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Application to Sierra Leone

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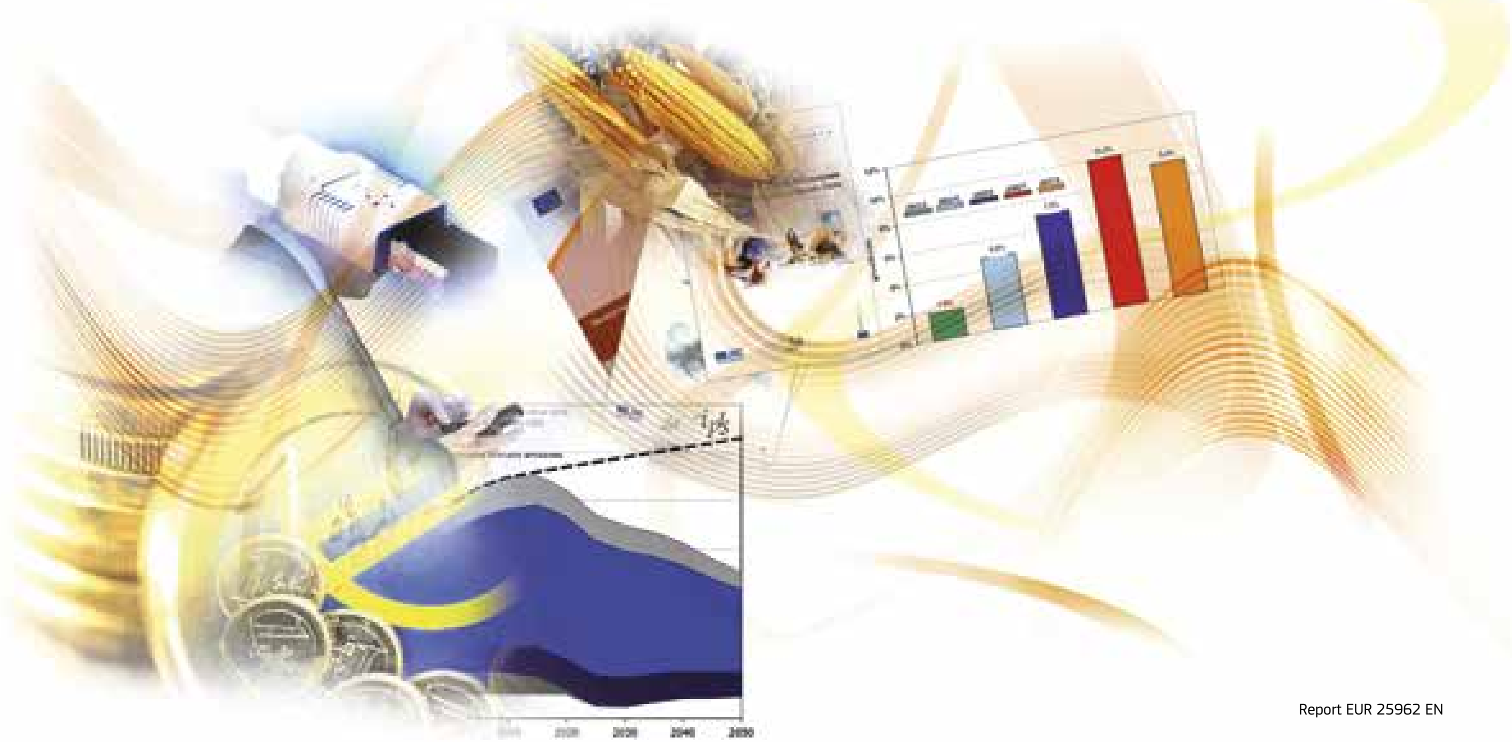

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List of acronyms

ABM	Agent based model
AGRISP	Agricultural Regional Integrated Simulation Package
AIDS	Almost Ideal Demand System
APES	Agricultural Production and Externalities Simulator
AROPAj	Agriculture, Recomposition de l'Offre et Politique Agricole
BECRA	Bio-Economic analysis of climate change impact and adaptation of Cotton and Rice based Agricultural production systems in Mali and Burkina Faso
CAPRI-FT	Common Agricultural Policy Regionalised Impact Modeling-Farm Types
CIHEAM	Centre international de Hautes Etudes Agronomiques Méditerranéennes
DA	Dressed animal
DM	Database Module
DMF	Data Management Facility
EMP	Econometric-Mathematical Programming
EU	European Union
FAAS	Federation Accounts Allocation
FAMOS	Forest and Agricultural Optimisation Model
FARMIS	Farm Modelling Information System
FSSIM	Farming System Simulator (SEAMLESS version)
FSSIM-AM	Farming System Simulator - Agricultural management module
FSSIM-Dev	Farming System Simulator for developing countries
FSSIM-MP	Farming System Simulator - Mathematical programming model
GAMS	General Algebraic Modelling System
GUI	Graphical User Interface
IAMM	Institut Agronomique Méditerranéen de Montpellier
ICM	Integration Code Module
INRA	Institut National de Recherche Agronomique
LDC	Less Developed Country
LP	Linear Programming
MAD	Mean Absolute Deviation
MAFFS	Ministry of Agriculture, Forestry and Food Security
ME	Maximum Entropy
MIP	Mixed Integer Programming
MP	Mathematical Programming
NAFFSL	National Federation of Farmers of Sierra Leone
OLS	Ordinary Least Squares
PAD	Percent Absolute Deviation
PDI	Protein Digestible in the Intestine
SD	Statistics Division
PIGLOG	Price Independent Generalized Log-Linearity
PMP	Positive Mathematical Programming
SCP	Smallholder Commercialization Program
SEAMLESS	System for Environmental and Agriculture Modelling, Linking Europe Science and Society
SLARI	Sierra Leone Agricultural Research Institute
USD	United States Dollar

Executive summary

This report presents a farm household model for use in the context of developing countries to gain knowledge on food security and rural poverty alleviation under different economic conditions and agri-food policy options. This model, called FSSIM-Dev (Farming System Simulator for Developing Countries), is an extension of the FSSIM model developed within the SEAMLESS project for impact assessment of agricultural and environmental policies on farm performances across Europe.

FSSIM-Dev is conceived to be applied for family or peasant agriculture where farm household production, consumption and labour allocation decisions are non-separable due to market imperfections. Contrary to most well-known household models which are econometric-based, FSSIM-Dev is a non-linear optimization model which simultaneously solves a set of microeconomic models reproducing the behaviour of representative farm households.

FSSIM-Dev is designed to capture five key features of developing countries' agriculture: non-separability of production and consumption decisions; interaction among farm households for market factors; heterogeneity of farm households with respect to their both consumption baskets and resource endowments; inter-linkage between transaction costs and market participation decisions; and the seasonality of farming activities and resource use.

Model use is illustrated in this report with an analysis of the combined effects of rice support policy and improved rice cropping management on the livelihood of representative farm households in Sierra Leone. Results show that, first, the improvement of rice cropping management is a key factor to significantly boost farm household income in the studied region. Second, the amount of N fertilizer required for, mainly, upland rice appears too high and costly and could not be applied by farm households without policy support. Third, both the rice policy and the improved crop management would increase farm productivity and boost household income but they are not sufficient to fight poverty since most of the farm household types would continue to live below the extreme poverty line of 1 USD-equivalent per day.

1. Introduction

Food security[1] has become one of the most important items on today's international political agenda and a serious issue for governments around the world. Guaranteeing sustainable and equitable food in the context of climate change, price volatility and the global financial crisis is a challenging task. Even if food availability has grown significantly and consistently over time, both globally and in developing countries, access to food is still limited particularly in many low income economies. According to the 2008 World Development Report (World Bank, 2008), three-quarters of the world's poor live in rural areas and most of them are farming. Although there are food security challenges across the world, major progress is yet to be made in Africa and South Asia's rural areas where most of the population is extremely poor (i.e. with less than 1 USD-equivalent per day at their disposal) and dependent on small holdings. To reduce rural poverty and improve food security both national governments and international community have developed several policies and programs. The European Union (EU) has made a significant contribution in this sense since 2005 through the STABEX (Stabilisation of Export Earnings) funds (an instrument of the 8th EDF – European Development Fund). These supports fall within a common policy framework for the EU and its Member States in the fight against world hunger and malnutrition[2]. This is motivated by its position as the world's main donor and one of the most important commercial partners of developing countries. These support policies have taken different forms such as: (i) increasing agricultural productivity through the support of agricultural inputs (mainly improved seeds and fertilizers), training and mechanization; (ii) facilitating the use of agricultural knowledge and technologies; (iii) improving infrastructure (rural roads, storage facilities, processing …); (iv) facilitating access to credit markets; etc.

Impact assessments of such supports upon the food security of farm households are however scarce and not always founded on solid science-based methods. Most studies have focused on the food security issue at the national level which may mask the food security situation at the household level. In fact, a country may be food secure at national level while large numbers of its households are food insecure. For a better understanding of farm household food security status, it is preferable to use methods and tools working at micro level, capable of providing detailed results on a farm household scale and of capturing heterogeneity across households.

Within this context, the main aim of this report is to present a decision making tool for ex-ante and ex-post assessment of such EU supports and to gain knowledge on food security and rural poverty alleviation in these countries under different policy options. This tool consists of a generic farm household model, called FSSIM-Dev (Farm System Simulator for Developing Countries), which is able to capture key features of developing countries agriculture, to provide detailed disaggregation regarding commodities and technology choices and to smoothly integrate results from biophysical models needed to improve knowledge on land degradation, land resources tenure and use. The term 'generic' here refers to its potential capacity to be re-usable, adaptable and easily extendable to achieve different modelling goals.

Model use is illustrated in this report with an analysis of the micro-economic impacts of both rice support policy and innovative technology/management on the livelihood of farm households in Sierra Leone. The aim is to gain knowledge on farmers' livelihood strategies and to assess the combined effects of input (fertiliser) subsidy policy and improved rice cropping management, using a set of FSSIM-Dev indicators such as land use, supply and demand of basic food commodities, labour use, farm household income and poverty gap. Poverty gap is measured here by the percentage deviation between the extreme poverty line of 1 USD-equivalent per person per day and the farm household income per household unit.

The report is structured as follows: section 2 presents the template of the developed FSSIM-Dev model. Section 3 describes the components and technical implementations of FSSIM-Dev, i.e. the electronic survey, the database and the Graphical User Interface. In section 4, the application of the model to the case of Sierra Leone with relevant policy analysis is dealt with in more detail. In section 5, we conclude on the relevance of this type of modelling framework and stress the added value of our results in comparison with other studies.

1 More details on food security concepts are given in Appendix 2.

2 European Commission (2010): Communication from the Commission to the Council and the European Parliament. An EU policy framework to assist developing countries in addressing food security challenges. SEC(2010)379, COM (2010)127 final, 31.3.2010, Brussels. Available from: http://ec.europa.eu/development/icenter/repository/COMM_PDF_COM_2010_0127_EN.PDF

2. The Bio-Economic Farm Household Model: FSSIM-Dev

2.1. Introduction

Over the last decade, development and use of farm-level models for policy analysis has become one of the major activities of agricultural economists. This growing interest can be attributed to several reasons among them (i) the increasing demand for tools and methods for impact assessment at very disaggregated level; (ii) the better understanding of farm-level decision making; (iii) the high heterogeneity among farms in term of both policy representation (i.e. policies are more and more farm specific) and policy impacts (i.e. policy affects farms and regions differently); and last but not least; (vi) they can be easily handled with standard computer packages, including spreadsheets and more sophisticated packages such as GAMS (General Algebraic Modelling System).

Five approaches are often used for building a farm level model: mathematical programming (MP) (including linear programming (LP), non-linear programming (NLP), mixed integer programming (MIP) and positive mathematical programming (PMP)), econometric approach, simulation approach, agent based model (ABM) and an advanced technique termed by Buysse et al., (2007b) as "econometric-mathematical programming" (EMP). The last approach has not been fully applied yet to policy analysis, mainly because of data availability and numerical solving problems (a first test was done recently by Jansson and Heckelei, 2011 and by Henry de Frahan et al., 2011). Agent based models are applied for case studies but not at a larger geographical scale due to their high data requirement. The choice of one of the five approaches depends often on data availability, model specification and research scope.

Our focus in this study is farm models based on mathematical programming (MP) approach, which consists to optimize (maximize or minimize) one or several objectives under a set of constraints. Farm programming models play a strong role in agricultural policy analysis, particularly where reliable time-series data are absent, or shifts in market institutions, or constraints have changed substantially over time.

The literature review reveals a wide range of farm programming models which investigate different questions at various locations. They can be grouped into two broad categories: (i) farm supply models seeking to describe the decision making process of one (individual or representative) farmer considered as a pure producer or "entrepreneur"; and (ii) farm household model, which combines consumer and producer models into a single model (i.e., the consumer is also the producer), aiming to represent household behaviour. The former are used mainly in developed countries while the latter are applied in rural area or/and developing countries where production and consumption decisions are linked. Within each category, models can be classified into empirical vs. mechanistic, normative vs. positive, static vs. dynamic, deterministic vs. stochastic, discrete vs. continuous, etc. (Janssen and van Ittersum, 2007). As an example of recently published farm supply programming models, we can cite those used for the following purposes: (i) to assess the impact of EU Common Agricultural Policy, e.g. FARMIS (Offermann et al., 2005); Onate et al., 2006; Riesgo and Gomez-Limon, 2006; Semaan et al., 2007; Viaggi et al., 2010; FSSIM (Louhichi et al., 2010); AGRISP (Arfini and Donati, 2011); CAPRI-FT (Gocht and Britz, 2011); (ii) to handle landscape and resource conservation problems, e.g. Bamière et al., 2011; Schuler and Kachele, 2003; FAMOS (Schönhart et al., 2011); (iii) to anticipate farms responses to climate change (Dueri et al., 2007; AROPAj (De Cara and Jayet, 2011), etc.

For farm household programming models, numerous models, mostly applied in Africa and South-America, are described in the literature. The more recent ones are used for simulating the effects of: public goods policies (Sanfo and Gerard, 2012), new energy plants (Bartolini and Viaggi, 2012), HIV/AIDS (Gill, 2010), new technologies (Laborte et al., 2009), alternative deforestation solution (Dolisca et al., 2008), new rice cropping systems (Yiridoe et al., 2006), increasing farm size and mechanization (Van den Berg et al., 2006) and better access to off-farm income (Holden et al., 2004).

However, most of the existing farm models are developed for specific purposes and locations and are not easily adaptable and reusable. A farm model enables to set up assessments for a wide range of farm types differing in (i) resource endowments (land, labour, equipment availability); (ii) production intensity (i.e. output per hectare); (iii) specialisation (arable, livestock, mixed); (iv) biophysical conditions (soil, weather); (v) farm management (organic, conventional, integrated); and (vi) production orientation (market, self-consumption), are scarce. This seems to be due, on the one hand, to the diversity of situations and policy schemes and, on the other hand, to the need of a considerable collaborative effort between scientists, programmers and software engineers to provide a user-friendly, easily-accessible modelling system, a goal that is not easy to reach.

The only published farm models that can be considered as partially generic and potentially extendable and adaptable for different contexts and conditions in the EU and elsewhere are: FSSIM (F*arming System Simulator*), a generic bio-economic farm model developed within the SEAMLESS project (Van Ittersum et al., 2008) and EU-FARMIS (*Farm Group Model for German Agriculture*), a comparative-static farm group model developed by BMELV (Osterburg et al., 2001, Offermann et al., 2005). Nevertheless, both of them are farm supply models and they need adjustments and improvements to correctly represent farm household behaviour in developing countries or/and rural areas.

