level of organisation are identified, the objectives and decision processes of its sub-systems can be ascertained in a relatively autonomous way. The rationality each level of organisation belongs to, is different.

[1] In our conceptual model, marketing systems are of the same hierarchical level as cropping and livestock systems. In such a short presentation we cannot detail this aspect and we will focus only the production processes: cropping and livestock systems.

Figure 2: Simplified farming system conceptual model



2. The methodology

The different stages of the methodology are shown in detail in Table 2.
The main principle underlying this modelling process is to build a model as simple as possible, to compare its results with the reality and to identify the reason for any gap: e.g. an inadequate objective function, a missing constraint, etc. The cycle begins again with the new version of the model and so on. This trial and error process appears to be the best way to deal with the trade-off between the accuracy of the model and the availability of data.
As shown in Table 3 there is a continuous to and fro process between the different axes that are often synchronous.
The authors of this paper, specialised in agronomy (crop and farming systems) and in agricultural economics (farming systems and marketing chains) were not formerly familiar with mathematical modelling. They had to build a team able to deal with the complexity of the farming systems, to make up for the lack of quantitative data, to be aware of the social demand and to make up for the lacking skills in modelling.
The bibliography on supply modelling and the inventory of the available data helped to define the type and the objective of the model. Then we began to build a prototype of generic model even before getting a database mainly to get accustomed to the process of modelling.
Extension officers provided information on 10% of the farms that they visit. This sample has been classified in types representative of the variety of farming systems. The ultimate step will consist in aggregating these micro-models in a regional supply model.
The difficulties in modelling the representative farming systems led to another consultation of the bibliography, particularly about the farmer's risk behaviour. Meanwhile the objective and structure of the model were reshaped according to the quality of the collected data.
In order to be more efficient it was decided to develop a model based on actual farms situations representing the different identified types. That is the only way to have the maximum of information about the decision-making process and to evaluate our hypotheses about the objective(s), constraints and strategies of the farmers. It is thus a good way to improve the modelling of the representative farming systems. It will help select the extra data needed to complete the database. Direct inquiries of farmers are made to obtain the required data.
This "actual farm" model will be presented as first results of the entire project both to policymakers and to extension officers.

3. First results

The first model

The programming model only keeps the decision-making levels of socio-economic nature. So far more technical levels are taken into account through the set of constraints and the characterisation of activities. In the future, they could be more precisely designed by use of a crop growth model.
Underlying hypotheses must remain realistic despite the simplicity requirement of the first model. Although Caribbean farmers aim at a complex set of objectives, the high integration to the market economy makes the income objectives dominant. Within the framework of linear programming the other objectives are included in the set of constraints. We have thus chosen the global farm income as objective function. This is the most frequent case in Guadeloupe. Nonetheless, we do not forget that in the case of dominant off-farm activity, farmers often seek maximisation of per hour income.
With regard to production factors, we restrict the model to labour hiring. This choice is consistent with the static nature of the model. Furthermore the Guadeloupean land market is particularly narrow.