In this study, we opted for using FSSIM as a starting point, with the aim to develop, based on this model, a generic farm household model that enables ex-ante assessment of agri-food and rural policies on the livelihood of farms/farm households in developing countries. This model is called FSSIM-Dev by reference to FSSIM and to developing countries (Dev).

In order to achieve these objectives, the following improvements and developments are made in the FSSIM model:

- Improvement of the existing FSSIM-MP modules in both methodological and technical aspects (crops, calibration, trend and policy modules);
- Development of new modules to further ameliorate the capability of the FSSIM-MP model to investigate farm-household systems in developing countries (household and perennial modules);
- Development of an up-scaling module for aggregating results at regional/village level, which enables to capture interaction among farm households;
- Development of a more generic policy module that allows parameterization of a wider range of policy instruments;
- Development of a user friendly interface to facilitate the development and use of the model by scientists, model developers and regulatory users;
- Development of an electronic survey for the collection of the required information to ensure model re-usability;
- Development of a straightforward procedure to integrate the outputs of biophysical models (yield and environmental externalities) as inputs in the FSSIM-Dev database.
- Improvement and extension of existing database in order to include information required by the new/modified modules;

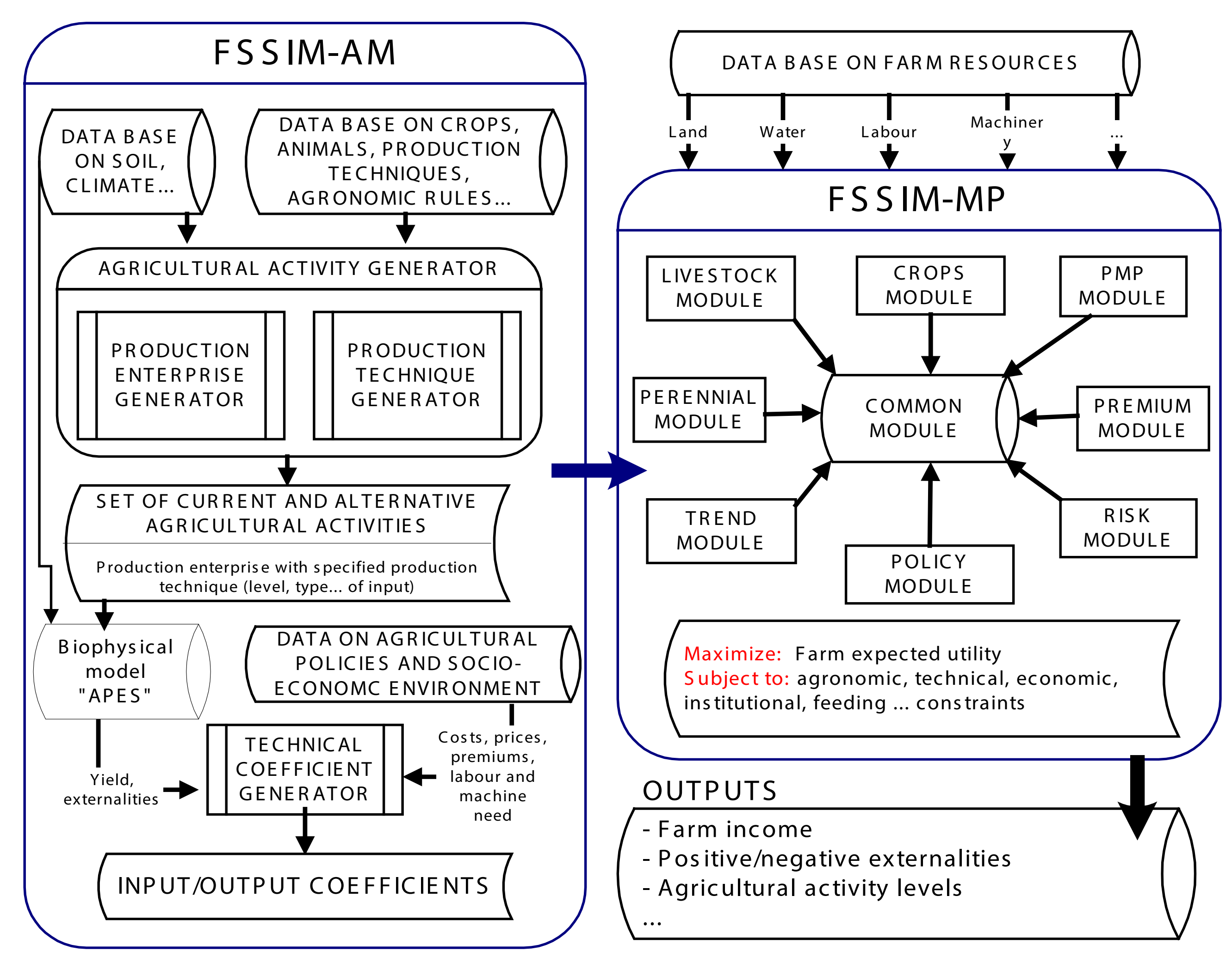
This section gives a detailed description of the extended FSSIM model version (i.e. FSSIM-Dev). It is structured as follows. In section 2.1, an overview of the SEAMLESS FSSIM model is provided. In section 2.2, the background and the aims of FSSIM-Dev is briefly reported. In sections 2.3 and 2.4, the methodologies for calibrating the model and for modelling perennial activities are presented. In section 2.5, the household module used to represent both supply and household decisions is set out. In sections 2.6, the policy and trend modules are described. In the last section, the aggregation module used to upscale results from farm to higher (regional/national) levels is exposed.

2.2. FSSIM, a generic bio-economic farm model

2.2.1. FSSIM specification and components

FSSIM is a bio-economic farm model developed within the SEAMLESS project, to assess the impact of agricultural and environmental policies on the performance of farms and on indicators of sustainability (Louhichi et al., 2010a; Janssen et al., 2010; Louhichi et al., 2010b). It consists of a data module for agricultural management (FSSIM-AM) and a mathematical programming model (FSSIM-MP). FSSIM-AM aims to identify current and alternative activities and to quantify their input and output coefficients (both yields and environmental effects) using the biophysical field model APES (Agricultural Production and Externalities Simulator) and other data sources. Once these activities have been generated, FSSIM-MP chooses those that best fit the farmer's behaviour, given the set of resources, the technological and political constraints, and forecasts farmer responses to new technologies, as well as to policy and market changes (Louhichi et al., 2010a). The principal outputs generated from FSSIM for a specific policy are forecasts on land use, production, input use, farm income and environmental externalities (e.g. nitrogen surplus, nitrate leaching, pesticide use, etc.). These outputs can be used directly or translated into indicators to provide measures of the impact of policies (Figure 1).

Figure 1. FSSIM and its modules



FSSIM was designed sufficiently generic and with a transparent syntaxes in order to be applied to many different farming systems across Europe and elsewhere. It has a modular setup to be re-usable, adaptable and easily extendable to achieve different modelling goals. It includes a set of modules, namely crops, perennial, premium, Positive Mathematical Programming (PMP), risk, trend and policy modules. These modules are solved simultaneously; they are linked indirectly by an integrative module named the "common module" involving the objective function and the common constraints. Thanks to its modularity, FSSIM-MP provides the ability to switch on/off modules (and their corresponding constraints) following the needs of the simulation, to select one or several calibration approaches between different options (risk, standard PMP, Röhm and Dabbert's PMP approach and Kanellopoulos et al. PMP approach) and to control the flow of data between the database and software tools. FSSIM-MP can be run with simple or detailed survey data (i.e. according to the level of detail of the available data). Additionally, it can read input data stored in any database (e.g. MS ACCESS DB), Excel or GAMS-Include files, provided that they are structured in the required format.

FSSIM can be applied to individual (i.e. real) or representative farms (i.e. typical or average farm) as well as to natural (territorial) or administrative region by considering the selected region as a large farm (i.e. if the heterogeneity among farms inside the region is insignificant) or by aggregating the results of individual or representative farms (i.e. if the inter-dependencies between farms are minors). It can be used for two purposes: (i) to allow detailed regional impact assessment of policy decisions, market change and technological innovations on farming practices and sustainability of the different farming systems; (ii) to facilitate the link of micro and macro levels in integrated way through the estimation of supply-response functions that can be integrated in a partial equilibrium market model.

The mathematical programming module of FSSIM (FSSIM-MP) is a constraint optimization model which maximizes an objective function at given prices and subsidies subject to a set of resource and policy constraints. It consists of a non-linear programming model, which maximizes the farm's utility defined as the expected income minus risk, according to the Mean-Standard deviation method (Hazell and Norton, 1986). FSSIM is referred to as a positive mathematical programming (Howitt, 1995a) model which integrates a large number of crop and animal activities.

The main specifications of FSSIM are (Louhichi et al., 2010b):

1 **A static programming model** which optimizes an objective function for one period (i.e. one year) over which decisions are taken. This implies that it does not explicitly take account of time. Nevertheless, to incorporate some temporal effects, agricultural activities are based on "crop rotations3" and "dressed animal4" rather than individual crops and animals.
2 **A positive model** in the sense that its empirical applications exploit the observed behaviour of economic agents to reproduce the observed production situation as precisely as possible;
3 **An activity based model** what means that one product can be produced by different activities[5], and each activity can produce several products. This makes suitable the integrated assessment of new policies which are linked to activity and not to product. This is the case of soil conservation policies in the USA, where all farm subsidies depend on the use of specific agricultural practices. In Europe, the Nitrate Directive is also an example of a policy targeting production processes/activities, not products. This approach makes possible to take into account positive and negative jointness in outputs (i.e. joint production)
4 **A primal based model** where technology is explicitly represented in order to simulate the switch between production techniques as well as between production systems;
5 **A discrete based model** to integrate easily the engineering production functions generated from biophysical models and to account positive and negative jointness in outputs (i.e. joint production) associated with the production process. These specifications enable FSSIM to explore the impacts of policy changes and technological innovation not only on the relationship between market and nonmarket goods, but also on the production process.
6 **A template based model:** FSSIM uses a model template for all the applications, i.e. the equations and variables used in FSSIM are the same but the set of parameters depend on farm data.

3 Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons for various benefits such as to avoid the build-up of pathogens and pests that often occurs when one species is continuously cropped.

4 The concept of 'dressed animal' represents an adult animal and young stock taking into account the replacement rate.

5 An arable activity corresponds to a crop rotation grown under specific soil and climate conditions and under well-defined management describing major field operations in detail.

The general mathematical formulation of FSSIM is presented below:

$$\begin{aligned} &\underset{x\geq 0}{Max}\ U = Z\text{-}\phi\sigma \\ &s.t \\ &Ax \leq b \end{aligned} \qquad (1)$$

Where **U** is the utility function to maximise, **z** is the expected income, **x** is the nx1 vector of the simulated levels of the agricultural activities, ϕ is the risk aversion coefficient, σ is the standard deviation of income due to price and yield variation, **A** is a (n×m) matrix of technical coefficients, and b is a n×1 vector of available resources and upper bounds to the policy constraints.

The farm's expected income is defined as total revenues including sales from agricultural products and compensation payments (subsidies) minus total variable costs from crop and animal production. Total variable costs include accounted linear costs for fertilizers, irrigation water, crop protection, seeds and plant material, animal feed and cost of hired labour as well as unaccounted cost due to management and machinery capacity reflected by the quadratic term of the cost function. Using mathematical notation, the non-linear income function can be presented as follow:

$$Z = p's + p^{a}{}'s^{a} + (sb - a)x \text{ -} d'x \text{ - } 0.5xQx' \qquad (2)$$

Where **Z** is the expected income, **p** is the (n×1) vector of the expected product prices, **s** is the (n×1) vector of simulated sold products, $\mathbf{p^a}$ is the (n×1) vector of additional price that the farmer gets when selling within quota, $\mathbf{s^a}$ is the (n×1) vector of simulated sold products within quota, **x** is the (n×1) vector of the simulated levels of the agricultural activities, **sb** is the (n×1) vector of subsidies, **a** is the (n×1) vector of accounting cost, **d** is the (n×1) vector of the linear part of the activities' implicit cost function and **Q** is the (n×n) matrix of the quadratic part of the activities' implicit cost function.

The accounting costs include costs for fertilizers, crop protection and seeds as well as plant material and cost of hired labour. **Q** and **d** are estimated using a variant of the Positive Mathematical Programming approach which guarantees exact reproduction of activity levels observed in the base year. In principle, any non-linear convex cost function with the required properties can reproduce the base year solution. For simplicity and lacking strong arguments for other type of functions, a quadratic cost function is usually employed.

The standard deviation of income (σ) is calculated according to the following formulation:

$$\sigma = \left(\frac{\sum_k (Zk_k - Z)^2}{\mathrm{N}} \right)^{1/2} \quad (3)$$

Z: expected income

- **Zk_k:** income over states of nature (k). Zk_k is calculated using the same equation applied for calculating the expected income Z (i.e. equation (4)). The unique difference is that the average producer price (p) and the average yield (y) are replaced, respectively, by the producer price (p_k) and the yield (y_k) over state of nature (k). p_k and y_k are vectors of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price and yield). Due to data missing, we assumed that there is no dependence between yield and price variation (i.e. no covariance). This assumption could be improved if more data are available.
- **N** is the number of states of nature

FSSIM has been applied for different climate zones and soil types and to a range of different farm types with different specializations, intensities and sizes. In most applications FSSIM has been used to assess the effects of policy changes (Louhichi et al., 2010a; Kanellopoulos et al., 2009; Mouratiadou et al., 2010) and to assess the impact of technological innovations (Belhouchette et al., 2011). In the various applications, different data sources, level of detail and model configurations have been used. The model is available for applications to other conditions and research issues, and it is available to be further tested and to be extended with new components, indicators or linkages to other models.

2.2.2. Brief overview on main FSSIM modules

FSSIM consists of 9 modules. The core module is the Common module that connects all the other modules, i.e. Crops module, Livestock module, Perennial module, PMP module, Premium module, Risk module, Policy module and Trend module. The three most important modules of FSSIM developed for Europe are shortly described here: Crops, Livestock and Common modules. The explanation concerning the other modules can be found in Louhichi et al., (2010a) and Janssen et al., (2010).

2.2.2.1. Crops module

In FSSIM, crop activities are defined as crop rotations6 grown under specific soil and climate conditions and under well-defined management describing major field operations in detail. It is assumed that in each year, all crops of a given rotation are grown on equal shares of the land. The concept of crop rotations allows accounting for temporal interactions between crops. The agricultural management of arable activities describes operations associated with fertilization, soil preparation, sowing, harvesting, irrigation and pest management of crops and results in different inputs and outputs. To quantify the amount of inputs and outputs (e.g. costs, labour requirements, input of agrochemicals, yields, externalities) associated to each crop activity, a simple survey is used completed by data generated from the agricultural management component (FSSIM-AM) and the biophysical model.

The selection of optimal crop activities is subjected to a set of technical, agronomic, institutional constraints. Among these constraints which are implemented in the crops module, the farm resource (mainly land and water) constraints used to match the available resources that can be used in a production operation and the possible uses made of it by the different activities. Two land constraints are retained - total and irrigable lands - and each land constraint is specified by soil type (or agri-environmental zone). The same generic rule is applied in all of these constraints: for each farm resource (f), the sum of the resource requirements of the selected crop activities in each farm cannot exceed initial available resource (B).

$$\sum_i A_{i,f} x_{h,i} \leq B_f \quad (4)$$

where:

- **f** indexes production factors (i.e. farm resources)
- **i** indexes agricultural activities
- **A** is a matrix of production factor requirements (i.e. resource use coefficients)
- **B** is a vector of initial available factors (i.e. resources availability)
- **x** is a vector of agricultural activity levels (i.e. x is a decisional variable)

In addition to these constraints, the crops module includes two equations for computing expected crop income (without premiums) and crop income over states of nature. The expected crop income is defined as total revenues from selling crop products minus accounting costs for fertilizers, irrigation water, crop protection, seeds and plant material. The income over state of nature is calculated in the same way as expected income but instead of using the average price and the average yield we use the price and the yield over state of nature.

2.2.2.2. Livestock module

Three different animal activities are modelled in FSSIM, i.e. dairy, beef, and small ruminants (sheep and goats). To represent livestock activity the concept of 'dressed animal' (DA) is used which represents a productive animal and a

6 Agricultural activities can be based on individual crops (i.e. mono-crop rotations) if data on crop rotations are not availability.

share of young animals. That is, all the animal categories of the same "family" are regrouped together under a dressed animal component, assuming a fixed herd size. Several dressed animals can be considered, depending on the livestock activities undertaken (e.g. dairy, beef) and production intensity level (lower, medium or high), and taking into account the link between intensity level and replacement and fertility rates. In the case of dairy activity, one dressed animal may comprise a productive cow, a bull and their off-springs. A replacement rate is based on the actual milk production per cow and sets the share of young animals in a dairy activity i.e. calves and heifers. For example, a typical dairy activity in Flevoland (The Netherland) may consist of 60.5% cows, 17.5% heifers, 20.8% calves and 1.2% bulls. Increasing the activity level by 1 unit will cause an increase in the number of all animals so that the share of animals in the activity remains constant. Beef activities are modelled in a similar way. Two distinct methods of raising animals for beef production are available i.e. a suckler system comprising a cow and its offspring, and a fattening system, which merely fattens purchased young animals till the moment of selling. The small ruminant activities for meat and milk production are modelled in a way similar to dairy and beef activities. The milk and meat production is used to determine an appropriate replacement rate and the feed requirements of different animals (Thorne et al., 2009).

The modelling of livestock activities has required imposing some constraints which are implemented in the livestock module. The first constraint specifies that the feed requirements of the herd in terms of fibre, energy and protein have to be covered by roughage produced on farm (fresh, hay or silage), purchased roughage (hay or silage), concentrates produced on-farm or purchased concentrates. Feed crops like grass and fodder maize are grown either in a rotation with other crops or as mono-crop activities. The quantities of on-farm produced and purchased feed depend mainly on prices of crop product (including feed) and input prices.

$$\sum_{J} u_J v_{J,nut} + \sum_{sf} pf_{sf,\mathrm{nut}} v_{sf,nut} \geq \sum_{\mathrm{i}} x_{\mathrm{i}} A_{nut,i} \qquad (5)$$

where

- **nut**: indexes nutrient term, such as energy (UF) and protein (PDI)
- **sf**: indexes the set of purchased supplement feed.
- **V**: nutrient value of the feed produced *j* for on-farm use (grass, fodder and crop products) as well as of the purchased feed expressed in term of protein and energy per t DM.
- **pf**: quantity of purchased supplement feed (t DM).
- **u** is a vector of on-farm used production (t DM)
- **A:** feed requirement per livestock activity (i.e. dressed animal, intensity level, and production system) expressed in term of energy and protein. This requirement is calculated taking into account requirements for maintenance, milk production, growth, gestation period, and grazing/moving.
- **X:** level of the selected livestock activity i (in head)

Three other feed restrictions are implemented: (i) fill unit distributed should be lower or equal to intake capacity; (ii) the share of concentrates in animal diets expressed in energy term is bounded to a maximum; (iii) an upper bound for feed availability from grazing is also imposed.

The last constraint limits the animal population to the livestock building capacity which depends on the initial farm building availability and the investment in new building. The livestock building enlargement depends on farm investment capacity and on animal requirement for building:

$$\sum_{\mathrm{i}} \mathrm{x}_{\mathrm{i}} . A_{Build',i} \leq \mathrm{B}_{\mathrm{'Build'}} + N_{'Build'} \qquad (6)$$

- **X**: level of the selected animal activities i (in head)
- **A**: animal requirement for building (m2/head)
- **B**: initial building availability (m2)
- **N**: investment in new building (m2)

As in the crops module, two equations for computing expected livestock income (without premiums) and livestock income over states of nature are included in the livestock module.

2.2.2.3. Common module

The common module involves the FSSIM objective function as well as a set of constraints linking between different modules. The objective function is based on the expected incomes (without premiums) from arable crops, perennial crops and animal activities computed on crops, perennial and livestock modules, respectively, plus the amount of premiums computed in the premium module, minus the PMP terms and risk component calculated in PMP and risk modules, respectively.

A part from the risk equation used to compute the standard deviation of income, three constraints are developed in the common module: labour, equipment and quota constraints. The first two constraints, which are very similar to land and water constraints developed in the crops module, specify that the sum of requirement for selected crop and livestock activities in labour and equipment, expressed in hour, should be less than the amount of initial labour and equipment available in the farm. The quota restriction states that for all quoted products ($Quota_{prd,l} \neq 0$), the sales within quota cannot exceed the quota level.

$$q^{a}_{j,l} \leq Quota_{j,l} \qquad (7)$$

- **j** indexes agricultural (crop or animal) products
- **l** indexes quota types (e.g. for sugar it's A and B)
- **q^a** is a vector of sold production within quota
- **Quota** is a vector of quota level

2.3. FSSIM-Dev: background and aims

Despite its strong relevance in both conceptual and technical terms (e.g. generic and modular setup, explicit representation of technology), the FSSIM model presents some limitations for representing farm-household behaviour in developing countries or/and rural areas.

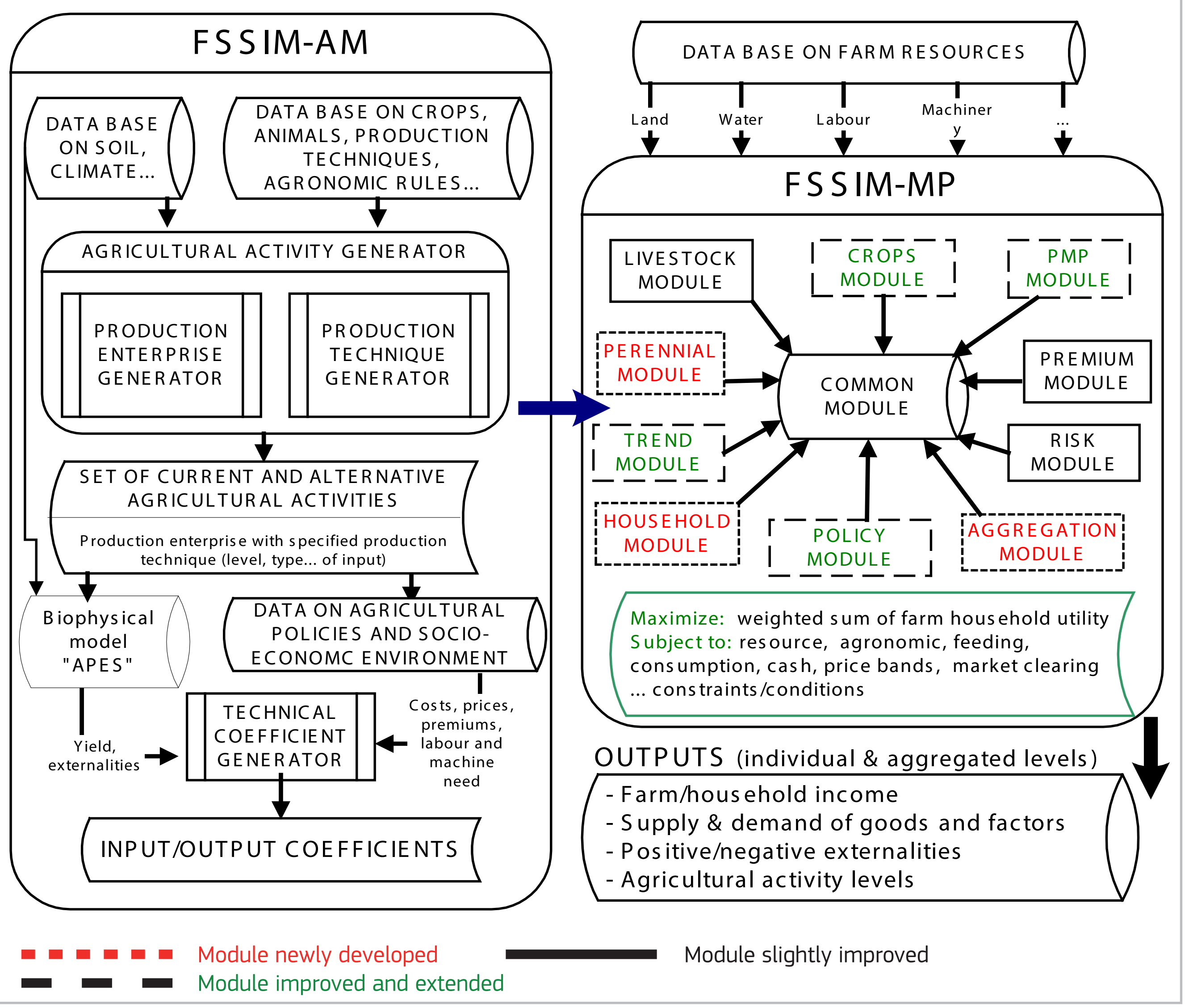
The first limitation is that since it is based on farm production theory, an approach which recognizes that production, labour allocation and consumption decisions are separable, it is not suitable for rural areas where these decisions are interdependent (i.e. non-separable). The existence of such non-separability indicates, in fact, the presence of market imperfections or failures that may have important policy implication. In such case, a farm household approach might be necessary depending on whether the good for which market fails is important in production (Singh et al., 1986).

The send limitation is that land markets, possibilities for off-farm labour, and structural changes are exogenously defined. The model independently simulates the behaviour of each farm, so it does not endogenously capture the interaction among farms for market factors, which are very important in rural areas.

The third limitation is related to the simulation of perennial activities. In FSSIM, perennial activities are introduced in an extremely simplified way, as constant surfaces with an annual cost. This means that the age structure of plantations as well as the different costs and economic returns associated to the period of development of specific species can not be taken into account with the FSSIM model.

The fourth limitation is its incapability to represent farmer behaviour with respect to production activities that are not observed during the reference period, commonly referred to as a self-selection problem.

Figure 2. FSSIM-Dev and its modules



The last limitation is related to the trend and policy modules. This part of the FSSIM model has been developed and specified for European context and cannot directly be used for local agri-food policies in developing countries.

To overcome these limitations, a significant number of improvements and extensions were made in FSSIM-Dev such as the development of household, perennial and up-scaling modules, the improvement of the calibration module with sound methods, and the extension of the trend and policy modules (Figure 2). Moreover, taking into account the ambition of a generic tool, all the modifications are integrated in a manner that respects existing model architecture and allows the switching on/off modules according to data availability and application type. This means that the resulting model is not a specialized model, applicable to specific condition but, rather, a model which can be applied to any relevant farm-household systems in developing countries.

Further in the next sections the newly developed and improved modules of FSSIM-Dev, mentioned above, are described in detail, namely: crops module, perennial module, household module, up-scaling module, calibration module, trend and policy modules.

2.4. Crops module: improvement of the resource constraint

The main improvements of the FSSIM crop module are related to the extension of resource constraint for modelling the seasonality of farming activities and resource use as well of the labour skills.

2.4.1. Modelling seasonality

Most of cropping activities are seasonal and are confined to periods of the year when temperature and rainfall are conducive to plan growth. Within cropping seasons, cultural operations are also performed in set sequences, and most of these have to be performed within a relatively short period of time (e.g. sowing is usually performed in one or two days within a field so that the crop will grow and ripen eventually). These characteristics of farming lead to distinct seasonal patterns in resource use and available supplies of production factors such as labour and equipments (Hazell and Norton, 1986). Unfortunately in FSSIM, the seasonality of cropping activities and resource use are not explicitly considered. In fact, resources are constraining only at annual level, which means that if a resource is limiting in certain seasons within the year, it cannot be captured with this kind of model. To take this into account, we have adopted a generic formulation in which the resource requirement (i.e. demand) and availability (i.e. supply) can be defined either by year or by season within the year according to context and data availability. This is performed using two new parameters dr and da which represent, respectively, the distribution over the seasons of annual resource requirement and annual resource availability.

According to this new specification, the resource constraint becomes the following:

$$\sum_{i} A_{i,f}\, dr_{i,f,se}\, x_i \leq B_f\, da_{f,se} \qquad (8)$$

- **f** indexes production factors (land, labour, water and equipments)
- **i** indexes agricultural activities
- **se** indexes seasons (the number and the length of seasons will be decided by user according to region specification and data availability. A season could be for example one month).
- **A** is a (m x n) matrix of annual production factor requirements (i.e. demand) for each crop/animal within agricultural activity *i* (we assume a common matrix for entire farms within the region)
- **B** is (n×1) vector of annual production factor availability
- $\mathbf{dr}_{i,f,se}$ represents *distribution* over seasons of annual production factor *requirements* (i.e. demand)
- $\mathbf{da}_{f,se}$ represents *distribution* over seasons of annual production factor *availability* (i.e. supply)

If only one season was retained it means that the resource constraint is defined at annual level and the coefficients *dr* and *da* are equal to one (*dr* = 1; *da* = 1) and if it is more than one season the constraint is working at seasonal level and the coefficients dr and da are less than one (dr <1; da < 1).

2.4.2. Modelling labour skills

Differences in labour skills are also commonly recognized in farm models because not all workers are equally capable of performing some tasks. For example, only some of the workers may have tractor driving skills. Another example arises in parts of Africa and Asia where tradition requires that some tasks must be performed by female (e.g. planting paddy). In the same line, children may be able to do some specific tasks such as bird scaring from the crops or to help in undertaking basic field operations.

In order to incorporate labour skills in the FSSIM-Dev model we opt for a generic formulation based on two new parameters: the first one represents the distribution of seasonal labour requirement over task (i.e. planting, scaring birds…) and over labour types (men, women and children) and the second one represents the distribution of seasonal labour availability over labour type.

According to this new specification, the labour resource constraint *(i.e. f = labour)* becomes the following:

$$\sum_{i,ta} A_{i,f}\, dr_{i,f,se}\, dl_{f,se,la,ta}\, x_i \leq B_f\, da_{f,se}\, dl_{f,se,la} \qquad (9)$$

- **la** indexes labour types (men, women, children)
- **ta** indexes task types (i.e. planting, scaring birds...)
- **f** indexes production factors
- **i** indexes agricultural activities
- **se** indexes seasons
- **A** is a (m x n) matrix of annual production factor requirements (i.e. demand) for each crop/animal within agricultural activity *i*
- **B** is (n×1) vector of annual production factor availability
- $\mathbf{dr}_{i,f,se}$ represents distribution over seasons of annual production factor requirements (i.e. demand)
- $\mathbf{da}_{f,se}$ represents distribution over seasons of annual production factor availability (i.e. supply)
- $\mathbf{dl}_{f,se,m,ta}$ represents distribution of seasonal labour requirement over task and labour types

2.5. Calibration module: improvement and extension

FSSIM is used to represent farmer decision making assuming that production, labour allocation and consumption decisions are separable. To reproduce this decision two calibration methods were applied: the risk or/and the Positive Mathematical Programming (PMP) approach. The first approach calibrates the model approximately and the latter calibrates it exactly exploiting the observed farmer's behaviour. Three PMP approaches, which can be selected by user according to data availability, are implemented in FSSIM: (i) the standard PMP approach (Howitt, 1995a); (ii) the Röhm and Dabbert's PMP approach (2003); and (iii) the Kanellopoulos et al.'s PMP approach (2009).