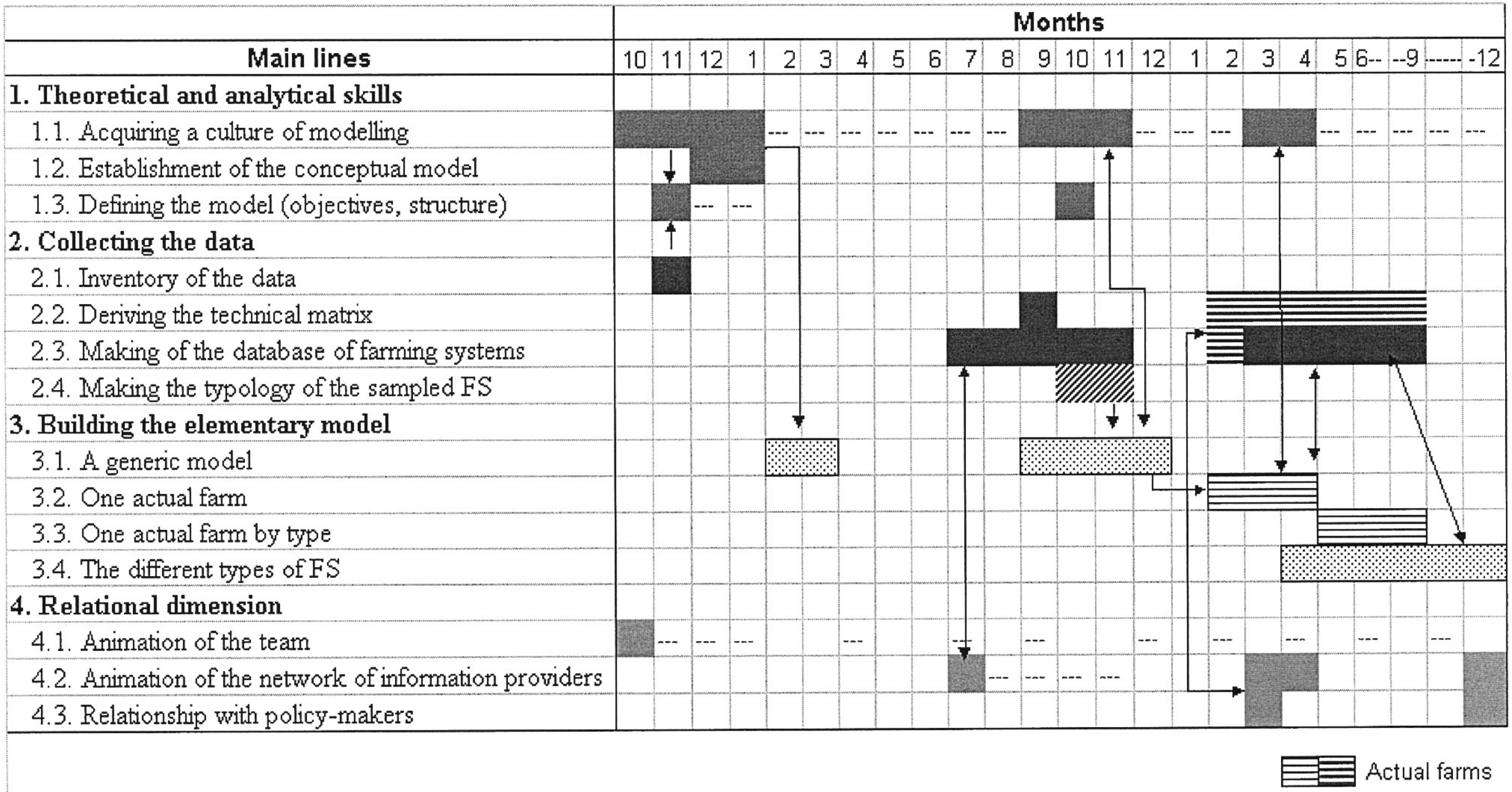
Table 2: Different axes of the adopted methodology

Main lines	Aim/Requirements	Description (means of achievement, components)
0. Forming of a team	• Multidisciplinarity • Multi-institutionality (social demand, data supplying)	The core of the team: • 1 agronomist (crop and farming systems) • 1 agricultural economist (farming systems and marketing chains) • 1 junior part-time agronomist Modelling: • 1 specialist of mathematical programming of farming systems (long-distance assistance and annual seminar) Analysing the agriculture: • 2 researchers in animal production, 1 agronomist (modelling), 1 agronomist (crop and farming systems) • 1 senior extension officer
1. Theoretical and analytical skills		
1.1. Acquiring a **culture of modelling**		Bibliography
1.2. Establishment of the **conceptual model**		Synthesis of previous studies on farming systems
1.3. Defining the **objectives of the model**	• Unified representation of the system to be modelled • Defining the objectives of the model	Team meetings
2. **Data** collection		
2.1. Inventory of the data		
2.2. Deriving the **technical matrix**		Critical evaluation of a published technico-economic database by specialists from the team or specialised extension officers

Table 2 (Cont.)

Main lines	Aim/Requirements	Description (means of achievement, components)
2.3. **Sampling** of farming systems		• Description by the extension officers of "their best-known" farming systems (detailed guidelines) • Homogenisation of this database by direct farmers inquiries
2.4. Building the **typology** of the sampled farming systems		
3. Building the elementary models		
3.1. A generic model	Introduction to modelling techniques	• Making the model • Meetings with modelling specialists
3.2. One real farm	• Feasibility • Identification of the constraints	• In-depth inquiry of the farmers • Adaptation of the proto-model • Follow-up interviews for calibration
3.3. One real farming system by type	• Identification of the constraints	• In-depth inquiry of the farmers • Adaptation of the proto-model • Follow-up interviews for calibration
3.4. The different types of farming systems		• Adaptation of the model • Follow-up interviews of extension officers for calibration
4. Relational dimension		
4.1. Animation of the team	• Exchange of multiple points of views • Acquisition of a common culture	• delivery of minutes of meetings and working papers • At least 2 meetings a quarter
4.2. Animation of the network of information providers	• Improving quality of the supplied data • Improving quality of the calibration of the model	• Presentation of applicable results after each phase of collective work with these partners
4.3. Relationship with policy-makers	• Increasing the appropriateness of the model (for the future users) • Improving the relationship with potential fund providers	• One seminar to present the project and the first results • One annual seminar

Table 3: Timetable showing the implementation of the project



Finally short cycle crops characterise the Caribbean agriculture. Therein intra-annual recursivity has to be included in the model very soon.