In FSSIM-Dev, the calibration process is strongly improved by using a generic procedure to switch between different PMP approaches (standard, Röhm and Dabbert, Kanellopoulos) as well as between PMP variants (standard, average cost, almost-linear,...) but also by implementing more robust PMP methods (Maximum Entropy criterion) based on estimation procedure, which are very useful when multiple data points are available.

The other improvement is that these PMP approaches are not only used to calibrate the farm supply decision under fixed farm limiting resources, as it has been done within the FSSIM, but to calibrate simultaneously the supply and consumption decisions of the farm household under fixed and variable farm limiting resources (i.e. at farm household and aggregated levels).

The following section describes these entire PMP approaches using stylized mathematical notation. For an easier understanding, these approaches are performed for individual farm model and assuming fixed farm resources.

2.5.1. The risk approach

Most of the risk methods assume that a non-correspondence between simulated and observed results means one of these two factors: (i) omission of some important element of the cost structure, such as specialized management skills in growing high-value vegetable; (ii) inadequate specification of the crops' riskiness and farmer' risk aversion (Hazell and Norton, 1986). Since it is difficult to estimate adequately this last factor without rich data set, the more common used way is to parameterize the model for different values of risk aversion and then to choose the value of the parameter that gives fit between the model's predicted crop allocation and the observed values (i.e. the risk aversion coefficient is used to partially calibrate the model). The difference between both values is assessed statistically by using the Percent Absolute Deviation[7] (PAD).

The main weakness of the risk approach is that it cannot calibrate the model exactly, but rather accepting a residual deviation between simulation and reality. Another problem that appears in this case relates to defining how credible the model is and determining the level of confidence that can be placed on model predictions. There is no consensus on the statistic measure to be used in evaluating the fit of predictions, but in most cases simple measures, such as the mean absolute deviation (MAD) or the percentage absolute deviation (PAD), are used. In addition, clearly and objectively defined threshold values of the different measures that determine acceptance or rejection of a model do not seem to be available in the literature. In FSSIM, we have adopted Hazell and Norton's suggestion which shows that a Percent Absolute Deviation (PAD) for production and acreage below 10% is good, equal to 5% is exceptional and more than 15% indicates that the model may need improvement before it can be used.

2.5.2. The Positive Mathematical Programming (PMP) approach8

2.5.2.1. Reminder on PMP

The PMP approach was developed to calibrate linear programming models of agricultural supply and to overcome their common problems: overspecialization and jumpy behaviour. The basic idea behind PMP is that, a divergence between model's prediction and observed farmer behaviour means that both technical constraints and cost (or yield) specification were not taken into account, and so they had to be estimated using additional information from observed activity levels and included in the objective function through

7 Percent absolute deviation: $PAD\ (\%) = \frac{\sum_{i=1}^{n} \left| \hat{X}_i - X_i \right|}{\sum_{i=1}^{n} \hat{X}_i} .100$

Where is the observed value of the variable i and X_i is the simulated value (the model prediction). The best calibration is reached when PAD is close to 0.

8 For a review of PMP models see Henry de Frahan et al. (2007), Paris (2011) and Heckelei et al. (2012).

a nonlinear cost (or/and production) function (Howitt, 1995a). The main advantages of the PMP specification are not only the automatic and exact calibration of optimization models, but also the smoothness of the model responses to policy changes and the possibility to make use of very few data to model agricultural policies (Röhm and Dabbert, 2003).

The original PMP approach developed by Howitt (1995a) involves three steps: calibration, estimation and simulation.

Calibration: consists of writing an LP model as usual but adding to the set of limiting resource constraints a set of calibration constraints that bind the activities to the observed levels of the base year period. The sole purpose of this phase is to obtain an accurate and consistent measure of the vector of dual values associated with the calibration constraints, but as pointed out by Heckelei and Wolff (2003) this phase can be integrated in the estimation phase by means of Lagrangean multipliers (Howitt, 1995a). Heckelei and Britz (2005) interpret this vector as capturing any type of model miss-specification, data errors, wrong or lacking representation of risk behaviour, unobserved production costs, missing technology information, aggregation bias, etc.

$$\begin{aligned} &\text{Max } Z = p'y'x - c'x \\ &\text{s.t} \\ &Ax \le B[\rho] \\ &x \le x^{\circ}(1+\varepsilon)[\lambda] \\ &x \ge 0 \end{aligned} \qquad (10)$$

Where ***Z*** is the objective function value, **x** and **c** are (n x 1) vectors of non-negative activity levels, and accounting costs per unit of activity, respectively, **p** and **y** are (1 x 1) vectors of expected output prices and yield per activity, respectively**.** **A** represents an (m x n) matrix of coefficients in resource constraints, **B** and ρ are (m x 1) vectors of resource availability and their corresponding shadow prices. The (n x 1) **x°** non-negative vector of observed activity levels, ε is an (n x 1) vector of small positive numbers for preventing linear dependency between the structural and the calibration constraints, and **λ** is an (n x 1) vector of duals associated with the calibration constraints.

Estimation*:* consists of employing the dual values **λ** delivered by the first phase to specify additional non-linear terms in the objective function which allows reproducing the observed activity levels without calibration constraints. These terms mostly refer to increasing marginal cost or/and a decreasing marginal yields (Howitt, 1995a). That is, both yield and cost changes are probably present; however, data on yield variability are more easily obtained by an empirical modeller than cost variation. A frequent case considers calibrating the parameters of a variable cost function **C(x)**, such that the 'variable marginal' cost **MC** of the activities is equal to the sum of the known cost **c** and the 'non-specified' marginal cost **λ.** In case of a quadratic function form[9], the following condition for calibration is implied:

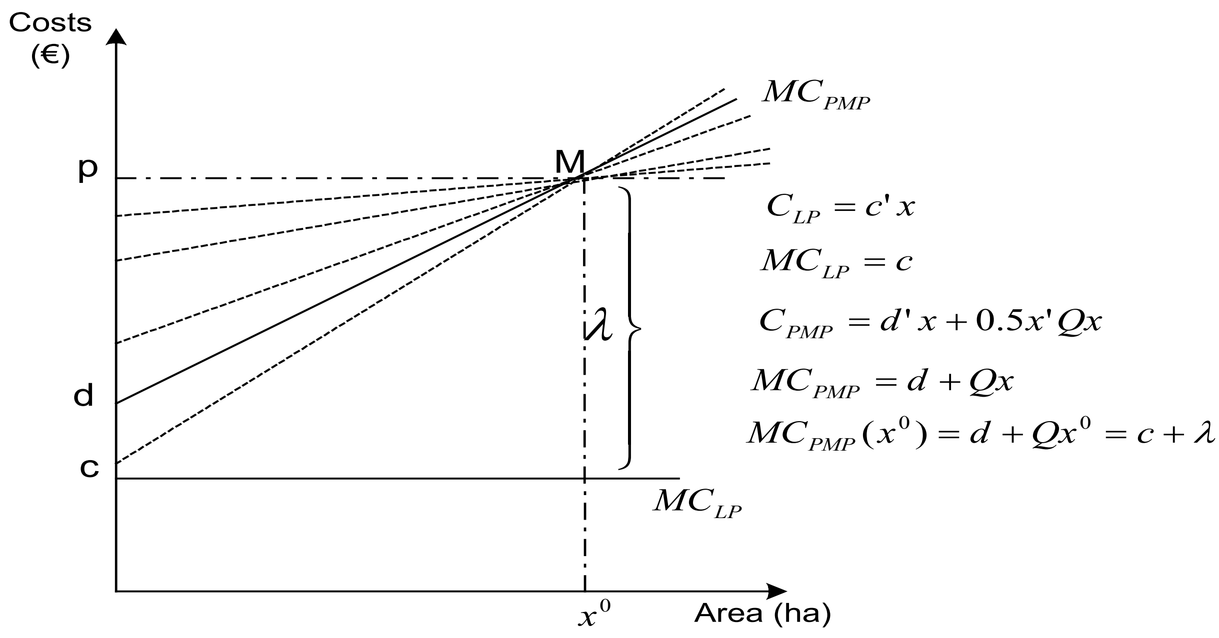
$$\begin{aligned} &C = d'x + 0.5x'Qx \\ &MC = \frac{\partial C^{v}(x)}{\partial x} = d + Q x^{o} = c + \lambda \end{aligned} \qquad (11)$$

Where **MC** is the vector of marginal costs, **d** is an (n x 1) vector of parameters of the cost function and **Q** is an (n x n) symmetric, positive (semi-) matrix, **c** is the vector of observed variable costs per unit of activity, **λ** are dual variables associated with the calibration constraints and **x°** is the vector of observed activity levels.

To solve the undermined system (11) with *N* equations and *[N+(N+1)/2*] parameters, the literature suggests many solutions which include simple *ad hoc* procedures with some parameters set a priori (Howitt, 1995a; Röhm and Dabbert, 2003), the use of supply elasticities (Helming et al., 2001), the direct derivation of the unknown parameters from the Kuhn-Tucker conditions (Judez et al., 2001), and the employment of maximum entropy criterion (Paris and Howitt, 1998; Heckelei and Britz, 2000; Paris and Arfini, 2000). All these PMP methods would exactly calibrate the initial model as long as equations (11) are verified, but lead to different simulation responses to external changes. That is, any marginal cost curve passing through the point M would be able to calibrate the model (Figure 3), meaning that there an infinite number of parameter values for **d** and **Q** which satisfy the specification conditions (11).

9 Other functional forms are possible. The generalized Leontief and the weighted-entropy variable cost function (Paris and Howitt, 1998) and the constant elasticity of substitution (CES) production function (Howitt, 1995b) in addition to the constant elasticity of transformation production function (Graindorge *et al.*, 2001) have also been used.

Figure 3. Calibration by Positive Mathematical Programming



The differences between the most known PMP approaches are summarised in the following section. They can be divided in two groups: PMP based on a single observation and PMP based on multiple observations. PMP methods based on a single observation described below are the following: the standard PMP approach, the Röhm and Dabbert's PMP approach, the Kanellopoulos et al.' s PMP approach and the Helming et al.' s PMP approach; while, PMP methods based on multiple observations are the Maximum Entropy-PMP approaches proposed by Heckelei and Britz (2000) and Paris and Arfini (2000). Except the Helming et al.'s PMP approach, all the other approaches are implemented in FSSIM-Dev to be selected by user according to data availability.

Simulation: in this last step, the calibration constraints of the first stage are removed and the estimated non-linear terms (cost (production) function) in stage two are added to the PL objective function in order to calibrate the model exactly to the observed situation. The obtained PMP model is ready for simulation.

$$\begin{aligned} &\max_{x \geq 0} \; Z = p'y'x - d'x - 0.5x'Qx \\ &\text{s.t} \\ &Ax \leq B \; [\rho] \end{aligned} \qquad (12)$$

2.5.2.2. PMP approaches based on a single observation

As explained above, the number of available observations is usually not enough to allow estimation of the undermined system (11) through traditional econometric procedure. In fact, just one observation is often available and, in many cases, no exogenous additional data that can be mobilised. Due to this data restriction, most of the existing PMP approaches have assumed that the symmetric matrix **Q** is diagonal (i.e. all off-diagonal elements of **Q** are set to zero) and calculated the remaining parameters using ad hoc assumption. The implicit assumption that off-diagonal elements are zero means that cross-activity relationships are ignored. Among these approaches, three particular ones have been retained and implemented in the FSSIM-Dev: the standard PMP approach, the Röhm and Dabbert's PMP approach and the Kanellopoulos et al.'s PMP approach. Within each approach, user can choose between various PMP variants based on different weights of the linear and the non-linear cost functions. A detailed description of these approaches is given below.

Another approach based on single observation and use exogenous information on supply elasticities was proposed by Helming et al. (2001). This approach is also described below, however is not implemented in FSSIM-Dev as it can be easily substituted by the Maximum Entropy-PMP approach presented further.

The standard PMP approach by Howitt (1995a)

The standard PMP approach is the original one developed by Howitt in 1995. In this approach, the ill-problem (11) is solved by equating **d** to **c** ($d_i = c_i$) and setting the diagonal elements of **Q** matrix as:

$$Q_{ii} = \lambda_i / x_i^0 \quad \forall i$$

From the standard approach, a set of PMP variants have been proposed in the recent years such as:

- The "average cost" PMP variant: in this variant the proposed solution equates the accounting cost vector **c** to the average cost of the quadratic cost function, which produces:

$$d_i = c_i - \lambda_i \text{ and } Q_{ii} = 2\lambda_i / x_i^0 \quad \forall i$$

- The "almost-linear" PMP variant: this variant assumes a very small value for the non-linear terms **Q**. It consists of retrieving a large share of the dual value l from the non-linear term and adding it to the linear term **d** such as:

$$d_i = c_i + 0.98\lambda_i \text{ and } Q_{ii} = 0.02\lambda_i / x_i^0 \quad \forall i$$

- In the same line, Heckelei (1997) suggests to set the linear cost term **d** to zero (di = 0) and calculating the diagonal elements **Q** as follow:

$$Q_{ii} = (c_i + \lambda_i) / x_i^0 \quad \forall i$$

The common formula for all these *ad hoc* PMP variants can be represented as follow:

$$d_i = c_i + \lambda_i - \alpha|\lambda_i| \text{ and } Q_{ii} = \alpha|\lambda_i| / x_i^0 \quad \forall i \quad (13)$$

Where α is an (n x 1) vector of parameters that determines the weights of the linear and the non-linear costs of activities. The larger the value of α, the less sensitive the model becomes to price changes. Inversely, a lower value of α implies a small increase in marginal costs and the model behave almost as a linear programming. A larger value of α can result in a negative intercept of the marginal cost function.

This common formula was implemented in FSSIM-Dev in order to facilitate the switch between the different *ad hoc* PMP variants by simply changing the value of α.

While being an appealing method for calibration, the original PMP has shown shortcomings in model calibration that, in turn, motivated further developments.

- One of these shortcomings discussed at several occasions in the literature is the unequal treatment of the marginal and preferable activities (i.e. the problems of zero-marginal product (cost) for one of the calibrating constraints) (Paris and Howitt, 2001). Because the differential marginal costs of the marginal activities captured by the dual vector λ are zero, the marginal costs of supplying these activities are independent of their levels while those of supplying the preferable activities are not under the average cost approach of calibration. For these marginal activities, calibrated marginal costs are equal to average costs and marginal profits are equal to average profits.
- The second shortcoming is the missing representation of economic behaviours with regard to activities of farms whose initial observed supply level is zero during the reference period (i.e. self-selection problem).
- The third standard PMP shortcoming pointed out by Röhm and Dabbert (2003) is the inclusion of greater competitiveness among close competitive activities whose requirements for limiting resources are more similar than with other activities.

Due to these limitations and others, a number of Positive Mathematical Programming (PMP) methods have been developed in the recent years. Some of them are described below.

The Röhm and Dabbert's PMP approach

In the original PMP approach, the parameters of the cost function for each crop are recovered separately from each other. In this way, the same crop grown under different variants (e.g. different agro-managements) are considered as two separate crops. Consequently, in the simulation phase substitution among these crops is lower than expected. Röhm and Dabbert (2003) propose a different modelling approach to take into account the higher elasticity of substitution between different variants than between different crops. For example, a reduction of payments for an agri-environmental measure (e.g. cover crop after wheat) will probably lead to a decline of adoption of this management measure. The land under this management is more likely to be allocated to the same crop (e.g. conventionally produced wheat) than to a different crop (e.g. corn). Such an adjustment is facilitated by including in the first step of PMP a set of additional calibration constraints which restricts the level of each crop and variant to its observed level.

Let's denotes **i** the set of crops and **v** the set of variants, the first PMP step according to this approach can be written as follow:

$$\begin{aligned}
&\max_{x \geq 0} Z = \sum_i \sum_v p_{iv} y_{iv} x_{iv} - c_{iv} x_{iv} \\
&\text{s.t} \\
&\sum_i \sum_v a_{ivj} x_{iv} \leq b_j \; [\rho_j] \\
&\sum_v x_{iv} \leq \sum_v x_{iv}^0 (1+\varepsilon_1) \; [\lambda_i] \\
&x_{iv} \leq x_{iv}^0 (1+\varepsilon_2) \; [\lambda'_{iv}]
\end{aligned} \quad (14)$$

Where Z is the objective function value, $\mathbf{x}_{iv}$ and $\mathbf{c}_{iv}$ are (n x 1) vectors of non-negative activity (i.e. combination of crop *i* and variant *v*) levels, and accounting costs per unit of activity, respectively, $\mathbf{p}_{iv}$, and $\mathbf{y}_{iv}$ are (1 x 1) vectors of expected output prices and yield per activity, respectively. $\mathbf{A}_{ivj}$ represents an (m x n) matrix of coefficients in resource constraints, $\mathbf{b}_j$ and ρ_j are (m x 1) vectors of resource availability and their corresponding shadow prices. The (n x 1) $\mathbf{x}_{iv}^{o}$ non-negative vector of observed activity levels, and ε_1 and ε_2 are (n x 1) vectors of small positive numbers ($\varepsilon_1 < \varepsilon_2$) and $\boldsymbol{\lambda}$ and $\boldsymbol{\lambda}'$ are (n x 1) vectors of duals associated with calibration constraints. The first calibration constraint is related to crop specified by variant type and the second one is related to crop.

The generated dual values $\boldsymbol{\lambda}$ and $\boldsymbol{\lambda}'$ from (7) are then used to estimate the parameters of the cost function which satisfy the following conditions.

$$c_{iv} + \lambda_i + \lambda'_{iv} = \mathrm{d}_{iv} + Q'_{iv}\, x^0_{iv} + Q_i \sum_v x^0_{iv} \qquad (15)$$

As shown in equation (8), Röhm and Dabbert (2003) divide the slope of the cost function of each crop into two parts, one for crop and other for variant.

As in the PMP standard approach, multiple sets of cost function parameters can satisfy the marginality conditions and one of these sets suggested by authors would be the following:

$$\begin{aligned} d_{iv} &= c_{iv} \\ Q'_{iviv} &= \lambda'_{iv} \big/ x^0_{iv} \\ Q_{ii} &= \lambda_i \Big/ \sum_v x^0_{iv} \end{aligned} \qquad (16)$$

A more generic formula can be represented as follow:

$$\begin{aligned} \mathrm{d}_{iv} &= c_{iv} + \lambda'_{iv} + \lambda_i - \alpha' \left| \lambda'_{iv} \right| - \alpha \left| \lambda_i \right| \\ Q'_{iviv} &= \alpha' \left| \lambda'_{iv} \right| \big/ x^0_{iv} \\ Q_{ii} &= \alpha \left| \lambda_i \right| \Big/ \sum_v x^0_{iv} \end{aligned} \qquad (17)$$

Where α and α' are (n x 1) vectors of parameters that determines the weights of the linear and the non-linear costs.

The final non-linear model according to this approach can be written in the following way:

$$\begin{aligned} & Max\ Z = \sum_i \sum_v p_{iv} y_{iv} \text{-} d_{iv} x_{iv} - 0.5 Q'_{iv} x^2_{iv} - 0.5 Q_i x^2_{iv} \\ & s.t \\ & \sum_i \sum_v a_{ivj} x_{iv} \le b_j \\ & x_{iv} \ge 0 \end{aligned} \qquad (18)$$

This approach seems the more appropriate for calibrating FSSIM because both are based on activity (i.e. combination of crop and variant) rather than crops (i.e. products). However, the implementation of this approach requires data on observed level per activity which are often unavailable.

The PMP approaches using exogenous information

In order to handle the problems of zero-marginal cost for marginal activities and avoid arbitrary parameter specifications, some PMP approaches have proposed the use of exogenous information on supply responses or on shadow prices of resources. Among these approaches we can cite:

- A first solution proposed by Helming et al. in 2001 which consist of using exogenous own-price supply elasticities for deriving the parameters of the quadratic cost function according to the following procedure:

Marginal revenue = marginal variable cost + marginal opportunity cost

(19)

$$r_i = c_i + d_i + Q_{ii} x_i + \sum_m \rho_m a_{im}$$

$$\varepsilon_i = \frac{\partial x_i}{\partial r_i} \frac{r_i}{x_i} \Leftrightarrow \frac{1}{\varepsilon_i} = \frac{\partial r_i}{\partial x_i} \frac{x_i}{r_i} = \frac{\partial (c_i + d_i + Q_i x_i + \sum \rho_m A_{im})}{\partial x_i} \frac{x_i}{r_i}$$

$$\text{Assuming}: \frac{\partial \rho_m}{\partial x} \approx 0$$

$$\frac{1}{\varepsilon_i} = Q_i \frac{x_i}{r_i} = Q_i \frac{x_i}{r_i} \Rightarrow \begin{cases} Q_i = r_i \big/ \varepsilon_i x^0_i \\ d_i = c_i + \lambda_i - Q_i x^0_i \end{cases}$$

The main limitation of this approach is that it assumes an insensitive marginal opportunity cost to land change (i.e. myopic approach), which can leads sometimes to significant differences between estimated and used elasticities. However, the idea of using supply elasticities to calibrate model parameters was rapidly increased and most of applications today rely on exogenous information on supply elasticities or on shadow prices of resources (Heckelei et al., 2012). This approach is not implemented in FSSIM-Dev as if data on supply elasticities exist it would be better to apply the Maximum Entropy-PMP approach presented further by using these elasticities as prior.

- A second approach proposed by Kanellopoulos et al. (2010) and implemented in FSSIM-Dev is based on the use of the land rental values to estimate the non-linear cost term of marginal activity. This is achieved by (i) adding the costs of rented land in the objective function; (ii) replacing the resource constraint of the available land with a flexible constraint where land is decision variable; and (iii) including a second set of calibration constraints (more details are given in Kanellopoulos et al., 2010).

$$\begin{aligned}
&\max_{x\geq 0} Z = p'y'x - c'x - gl \\
&\text{s.t} \\
&Ax \leq b\,[\rho] \quad \forall j \neq \text{ land} \\
&x \leq l \\
&x_i \leq x_i^0(1+\varepsilon)\,[\lambda 1] \\
&x_i \geq x_i^0(1-\varepsilon)\,[\lambda 2]
\end{aligned} \tag{20}$$

Where, **g** denotes the average gross margin and **l** the rented land in ha. The first calibration constraint is related to activities that result in gross margins higher than the average gross margin and the second one is related to activities that result in gross margins lower than the average gross margin (ε).

As in the PMP standard approach, the dual values λ1 and λ2 are used to estimate the linear and the non-linear PMP terms of the cost function according to the following formalism.

$$\begin{aligned}
&d_i = c_i + (\lambda 1_i + \lambda 2_i) - \alpha \left| \lambda 1_i + \lambda 2_i \right| \quad \forall i \\
&Q_{ii} = \alpha \left| \lambda 1_i + \lambda 2_i \right| / x_i^0
\end{aligned} \tag{21}$$

- Another *ad hoc* approach was discussed on Röhm and Dabbert (2003) but rarely used consists of retrieving some share of one limiting resource dual value ρ and adding it to the calibration dual vector λ to obtain a modified calibration dual vector for both marginal and preferable activities.

Discussion on PMP with a single observation

All the PMP approaches presented above use a single observation and go without any type of estimation by setting all off-diagonal elements of Q to zero and calculating the remaining parameters using some ad hoc assumptions or exogenous information. These specifications became, nevertheless, strongly disputable over the last years. The use of just one observation generates models that might not be robust and leads to an arbitrary specification of the objective function's parameters. As reminded by Heckelei and Britz (2005), when very little information is available, the recovered parameters might be inconsistent and the reproduction of supply responses might be unrealistic.

Moreover, the assumption of diagonal Q is also unrealistic. This assumption implies that there is no substitution or complementarity cost effects between production activities carried out in the same region or farm. However, the practice of rotations in crop production, for example, indicates that farmers are well aware of the interdependencies among crops and use them to stabilize or increase profits.

To overcome these problems; Paris and Howitt (1998) suggest using multiple observations and more robust estimation methods such as Maximum Entropy. Multiple observations mean here several years of data (time series) or several farm data pooled together. However, PMP with large farm-level datasets but without any estimation procedure will only make use of a single data point and imposes considerable structure on the technology as embodied in the cost function (Henry de Frahan, 2005). Inversely, PMP with single data and with estimation procedure will leads to same results as standard PMP approach.

2.5.2.3. PMP approaches based on multiple observation

In order to reduce the arbitrary behaviour of the model and to estimate more reliable cost functions covering all the parameters, several economists have suggested using large number of observations with an estimation procedure.

A literature review shows the existing of a set of PMP approaches which use estimation procedure and cross-sectional data for the specification of non-linear cost functions. Foremost among these approaches are: (i) the Maximum entropy (ME)-PMP approach proposed by Paris and Howitt (1998) and extended by Heckelei and Britz (2000); and (ii) the Maximum entropy (ME)-PMP approach suggested by Paris and Arfini (2000). Both approaches are PMP based because they use the first step where the shadow values are derived from a linear programming model. These two approaches are implemented in FSSIM-Dev and can be used when considering several years of data or when the data on several farms can be pooled together.

The Maximum Entropy-PMP approach by Heckelei and Britz (2000)

To recover all the parameters of the cost function and to capture the possible interactions among the various activities, Paris and Howitt (1998) suggested using the Maximum Entropy (ME) criterion10. ME approach has been mainly used to overcome two empirical problems that hamper traditional econometrics for parameter estimation: multi-collinearity and ill-posed problems (i.e. when the number of parameters to estimate is greater than the number of observations). This approach allows empirical specification and estimation of underdetermined models as well as inclusion of prior knowledge in a technically straightforward way, making estimates potentially more efficient (Jansson, 2007). Moreover, it has the potential of incorporating more than one observation on activity levels into the specification of the parameters. The principal limitation of Maximum Entropy is the definition of support points for the unknown parameters (i.e. **d** and **Q**).

Paris and Howitt (1998) have demonstrated how to recover cost functions from very limited data sets using a ME estimator. They re-parameterize the **Q** matrix based on LDL' (Cholesky) decomposition to ensure appropriate curvature properties of the estimated cost functions. This estimator in combination with PMP enables to calibrate a quadratic variable cost function accommodating complementarities and competitiveness among activities still based on a single observation but using a priori information on support bounds. However, according to Heckelei and Britz (2000), using maximum entropy with only one observation is not an improvement over the standard PMP approach. That is, without any additional information such as a full matrix of supply elasticities, the behavioural simulation of the resulting calibrated model would be still arbitrary because heavily dominated by the support points for the unknown parameters. They propose a ME extension which makes it possible to use more than one cross sectional framework and to define prior directly on Q (and not on the elements of a LDL' decomposition of Q as proposed by Paris and Howitt 1998). They obtain a greater successful ex-post validation than using the standard "single observation" maximum entropy approach. This extension was used to calibrate the cost functions of the regional activity supplies of the Common Agricultural Policy Regional Impact (CAPRI) modelling system (Heckelei and Britz, 2001).

The adaptation of this approach to farm model such as FSSIM-Dev can be described as follow:

The marginal cost of the f-th farm can be represented by the following equation:

$$\mathrm{MC_f} = \mathrm{d_f} + \mathrm{Q_f x_f^0} \quad = \lambda_\mathrm{f} + \mathrm{c_f} \qquad \forall \mathrm{x}^0 > 0 \qquad (22)$$

Where Q_f represents a (n×n) matrix of the quadratic part of the activities' implicit cost function in farm *f* and it is equal to:

$$Q_f = (cpi_f)^g S_f B S_f^{'} \qquad (23)$$

where $\boldsymbol{cpi_f}$ stands for a farm "*crop profitability index*" defined as the relation between the farm and average regional revenue per hectare $cpi_f = (p' y_f / L_f) / (\sum_f p' y_f / \sum_f L_f)$

where *p* denotes the (n×1) vector of price, *y* represents the (n×1) vector of crop yield in farm *f*, and *L* is the total arable land in farm *f*. The parameter $\boldsymbol{g}$ is the exponent of crop profitability index to be estimated, $\boldsymbol{S_f}$ constitutes the (n×n) diagonal *scaling matrices* for each farm *f*, and it is given by,

$S_{f,i,i} = \sqrt{1/x_{f,i}^0}$ and finally $\boldsymbol{B}$ is a (n×n) parameter matrix related to $\boldsymbol{Q_f}$. The matrix B- common across farms inside the same region is estimated as to describe the differences in marginal costs depending on the differences in levels (Heckelei and Britz, 2000).

To stress the effect of *scaling mechanism*, Heckelei and Britz (2000) give an example for two farms with identical total area but different shares of crop land. According to the example, assume that there is 10 ha increase in the acreage of a crop. If the total acreage of this crop in farm one is 1 ha, and 100 hectares in farm two prior to the change of the acreage, then 10 hectare increase in the acreage of this crop would imply 1000 percent relative increase for the first farm but only 10 percent for the second farm. Hence, the scaling of B matrix assures the same marginal cost increases in both farms for the same percentage increase in crop acreage. Using this scaling mechanism it is possible to take into account this difference in the calculation of marginal costs depending on the differences in crop acreage for different farms.

10 The definition of entropy as information measure is due to Shannon (1948) and after Janes (1957) introduces the maximum entropy principle in order to obtain probability distribution that is consistent with the available information (cited by Golan et al. 1996).

The general formulation of the corresponding ME problem is as follows:

$$\max H(pd,pb,pg) = -\sum_f\sum_k\sum_i pd_{fki}\ln pd_{fki} - \sum_k\sum_i\sum_j pb_{kij}\ln pb_{kij} - \sum_k pg_k \ln pg_k \qquad (24)$$

Subject to:

Data-consistency constraints

$$\lambda_{fi} + c_{fi} = d_{fi} + (cpi_f)^g \sum_j s_{fii} b_{ij} s_{fij} x_i^0 \quad \forall f,i,j,x^0 > 0$$

$$d_{fi} = \sum_k pd_{fki} zd_{fki} \quad \forall f,i$$

$$b_{ij} = \sum_k pb_{kij} zb_{kij} \quad \forall i,j$$

$$g = \sum_k pg_k zg_k$$

Adding-up or normalization constraints

$$\sum_k pb_{kij} = 1 \quad \forall i,j$$

$$\sum_k pd_{fki} = 1 \quad \forall f,i$$

$$\sum_k pg_k = 1$$

Curvature restrictions

$$b_{ij} = b_{ji} \quad \forall i,j$$

$$l_{ii} = \sqrt{b_{ii} - \sum_h l_{ih}^2} \quad \forall i$$

$$l_{ij} = \frac{b_{ij} - \sum_h l_{ih} l_{jh}}{l_{ii}} \quad \forall i,j \text{ and } j > i$$

Non-negativity conditions

$$l_{ii} \geq 0; \quad pb_{kij} \geq 0; \; pd_{fki} \geq 0 \; ; pg_k \geq 0$$

where *i* and *j* index crop activities, $\boldsymbol{d_f}$ is a (n×1) vector of the linear part of the activities' implicit cost function in farm *f*, $\boldsymbol{Q_f}$ represents a (n×n) matrix of the quadratic part of the activities' implicit cost function in farm *f*, $\boldsymbol{S_f}$ constitutes the (n×n) diagonal scaling matrices for each farm *f*, and finally ***B*** is a (n×n) parameter matrix related to $\boldsymbol{Q_f}$ ***zd, zb*** *and* ***zg*** are the support points for the unknown parameters ***d,*** the exponent of crop profitability index ***g*** and the matrix ***B***, respectively.