Therefore the first model can be written as follows:

maximise: $E(x) = c'x - f$
subject to:
$Ax \leq b$
and $x \geq 0$

where E is expected profit;
c is an n by 1 vector of activity expected revenues;
x is an n by 1 vector of activity levels;
f is fixed costs;
A is an m by n matrix of technical coefficients;
b is an m by 1 vector of resource stocks.

Table 4 portrays this simple LP model.

Table 4: A Linear Programming Model (Hazell and Norton 1986, 11)

	Activities				
	X_1	X_2	...	X_n	**RHS**
Expected income	c_1	c_2	...	c_n	Maximise
Resource constraints:					
1	a_{11}	a_{12}	...	a_{1n}	$\leq b_1$
2	a_{21}	a_{22}	...	a_{2n}	$\leq b_2$
.	.	.	...	.	
.	.	.	...	.	
m	a_{m1}	a_{m2}	...	a_{mn}	$\leq b_m$

with $X_j \geq 0$, all $j = 1$ to n

The first results

This simple LP program leads to this solution: the farmer chooses the most profitable activity, more often an off-soil one, using all the surface and buying thousands of hours of work. This solution is naturally unrealistic. The way to the complexity of the conceptual model is still long. At this stage the model can be improved by adding constraints on access to market (manpower, credit, products), *idem est* lines in matrix b. It results in the diversification of the model but still among the high-income activities while in most of the actual farming systems there is a balance between low-income and high-income activities.
One can remark than income level is generally positively correlated with risk level. It is then clear that the model has to take into account other variables among which the variability of the income associated with each activity and the risk aversion of the decision-maker.

With regard to introducing risk factors in the model, the probabilistic approaches have been rejected so far because of the need to assume the normally distributed risks and because of the scarcity of data. Then the Focus-Loss model developed by Boussard and Petit (Boussard 1970; Boussard and Petit 1967) was chosen. This method takes into account the significant role of patrimony in the risk-averse behaviour. Furthermore one doesn't need more gross margins data than what is known by the farmer. Hazell made a particularly clear presentation of the method (Hazell and Norton 1986, 103).

The focal loss (f_j) is the difference between the expected gross margin (c_j) and the worst one (c^*_j),
$f_j = c_j - c^*_j$, all j.
The maximum permitted loss (call it *LOSS*) is defined as the difference between expected total gross margin and the minimum income (MINI) required to cover farm fixed costs. That is,

$$LOSS = \sum_j c_j X_j - MINI$$

In order to emphasise diversification Boussard and Petit impose the requirement that no single activity has a total focal loss greater than 1/k of the maximum permitted loss for the farm plan. That is,

$$f_j \leq 1/k\ (LOSS),\ \text{all } j.$$

The whole program is portrayed in Table 5. As expected it increases significantly the diversification of the set of activities. We are now attempting to improve the model by introducing other secondary objectives, credit and cash flow constraints, pest and disease problems, seasonality, etc.

Table 5: A Focus-Loss Model (Hazell and Norton 1986, 103)

	Activities					
	X_1	X_2	...	X_n	LOSS	RHS
Expected income	c_1	c_2	...	c_n		Maximise
Minimum income constraint	c_1	c_2	...	c_n	-1	= MINI
Activity constraints:						
X_1	f_1				-1/k	≤ 0
X_2		f_2			-1/k	≤ 0
.			...			
.						
X_n				f_n	-1/k	≤ 0

Conclusion

We are still at the beginning of the development of the model using a to and fro approach. We, as leaders of the project, have to be involved simultaneously in various activities (Table 3). Although it makes the project very attractive, there is a risk of dispersal.
As expected, the multidisciplinary and multi-institutional nature of the team helps to counterbalance the small number of researchers fully devoted to the project. Furthermore it guarantees one of the main requirements of the modelling process, integration of disciplinary knowledge and requirements through their pooling and hierarchical structuring.

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