The three equations (18.8; 18.9; 18.10) are known as *curvature restrictions* and they result from a classic Cholesky decomposition of the form **B = L.L'.** They are included in order to guarantee that a positive (semi) definite matrix *B* and consequently positive (semi) definite matrices ***Q*** will be recovered. A violated curvature property might result in a specification of the objective function that does not calibrate to the base year, since in this case only first order but not second order conditions for a maximum are satisfied at the observed activity levels (Heckelei and Britz, 2000).

To define the number of support points for the unknown parameters **d** and **Q**, their centre (i.e. *a priori* expectation), their bounds and their spacing, Heckelei and Britz (2000) have taken the following assumption:

- for the linear terms **d**, 5 support points (i.e., K=5) are also chosen, centred around the observed costs and ranged between ± 90 times the regional average in revenue per hectare:

$$zd = c + (-90,-30,0,+30,+90)\sum_f p'y_f / \sum_f L_f$$

p denotes the (n×1) vector of price, ***y*** represents the (n×1) vector of crop yield in farm *f*, and ***L*** is the total arable land in farm *f*.

- for the **B** matrix, the support values are suggested to be defined as follows:

$$zb_{ij} = zbs_{ij} amc_{ij}$$

Where

$$zbs_{ij} = \begin{cases} (0.001, 3.33, 0, 6.66, 10) & \forall i = j \\ (-2, -2/3, 0, +2/3, +2) & \forall i \neq j \end{cases}$$

$$amc_{ij} = \tfrac{1}{2}(MC_i + MC_j)$$

MC represents the land weighted average of marginal cost for activity *i* across farms.

As explained above, this approach allows estimating a full matrix for all the observed activities in each farm type, but not for the unobserved (not produced) activities: this is the self-selection problem mentioned previously. This leads to two further problems. First, the cost function must accommodate true zeroes. Second, it is necessary for simulation that the parameters of the cost function are estimated for all the outputs for all the farms in the sample.

The Maximum Entropy-PMP approach by Paris and Arfini (2000)

Paris and Arfini (2000) have proposed an extended PMP approach which is very useful for calibrating farm model based on cross-sectional data. They use Maximum Entropy (it should be considered that Ordinary Least Squares (OLS) method can also be used for such estimation) for estimating an overall cost function associated with a whole Technical Economic Orientation (frontier cost); each farm in the sample therefore being characterized by the same cost function and a ***u*** errors vector able to reflect its distance from the cost frontier. This means that the sample farms are assumed to operate under a common technology.

The data-consistency constraints of this ME-PMP model can be specified as follows:

$$\bar{\lambda} + \bar{c} = Q\bar{x}^0$$

$$\lambda_f + c_f = Qx_f^0 + u_f \quad \forall x^0 > 0$$

$$\lambda_f + c_f \leq Qx_f^0 + u_f \quad \forall x^0 = 0$$

$$Q = LL'$$

$$\sum_f u_f = 0$$

Where ($\bar{\lambda}+\bar{c}$) is the vector of marginal cost for the entire sample in each region, ***u*** is the error term representing deviations from the cost frontier, ***x⁰*** is the observed production levels, and $\boldsymbol{Q_f}$ represents the (n×n) symmetric and positive matrix which is common across farms inside the same region. The two last equations respectively require (i) the necessary conditions for the Cholesky factorization; and (ii) the sum of the ***u*** errors is equal to zero.

With this approach the total variable cost for the f-th farm is stated as $c(x_f)=u'_f x_f+0.5x'_f Qx_f$, while the corresponding cost function for the entire sample in each region is $c(x)=0.5x'Qx$.

The estimated frontier cost function will allows overcoming the self-selection problem (i.e. unobserved activities) during the simulation step.

Discussion on PMP with multiple data points

The use of multiple cross-sectional observations in combination with PMP and an estimation procedure constitutes one of the successful PMP extensions. In fact, these approaches allow overcoming most of the well known original PMP problems such as the unequal treatment of the marginal and preferable activities, the self-selection problem, the under-determined system, the lack of cross-activity relationships. However, Heckelei and Wolff (2003) have explained that PMP is not well suited to the estimation of programming models that use multiple cross-sectional or chronological observations. They show that the shadow prices of resource constraints derived from the linear model is expected to be different from the one implied by the non-linear model which is assumed to represent farmer behaviour. They argue that the second stage of the standard PMP uses these "apparently" wrong values at the observed activity levels through enforcement of the marginal cost equations, thereby implicitly imposing biased values for the estimation of the marginal cost as well. To avoid inconsistency between steps 1 and 3, they suggest to skip the first step altogether and employ directly the optimality conditions of the desired programming model to estimate simultaneously shadow prices and parameters without using dual values on calibration constraints. Their examples deal with the estimation of the parameters of various optimisation models that (1) incorporate a quadratic cost function and only one constraint on land availability, (2) allocate variable and fixed inputs to production activities represented by activity-specific production functions or (3) allocate fixed inputs to production activities represented by activity-specific profit functions (Henry de Frahan, 2005).

As stated by their authors, this alternative approach to PMP has some theoretical advantage over the original PMP for the estimation of programming models. It also has some empirical advantage over standard econometric procedures for the estimation of more complex models characterized by more flexible functional forms and more constraints as well as the incorporation of additional constraints relevant for simulation purpose.

Despite its attractiveness, this approach has been rarely applied to policy analysis, mainly because of data availability and numerical solving problems. The only application at farm level was done at the best of our knowledge by Buysse et al. (2007a) to analyse the reform of the Common Market Organization in the EU's sugar sector. They use a sample of 117 Belgian sugar beet farms across 9 years to estimate parameters of a cost function quadratic in activity levels by employing GME on the first order conditions of the farm programming models. Jansson and Heckelei (2011) have developed recently a larger application but working at regional and not at farm level. They estimate the parameters of 217 regional programming models with 23 crop production activities for the EU using Bayesian highest posterior density estimator. However, in these two applications and in order to render the estimation exercise feasible, authors assume that constraints are binding for all observations.

2.5.3. Conclusion

This section described the set of calibration approaches that are implemented in FSSIM-Dev to be selected by user according to data availability and modeller conviction on risk/PMP approaches. Some of these approaches are complementary and others are rather substitutable. All the implemented PMP approaches and variants guarantee exact calibration of supply decision at farm and aggregated levels taking into account the trade of factors among farms. Nevertheless, different approach can produce different results when they are used to predict the future behaviour of the farmer. To assist user on selecting the suitable approach for his/her specific context, we suggest, first, to check the available dataset (single or multiple data; exists or not prior information; observed data is specified by products or by agricultural activities…) and, then, to select the corresponding one according to the description given above. In the case when different approaches can be applied to the same data set, the only solution to select the more efficient one will be through an ex-post validation or a sensitivity analysis. Along this same line, a sensitivity analysis procedure was implemented within FSSIM-Dev to be used for comparing model behaviour under different calibration approaches. In this sensitivity analysis, we run some simulations based on 10 % increases of single product prices and we calculate the percentage change in supply related to this price change. The estimated point elasticities can, then, be compared with comparable estimations from literature.

2.6. Investment and perennial activities module

This section presents the modelling approach for perennial activities and investments in the FSSIM-Dev model. The approach builds on the general theory of agent behaviour, namely that farmers adjust to a risky and changing environment making sequential decisions at several timescales: a) Intra-seasonal decisions on input use; b) Yearly decisions on cropland allocation to annual crops; and c) Long-run decisions on perennial crops, machinery and other investments.

Modelling farmers' behaviour requires taking into account the interdependencies between production and investment decisions on one hand and the dynamic structure of the production process on the other hand. Ideally, these investment and dynamic decisions should be modelled dynamically. Nevertheless, since FSSIM-Dev is a comparative static model, we have chosen to frame the dynamic decision issues into a static modelling framework. The only difference compared to an approach using a dynamic model performing inter-temporal optimisation is that the results do not show the path of development in time, but only the initial and the final situation. However, given the high level of uncertainty associated to each of the steps represented in dynamic models, the complexity of a model performing inter-temporal optimisation is rarely justified in practical terms.

Some dynamic features can be easily incorporated in a static framework. This is the case when adjustment costs are relatively low. Assuming that farmers can yearly adjust production decisions without incurring additional major costs, these decisions can be modelled as essentially static decisions. Following this reasoning, a steady state approach has been adopted for modelling crop rotations and livestock activities in FSSIM.

On the contrary, in the case of fruit production, adjustment of land-use decisions involves rather high costs. Perennial production is a dynamic process, characterised by significant establishment costs, long gestation periods and interrelated production and investment decisions. Moreover, investment in tree-crops entails high sunk costs, as the resale price of the plantation is close to zero. Because of the high sunk costs associated to tree-crop investments, current decisions are largely influenced by past decisions and have effects on future ones. Given the relatively long lifetime of perennial crops, adopting a steady state approach will give the response of perennial producers to changes in incentives in the long-run. As a result, different approaches may be used to model tree-crop activities depending on the horizon of the analysis:

- In the short term, we assume a constant area for perennial crops, that is, no land competition between annual and perennial crops are depicted.
- In the long term, we adopt a steady state approach, allowing for adjustments in the area allocated to perennial activities and, therefore, modelling the competition for land between annual and perennial crops.
- In the medium term, an innovative modelling approach is used to take into consideration sunk cost and adjustment cost effects of investment decisions. This modelling framework provides the mid-term response of perennial producers to changes in incentives. Basically, we make a distinction between the existing stock of perennial crops and new plantations in terms of input-output coefficients.

Hereafter a brief review of the economic literature on investment modelling is given, with a focus on farmer investment behaviour and tree-crop investments. Next, the suggested approaches to model perennial activities in the short, medium and long run are presented. Finally, the perennial module as it is integrated in FSSIM-Dev is described.

2.6.1. Review of investment modelling approaches

2.6.1.1. Modelling farmer investment behaviour

Contributions to modelling investment behaviour are modest compared to those in other areas of farm behaviour. The underlying principle of the optimal inter-temporal investment theory is the adjustment cost hypothesis which is based on the premise that, in the short run, decision makers incur costs in adjusting to changes in economic conditions (Arrow, 1982). The adjustment problem faced by farmers is often attributed to asset fixity in agriculture, which is defined in terms of the divergence between acquisition price and salvage value of durable assets (Hsu and Chang, 1990). A number of works recognize the importance of accounting for adjustment costs in modelling investment decisions (Lucas, 1967; Epstein, 1981).

Apart from asset fixity and adjustment costs, the literature on investment behaviour has focused on related topics, such as risk and uncertainty, technical change and imperfect credit markets.

Investment behaviour under irreversibility and uncertainty has received much attention in recent economic literature (Dixit and Pindyck, 1994; Abel and Eberly, 1994). As stated by Dixit and Pindyck (1994), a decision to invest made now will imply changes in the set of future potential decisions. They introduce into the analysis the option to postpone decisions until more information is available. This investment theory focuses in the value of waiting for more information and the resulting delay in investments, which can be especially important for irreversible decisions.

Irreversibility is often tied up with the concept of sunk costs, which by definition are non recoverable. Irreversibility occurs when technology for replacing an investment does not exit (technical irreversibility) or when reversibility is technically feasible but at a so high cost that becomes economically non-optimal (economic irreversibility). In the case of perennial production, economic irreversibility happens because restoration costs are very high (reversing land to the original pre-planting situation in order to allow for changes in land use is very costly).

Other approaches have also been used to analyse investment decisions under irreversibility. Abel and Eberly (1994) introduce an augmented adjustment-cost function that includes traditional convex adjustment costs, as well as the possibility of sunk costs. Chavas (1994) examine production and investment decisions under sunk costs and temporal uncertainty. The model integrates production and investment decisions with entry-exit decisions.

Most of above mentioned studies use econometric approaches. Regarding mathematical programming approaches, regional and sector models often neglect investment decisions. Most regional and sector models adopt a static representation of output supply, adopting steady-state specifications for livestock, perennial crops and other investment decisions. One of the few exceptions is the work from Alig et al. (1998), who build a dynamic sector model linking the agricultural and forestry sectors in the United States.

At the farm level, however, many dynamic optimisation models have been built. Dynamic optimisation techniques are often used to analyse farm investment decisions such as machinery replacement, livestock activities or investment on irrigation technology (Abalu, 1975; Kennedy, 1986; Hu et al., 1992).

2.6.1.2. Tree-crop modelling in the economic literature

Economic models addressing decisions on the mix of annual and perennial crops are scarce in the economic literature. Most studies on tree-crop modelling deal only with perennial crops.

The production of perennial crops involves time dimensions not similarly found in annual crops. Among the specificities of perennial crop production, we highlight: 1) a long biological lag between planting and first bearing; and 2) an uneven distribution of yields over the life of the tree, usually increasing until reaching maturation, rather still during the full production period and decreasing afterwards.

Most research on perennial crop supply is related to individual perennial crops. Early studies either rely on time series data to estimate behavioural functions (French and Matthews, 1971) or on linear programming techniques (Dean and De Benedictis, 1964).

Starting from the work of French and Mathews (1971), a number of papers analyse the supply response of perennial crops taking into account planting and removal relationships (French et al., 1985; Akiyama and Trivedi, 1987; Hartley et al., 1987). Most of these studies focus on the influence of market conditions and price anticipations on perennial crop supply response but fail to consider the investment nature of perennial production decisions.

However, tree planting decisions are inherently dynamic processes. Therefore, they are better viewed from an investment perspective. Unlike barley or other annual crops, tree-crops require significant establishment costs and have long gestation periods. While farmers can replace annual crops costly from one year to the other, removing and replacing tree-crops with other crops require a significant amount of resources and effort. In short, tree-crops are fairly irreversible investments. This fact has important implications for farm cropland allocation, since it reduces farm flexibility to react to changing technological, economic or institutional conditions.

Several authors adopt the Dixit and Pindyck framework for assessing investment decisions in perennial crops (Price and Wetzstein, 1999). The real option value can be identified either by dynamic programming or contingent claim analysis. Most applications of this approach use the contingent claim analysis because it does not require the knowledge of risk and time preferences of producers. Price and Wetzstein (1999) use an irreversible sunk-cost investment model for analysing optimal entry and exit thresholds for peach production.

While some dynamic optimisation models deal with perennial crops, they usually do not model land allocation mechanisms between annual and perennial crops. For instance, Teague and Lee (1988) developed a linear programming model for analysing perennial crop decisions under different capital constraints.

Attempts to model the mix of annual and perennial crops are very rare in the economic literature. At the farm level, we can mention the two-stage stochastic model developed by Marques et al. (2005). They consider a first stage for "perennial" decisions and a second stage for "annual" decisions. However, in this model, only long-run perennial decisions are modelled and then, the model gives the optimal long-run solution.

In summary, a number of studies analyse in great detail perennial production decisions, using either econometric or optimisation techniques, but integrated models that take into account the interdependence between perennial and other land-use options are still lacking.

2.6.2. Modelling the mix of annual and perennial crops

2.6.2.1. The perennial module in FSSIM-Dev

We will use a stylized mathematical notation to illustrate the approach selected to model perennial activities in FSSIM-Dev. Assume that we want to model the mix of annual and perennial activities in a joint mathematical programming framework. Denote *i* the set of annual activities and *j* the set of perennial activities, the mathematical programming model can be formulated:

$$\text{Max} \quad Z = \sum_j r_j X_j + \sum_k r_k X_k \qquad \text{(Objetive function)}$$

$$s.t. \quad \sum_j X_j + \sum_k X_k \leq l \qquad \text{(Land constrain)}$$

$$\sum_j a_{ij} X_j + \sum_k a_{ik} X_k \leq b_i \qquad \text{(Other constraints)}$$

$$X_j \geq 0 ; \quad X_k \geq 0 \qquad \text{(non-negativity conditions}$$

where X_j area allocated to annual crop *j*

X_k area allocated to perennial crop *k*

r_j net return associated to annual crop *j*

r_k net return associated to perennial crop *k*

l total land availability

b_i availability of resource *i*

a_{ij} input requirements associated to annual crop *j*

a_{ik} input requirements associated to perennial crop *k*

The major factors affecting the desired level of production of each commodity are expected profitability of this commodity and expected profitability of alternative land uses. Given that some farm resources are limited, decisions on annual and permanent crops are made jointly. The modelling approach will depend on the time frame of the analysis.

2.6.2.2. Short-term modelling of tree-crop activities

In the short-run, land allocated to perennial activities would be fixed to the existing capacity in the base year:

$$X_k = X_k^0 \qquad \forall\, k$$

Given the age structure of the existing plantation, costs and revenues associated to each perennial activity can be calculated. In the short-run, given that the tree-crop area is fixed, the supply response of perennials is quite small. However, farmers usually adjust crop production depending on economic and institutional conditions. If we want to take into account the possibility of adjusting decisions on permanent crops, we need to consider not only short-term decisions but also long-run decisions.

2.6.2.3. Long-term modelling of tree-crop activities

In the long-run, decisions on the mix of annual and perennial crops can be simulated in a multi period framework. In that case, understanding planting and replanting decisions over time is important to model the long-run response of perennial producers. In a multi period framework, decisions on new planting and replanting are modelled in an explicit way. The model gives the optimal adjustment path through time and there is no need to assume that the stock of trees will ever attain equilibrium.

Nevertheless, under some specific conditions, a steady-state solution could be reached after some time. Once the steady-state solution has been reached, the optimal cropland allocation does not change over time and then the replacement rate remains constant. As a result, in the long-run, land allocated to perennial activities would be fixed to the steady-state situation:

$$X_k = X_k^s \qquad \forall\, k$$

Assuming that the steady-state solution could be reached in a reasonable time frame, the perennial activities can be accommodated in a static framework in a similar way to annual activities, by considering annualized costs and revenues. Tree-crops do not yield a uniform stream of output over their economic lifetime, nor do they have uniform input requirements. Therefore, profitability of tree-crops should be measured through the net present value.

Denoting n_k the economic lifespan of the k^{th} tree-crop, t the age of the tree-crop, d the discount factor, $R_{k,t}$ the revenue associated to the k^{th} tree-crop with age t and $C_{k,t}$ the associated cost, the net present value is given by:

$$NPV_k = \sum_{t=1}^{n_k} d^{t-1} (R_{k,t} - C_{k,t})$$

The net present value gives an indication about the profitability of the tree-crop activity through its lifetime. In order to compare activities with unequal lifespan, the equivalent annual value (EAV) should be used:

$$EAV_k = \frac{NPV_k}{\sum_{t=1}^{n_k} d^{t-1}} = \rho_k \; NPV_k$$

$$\rho_k = \begin{cases} \dfrac{1}{n_k} & \text{when} \quad d = 1 \\ \dfrac{1-d}{1-d^{n_k}} & \text{when} \quad 0 < d < 1 \end{cases}$$

The equivalent annual value can be used for both annual and perennial activities. In this way, we can model tree-crop activities and annual activities in a joint framework. The resulting model will give the long-run response.

The steady-state solution gives the optimal stock of productive trees, taking into account that for each hectare of productive trees there will be a percentage of young non-bearing trees necessary to maintain the productive stock through time.

However, given the extent of the gestation period and the long lifespan of most perennial crops, reaching the steady-state would take a rather long time. As a result, for most modelling purposes, the steady-state solution might be unrealistic.

2.6.2.4. Medium-term modelling of tree-crop activities

In the case we are interested in modelling tree-crop activities in the medium term, previous approaches might not be satisfactory: short-run approaches do not allow for any flexibility in tree-crop decisions and long-run approaches might be too unrealistic.

Looking for an intermediate solution, we suggest modifying the steady-state approach to allow taking into consideration possible effects linked to the irreversible nature of investment decisions. Tree-crop planting decisions are typical long-run decisions, but farmers can adjust previous investment decisions on a yearly basis. Therefore, the idea is to consider the potential adjustment decisions that farmers can choose for perennial activities at any given moment of time. Assuming initial steady-state equilibrium, these decisions can be summed up in the following four adjustment strategies:

- Maintenance of the existing plantation: the initial steady-state situation is kept by replacing old trees (replacement rate fixed to the initial steady-state rate).
- Decline of the plantation area: existing trees are kept until the end of the lifespan but old trees are not replaced (zero replacement rate), so plantation area will gradually decrease through time.
- Removal of the plantation area: some trees are removed before the end of their economic lifetime in order to allocate land to other activities. Hence plantation area will abruptly decrease.
- Growth of the plantation area: planting new trees will increase the area allocated to perennial crops (a steady-state situation is assumed for new plantings).

The farmer can choose a combination of these four strategies, that is, he/she can for instance decide to replace old trees in a share of the initial plantation area and not to replace in the rest. As a result, both the total land allocated to the perennial crop and the age structure of the plantation can change over time.

This modelling framework would enable to take into consideration sunk cost and adjustment cost effects of investment decisions, allowing for more flexibility in tree-crop related decisions and providing a mid-term response of perennial producers to changes in incentives.

One way to incorporate these adjustment options in a static model would be to define a “mixed perennial activity” from these four adjustment strategies (activities in the perennial module). This “mixed perennial activity” (X_k) – defined (by the model) as a perennial crop with a given age structure – can enter the model in the same way as for annual activities.

Denoting rr the replacement rate and δ the depreciation rate, and n_k the economic lifespan of the k^{th} tree-crop, it follows that the steady-state rate will be:

$$rr^s = \delta = \frac{1}{n_k}$$

L being the time lag between the base year and the baseline in the model, the following additional equations are needed to account for these four adjustment strategies:

Equation (1) $X_k = x_k^0 + X_k^g - X_k^r \qquad \forall\, k$

Equation (2) $X_k^m + X_k^d + X_k^r = x_k^0 \qquad \forall\, k$

Equation (3) $X_k^r = X_k^d * L_k * \delta_k \qquad \forall\, k$

where X_k total area allocated to tree-crop *j*

x^0_k existing plantation area in the base year

X^m_k area of the "plantation maintenance" activity

X^d_k area of the "plantation decline" activity

X^r_k area of the "plantation removal" activity

X^g_k area of the "plantation growth" activity

Equation (1) points out that the area allocated to perennial crops can be maintained (constant replacement rate), can decrease because old trees are not replaced (replacement rate equals zero), or can increase because new trees are planted (reducing the area allocated to annual crops).

As for equation (2), it specifies the relationship between initial area and area kept in the baseline. Equation (3) depicts tree removal when old trees are not replaced.

Input-output coefficients for each perennial activity (plantation maintenance, plantation decline, plantation growth and plantation removal) can be determined taking into account the corresponding age structure of the activity. For instance, denoting by a_{ikt} the requirement of input *i* for tree-crop *k* of age *t*, the input requirements for the "maintenance activity" (a_{ik}^m) will be:

$$a_{i,k}^m = \frac{1}{n_k}\sum_{t=1}^{n_k} a_{i,k,t}^m$$

Given that the age structure of the "mixed perennial activity" can change over time, the resulting input-output coefficients will depend upon the adjustment decisions taken.

The equivalent annual value (EAV) can be formulated as the difference between the equivalent annual revenue (EAR) and the equivalent annual cost (EAC). Accounting for the equivalent annual revenue (EAR) and the equivalent annual cost (EAC) for each perennial activity (plantation maintenance, plantation decline, plantation growth and plantation removal) also requires taking into consideration the corresponding age structure of the activity.

Cost and revenue calculation for plantation maintenance (superscript m)

$$EAC_k^m = \rho_k^m \sum_{t=1}^{n_k} d^{t-1}\, C_{k,t}^m \;;\; EAR_k^m = \rho_k^m \sum_{t=1}^{n_k} d^{t-1}\, R_{k,t}^m$$

Similarly, for plantation decline (superscript d)

$$EAC_k^d = \rho_k^d \sum_{t=1}^{n_k-1} d^{t-1}\, C_{k,t}^d \;;\; EAR_k^d = \rho_k^d \sum_{t=1}^{n_k-1} d^{t-1}\, R_{k,t}^d$$

Plantation growth (superscript g)

$$EAC_k^g = \rho_k^g \sum_{t=1}^{n_j} d^{t-1}\, C_{k,t}^g \;;\; EAR_k^g = \rho_k^g \sum_{t=1}^{n_k} d^{t-1}\, R_{k,t}^g$$

Plantation removal (superscript r)

$$EAC_k^r = C_{k,t}^r$$

The equivalent annual factors can be expressed:

$$\rho_k^m = \rho_k^g = \frac{1}{\sum_{t=1}^{n_k} d^{t-1}} \;;\; \rho_k^d = \frac{1}{\sum_{t=1}^{n_k-1} d^{t-1}}$$

This modelling framework enables making a distinction between existing tree stock and new plantations. In a hypothetical situation where new economic conditions do not favour fruit production, farmers could decide to keep existing trees until the end of their economic life without replacing them afterwards.

In a first moment, maintenance of the existing plantation and new plantation are treated in a similar way; that is, assuming a steady-state situation. As a result, input-output coefficients will be the same for both activities. Nevertheless, we can also incorporate rising costs of adjustment related to new plantings.

2.6.3. Module for perennial activities

2.6.3.1. Integrating annual and perennial crops in FSSIM-Dev

Basically, FSSIM-Dev is a static farm model. However, it can incorporate some dynamic features, such as crop rotations or livestock activities. In order to integrate inter-temporal effects, agricultural activities are defined under "crop rotations" and "dressed animal" instead of individual crops and animals.

Even though decisions on crop rotations can be viewed as multi-year decisions, it seems reasonable to assume that farmers can switch from one rotation to another without high adjustment costs. Unlike crop rotations, changing decisions on perennial activities from year to year implies high adjustment costs. Decisions on perennial activities are better viewed as long-run investment decisions involving sunk costs and therefore require a different modelling approach.

The objective of the perennials component is to provide a modelling framework to represent perennial activities and their linkages with annual crops.

Lacking information on current age structure of perennial crops, we will assume a steady-state situation in the base year. That means, for each hectare of a perennial crop whose lifespan is *n* years, we consider that there are 1/*n* hectares of trees planted in the current period, 1/*n* hectares of one-year old trees, 1/*n* hectares of two-year old trees, and so on.

Faced to changes in the technological, economic or institutional setting, the farmer will decide either to maintain the initial plantation or to change the area allocated to the perennial crop. In order to model tree-crop decisions in a static framework, we distinguish four adjustment strategies:

- Maintenance of the existing plantation: the initial steady-state situation is kept by replacing old trees. The replacement rate will therefore be equal to the physical depreciation rate (1/*n*, being *n* the lifespan of the plantation).
- Decline of the plantation area: existing trees are kept until the end of their economic lifetime but old trees are not replaced. In this case, the replacement rate will be zero and, therefore, the plantation area will decrease by the physical depreciation rate each year.
- Removal of the plantation area: some trees are removed before the end of their economic lifetime in order to allocate land to other activities. Hence plantation area will decrease.
- Growth of the plantation area: planting new trees will increase the area allocated to the perennial crop.

As the farmer can choose a combination of these four strategies, all possible tree-cropping decisions can be modelled by means of these four adjustment strategies. Each "mixed perennial activity" is then built as a combination of these four activities. Once these "mixed perennial activities" have been defined, they can enter the FSSIM-Dev model in the same way as for annual activities. The perennial module will consists of defining these mixed perennial activities for each perennial crop as well as assessing the associated input-output coefficients.

2.6.3.2. Definition of perennial activities

Cropping activities are defined as a combination of crop rotation (r), agri-environmental zone (s), production technique (t) and production system (sys). A distinction is made between current activities, or activities currently practiced in the region under consideration, and alternative activities, or activities unobserved in the baseyear but that might be practiced in the future. For perennial crops, activities are defined as mono-crop rotations. For simplicity, we will denote an annual activity as a crop rotation (*j*) in an agri-environmental zone (*s*). Similarly, a perennial activity will be defined as a perennial crop with a given age structure (*k*) in an agri-environmental zone (*s*).

Two alternative ways to handle perennial activities can be suggested:

Option 1. For each perennial crop, we define four perennial activities (steady-state plantation, non-replaced plantation, new plantation and plantation removal).

Option 2. For each perennial crop, we define a "mixed perennial activity", built upon the four potential strategies. Once the "mixed perennial activities" have been defined, they can be incorporated in the FSSIM-Dev model in the same way as for annual activities.

Within both options, some previous calculations are needed in order to obtain the input-output coefficients for each perennial activity. Option 1 might seem preferable because the adjustment strategies remain visible and the input-output coefficients associated to each activity remain exogenous. However, given that we define four interrelated activities for each perennial crop, we will need to specify the linkages between these activities by means of additional equations.

In any case, both options are equivalent so the choice between them will be based on computational ease and integration within the FSSIM-Dev framework.

Regardless of the option finally chosen, the integration of perennial activities will affect some equations in the FSSIM-Dev model, mainly the equations on cropland allocation, which are defined by agri-environmental zone. Basically, we need additional equations to define the linkages between the assumed potential strategies and between perennial and annual crop activities.

Being $X_{j,s}$ and $X_{k,s}$ the land allocated to the annual activity *j* and the perennial activity *k* in agri-environmental zone *s*, and denoting $Tland_s$ the total available land in agri-environmental zone *s*, the land constraint can be formulated:

$$\sum_j X_{j,s} + \sum_k X_{k,s} \leq Tland_s \tag{25}$$

The definition of the mixed perennial activities $X_{k,s}$ depends on the timeframe of the analysis. In the short-run, we will assume a fixed area for perennial activities:

Short-run

$$X_{k,s} = x^0_{k,s} \tag{26}$$

In the long-run, the area of tree-crops can be adjusted and steady-state equilibrium could be reached:

Long-run

$$X_{k,s} = X^m_{k,s} \tag{27}$$

In the medium-run, the area of tree-crops will depend both on the initial plantation level and on the strategic decisions taken. Assuming a constant depreciation rate δ_k for each perennial activity ($1/n_k$), and denoting x^0_{ks} the observed level of the perennial activity in the base year per soil type (in ha), and l the time lag between the base year and the baseline in the model, the following equations must hold:

$$\frac{X^d_{k,s}}{(1-\delta_k)^l} + X^m_{k,s} = x^0_{k,s} - X^r_{k,s}$$

$$X_{k,s} = X^m_{k,s} + X^d_{k,s} + X^g_{k,s} - X^r_{k,s}$$

$$X_{k,s} = x^0_{k,s} + X^g_{k,s} - X^r_{k,s} \qquad \forall\, k \tag{28}$$

$$X^m_{k,s} + X^d_{k,s} + X^r_{k,s} = x^0_{k,s} \qquad \forall\, k$$

$$X^r_{k,s} = X^d_{k,s} * L_k * \delta_k \qquad \forall\, k$$

where $X_{k,s}$ total area allocated to tree-crop k in agri-environmental zone s

$x^0_{k,s}$ existing plantation area in the baseyear

$X^m_{k,s}$ area of the "plantation maintenance" activity

$X^d_{k,s}$ area of the "plantation decline" activity

$X^r_{k,s}$ area of the "plantation removal" activity

$X^g_{k,s}$ area of the "plantation growth" activity

In this way, a difference is made between existing plantations and new ones. When deciding about new plantings, the farmer will compare total profitability of these activity (including establishment costs) with those of other land-use options. On the contrary, for existing plantations, the farmer will continue production as long as full-production profitability (excluding establishment costs) will be greater for this activity than for other options.

2.6.3.3. Input-output coefficients for perennial activities

As we have just seen, perennial activities in FSSIM-Dev are defined as mono-crop rotations. For each sample region, data for current perennial activities come from two main data sources: local-expert surveys and other studies.

For annual cropping activities, data collection and estimation of input-output coefficients are based on averaged yearly values over a reference period. On the contrary, in the case of perennial activities, input-output coefficients depend on the age of the tree-crop and therefore average values for the plantation will depend on its age structure.

Data on observed plantation area in the base year is easily available but without taking into account the age-dependence of these variables. As information on the age structure of tree-crops is not provided, we will assume an initial steady-state situation. We can illustrate this with an example. Imagine that we try to represent a peach-tree plantation whose lifespan is 15 years. A steady-state situation implies 1/15 share of one-year old trees, 1/15 share of two-year old trees and so on.

Crop management data as well as economic data come from the field surveys. Input-output coefficients for perennial crops are age-specific. However, giving the difficulty to obtain detailed management and economic data through the lifetime of the plantation, a decision has been made to simplify data collection by distinguishing three age-classes for each perennial crop. Being t the age of the tree-crop, p the number of years needed to reach maturity and n the economic lifetime of the perennial crop, we differentiate three age-classes *te*, *tg* and *tp*:

(20) establishment period: from planting to first bearing (*te* :{1, ...,g-1})
(21) growth period or maturation period: from first bearing to full production (*tg* :{g,...,p-1})
(22) productive period: full production (*tp* :{p,...d})
(23) decline period: declining production (*td* :{d,...n})

Input-output coefficients are assumed constant inside each age-class. Table 1 shows main survey data for each perennial crop. Apart from revenue and cost data, input requirements for each age-class and input category i (fertilisers, pesticides, water, labour, etc.) are defined. Basically, input-output data for perennial crops do not differ from those of annual crops, apart from the fact that they are differentiated by age-class and that we need to consider establishment cost and removal costs.

Table 1. Data requirement for perennial crops

	Plantation period	Growth period	Productive period
Period length	*te* :{1, ...,g-1}	*tg* :{g,...,p-1}	*tp* :{p,...n}
Average cost (€/ha)	$CE_{k,s}$	$CG_{k,s}$	$CP_{k,s}$
Average revenue (€/ha)		$RG_{k,s}$	$RP_{k,s}$
Removal cost (€/ha)			CR_{js}
Input use (units/ha)	$IE_{i,k,s}$	$IG_{i,k,s}$	$IP_{i,k,s}$

From these primary data, we compute the equivalent annual cost (EAC) and the equivalent annual revenue (EAR) for each perennial activity. As for input requirements, we compute the equivalent annual input use (EI), taking into account the coefficients of presence of trees of each age-class.

Actually, some calculations will be needed in order to turn the primary age-class dependent data into age dependent data or perennial activity dependent data.

One option will be to directly compute the parameters associated to each perennial activity (steady-state plantation, non-replaced plantation, new planting and plantation removal). That is, we will compute the perennial activity data from the primary age-class dependent data.

In the peach-tree example above, assuming that the peach-tree starts bearing fruit in the second year after planting, reaches maturity in the fifth year and has a lifespan of 15 years, we can define four peach activities (steady-state plantation, non-replaced plantation, new plantation and plantation removal). The first one (steady-state plantation) implies 1/15 share of non-bearing trees, 4/15 share of young trees and 10/15 share of mature trees. Input-output coefficients for this peach activity will be calculated accordingly. For instance, the equivalent annual cost will be 1/15 share of establishment costs (CE), 4/15 share of growth costs (CG) and 10/15 share of full production costs (CP).

A brief description of the needed calculations follows.

Coefficients calculation for plantation maintenance (superscript m)

$$EAC^m_{k,s} = \rho^m_k \left[\sum_{t=1}^{g_k-1} d^{t-1}\, CE_{k,s} + \sum_{t=g_k}^{p_k-1} d^{t-1}\, CG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\, CP_{k,s} \right]$$

$$EAR^m_{k,s} = \rho^m_k \left[\sum_{t=g_k}^{p_k-1} d^{t-1}\, RG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\, RP_{k,s} \right]$$

$$EAI^m_{i,k,s} = \frac{1}{n_k} \left[\left(g_j - 1\right) IE_{i,k,s} + \left(p_k - g_k\right) IE_{i,k,s} + \left(n_k - p_k - 1\right) IE_{i,k,s} \right]$$

Coefficients calculation for plantation decline (superscript d)

$$EAC^d_{k,s} = \rho^d_k \left[\sum_{t=g_k}^{p_k-1} d^{t-1}\, CG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\, CP_{k,s} \right]$$

$$EAR^d_{k,s} = \rho^d_k \left[\sum_{t=g_k}^{p_k-1} d^{t-1}\, RG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\, RP_{k,s} \right]$$

$$EAI^d_{i,k,s} = \frac{1}{n_k - g_k - 1} \left[\left(p_k - g_k\right) IG_{i,k,s} + \left(n_k - p_k - 1\right) IG_{i,k,s} \right]$$

Coefficients calculation for plantation growth (superscript g)

$$EAC^{g}_{k,s} = \rho^{g}_{k}\left[\sum_{t=1}^{g_k-1} d^{t-1}\ CE_{k,s} + \sum_{t=g_k}^{p_k-1} d^{t-1}\ CG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\ CP_{k,s}\right]$$

$$EAR^{g}_{k,s} = \rho^{g}_{k}\left[\sum_{t=g_k}^{p_k-1} d^{t-1}\ RG_{k,s} + \sum_{t=p_k}^{n_k} d^{t-1}\ RP_{k,s}\right]$$

$$EAI^{g}_{i,k,s} = \frac{1}{n_k}\left[\left(g_k-1\right) IE_{i,ks} + \left(p_k-g_k\right) IE_{i,k,s} + \left(n_k-p_k-1\right) IE_{i,k,s}\right]$$

Coefficients calculation for plantation removal (superscript r)

$$EAC^{r}_{k,s} = CR_{k,s}$$

An alternative option will be to turn age-class data into age dependent data. In this case, the age structure of the perennial activity can be made explicit. And accounting for equivalent annual costs and revenues for the alternative strategies will be straightforward. Input requirements for each sub-activity will be the sum, across all ages, of the percentage area of a given age multiplied by the input requirement associated with this age.

Continuing with the peach-tree example, we first define the input-output coefficients for each age of the perennial crop, which is quite straightforward, and then we use the standard formulation to compute the equivalent annual cost, revenue and input use parameters.

2.6.4. Conclusion

This section presented the three adopted approaches for modelling perennial activities in the FSSIM-Dev model. The selection of a modelling approach depends on the time frame of the analysis:

- In the short term modelling approach, we assume a constant area for perennial crops, that is, no land competition between annual and perennial crops are depicted.
- In the long term modelling approach, we adopt a steady state approach, allowing for adjustments in the area allocated to perennial activities and, therefore, modelling the competition for land between annual and perennial crops.
- In the medium term modelling, an innovative modelling approach is used to take into consideration sunk cost and adjustment cost effects of investment decisions. This modelling framework provides the mid-term response of perennial producers to changes in incentives. Basically, we make a distinction between the existing stock of perennial crops and new plantations in terms of input-output coefficients.

2.7. Farm-household module: non-separability of consumption and production decisions

Farm household models are a sample of micro research on less-developed country (LDC) rural economies. They are mostly applied for family or peasant agriculture (i.e. small farms) where production and consumption decisions are linked due to market imperfection. The fundamental difference between a farm household model and a pure consumer model is that, in the latter, the household budget is generally assumed to be fixed, whereas in household-farm models it is endogenous and depends on production decisions that contribute to income through farm profits (Taylor and Adelman, 2003). The primary motivation for constructing household models is to analyze the impact of production and consumption decisions on variables of interest, including farm household welfare, market exchange, household resource use and sustainability issues (Singh et al., 1986). These models can also provide a promising perspective for understanding the impacts of exogenous factors such as technological innovation and policy changes on farm household behaviour and rural areas (Taylor and Adelman, 2003). The following section gives a short overview on farm household models, their specificities and their main assumptions and reviews the well-known ones. This review will facilitate the selection of the suitable approach to implement in FSSIM-Dev for modelling household decisions.

2.7.1. Brief literature review on farm household modelling

2.7.1.1. Why non-separability?

Traditionally, economists model individual decisions depending on which point of view the question is addressed; one strand of the economic literature discusses the issues related to consumption behaviours when production decisions are considered in a different setting and workers' allocation of time between on farm labour, off farm labour and leisure in another one. This assumption of separability between production and consumption decisions facilitates analysis, but entails several important restrictions. The implications of assuming separability are certainly less damageable in developed countries. However, this separation is often less clear-cut for agricultural households in developing countries where households may be the locus for both consumption and production.

Household farms are a fundamental productive unit characterizing most developing economies. The dual role of many household in developing countries as producer and consumer raises the question of the interdependence between production, labour allocation and consumption decisions. First, agriculture is still characterized by auto-consumption, partly because local markets may fail to satisfy demand or to provide outlets for production. Second, the opportunity cost of employing members of the family on the farm may be very low given the scarcity of land. Household agricultural activities can therefore be both a source of cheap food and an opportunity to allocate labour between family members.

Farm-household models were first introduced to explain empirical puzzles, such as decreases in marketed surplus after increases in price of staple for Japanese rural households (Kuroda and Yotopoulos, 1978). As farm profits are a part of family income, increases in prices can have a positive effect on revenue and a direct negative impact on consumer's utility. Demand depends on prices and income as usual, but prices now have an added effect on income via profits. This profit effect reduces the usual negative relationship between price and quantity demanded.

Farm-household models are also useful for understanding household behaviour when markets are imperfect. Production and consumption decisions are linked because the deciding entity is both a producer and a consumer. However, remains the question if consumption affects production in return. As long as markets are perfect for all goods, including labour, households are indifferent between consuming own-produced and market-purchased goods and allocate indifferently production between consumption and market sales. In other words, consumption decisions do not affect production decisions and production is independent of household preferences and income. The main question to answer is to determine whether or not there are market failures. If there are market failures, a household approach might be necessary depending on whether the good for which market fails is important in production.

In presence of transaction costs, selling price differs from buying price. Transactions costs generate thus a price band. If the width of the price band is large and the households marginal cost curve crosses its demand curve within the band, then the household does not participate in the market. A market exists but some households won't enter because the benefits from exchanging are less than the costs incurred. A market fails when the cost of a transaction through market exchange creates disutility greater than the utility gain that it produces, such that no market transaction occurs (De Janvry et al., 1991). It has to be noted that market failure is household specific and not commodity specific. Tests for separability rely thus essentially on testing whether or not household characteristics in consumption significantly affect production decisions. Variables on household size, such as the number of adults and children (Vakis et al., 2004), or education background are usually considered as household characteristics in consumption. When one or more market is missing then recursiveness breaks down and non-separability regarding production and consumption decisions has to be assumed; consumption variables determine production. Farm-Household models provide explanation of household behaviour in response to exogenous shocks in missing markets scenarios. Some households will behave as net-buyers, others net-sellers and others autarkic. A main issue in farm household modelling is how to determine the household-specific shadow price.

Empirical evidence largely supports the hypothesis that farm household production and consumption decisions are "non-separable". Benjamin (1992) suggests testing for separability by controlling whether demographic variables affect farm production decisions. He founds that, for agricultural households in rural Java, the separation hypothesis cannot be rejected. However, following a similar approach, Lopez (1986) found that the hypothesis of independence must be rejected on Canadian data. Bowlus and Sicular (2003) show on Chinese data that labour demand is a function of household size and composition. Carter and Yao (2002) demonstrate that households whose land endowment lies within two critical values, will not enter the land rental market, thus exhibiting non-separability (Lovo, 2011).

2.7.1.2. Theoretical framework and quantitative methods

A literature review reveals the existence of three alternative economic theories regarding farm household behaviour. Each theory assumes that households have an objective function to maximize, with a set of constraints. The first is the "profit-maximizing theory", which has been criticized on the grounds that it overlooks the aspect of consumption in household decision-making processes (Schultz, 1964). The second, the "utility-maximizing theory", incorporates both the production and consumption goals of households (Chayanov, 1966; Singh et al., 1986; Sadoulet and De Janvry, 1995). Finally, the "risk aversion theory" states that the objective function of households is to secure the survival of the household by avoiding risk (Roumasset, 1976; Morduch, 1993; Mas-Colell et al., 1995)[11].

Utility-maximizing theory is the most used when household consumption and production decisions are interdependent such as in rural areas. According to this theory, farm households are assumed to maximize the utility derived

11 For a review of these three theories see Mendola (2007).

from consumption of all available commodities (i.e. home-produced goods, market-purchased goods, and leisure), subject to full income constraints. Formally, the basic farm household model can be presented as follows (Sadoulet and De Janvry, 1995):

$$\begin{gathered} Max\ U(c, c_l; z^h) \\ s.t. \\ p^a c^a + w^l c^l = \pi + w^l E_l \\ f(q, x, l) = 0 \\ c^l + l^s = E_l \end{gathered} \tag{30}$$

with

$$\pi = p^w v - p^x x - w^l l \tag{31}$$

where **U** is a consumer's utility function defined over a vector of commodities consumed **c** and leisure $\mathbf{c^l}$, depending on household **h**'s characteristics $\mathbf{z^h}$. **f(q,x,l)** represents the household's production technology, relating farm outputs **q** to the amount of inputs **x** and labour **l**. $\mathbf{l^s}$ and $\mathbf{B^l}$ are the household's labour supply and the initial endowment of labour. π is the profit function, with $\mathbf{p^v}$, $\mathbf{p^a}$ and $\mathbf{p^x}$ are the vectors of selling prices, buying prices and input prices, respectively. **v** are the output quantities sold on the market and $\mathbf{w^l}$ the wage rate.

If perfect markets are assumed, the household model is separable. Despite exhibiting a single decision-making process, the optimisation program can be solved recursively: first, the producer's profit maximization problem, then, the consumer's utility maximization problem, under the constraint of a given optimized level of profit. As mentioned previously, the key asset of farm-household models is that they account for the profit effect. However, if the market fails for a household, separability does not hold any more and the household's production and consumption decisions must be solved simultaneously (Singh et al., 1986).

The solution to the household model yields a set of equations for outputs, input and consumption demands. In case of market failures, shadow prices must be computed for non-tradable goods. Following Kuiper (2004), we retain three approaches to translate the theoretical framework to a quantitative household model: reduced-form equation, a system of structural equations and a Mathematical Programming model.

A reduced-form equation approach

To address specific research questions, it may not be necessary to estimate a complete household model. For the variable of interest, exogenous variables need to be identified and the resulting equation estimated econometrically. Reduced-form equations can be derived from the first-order conditions of the household maximization program, describing how endogenous variables relate to an exogenous variable of interest. It then suffice to postulate general conditions on the functional form (Paolisso et al., 2002; Smale et al., 2001; Woldenhanna and Oskam, 2001). One of the main advantages of this approach is that it doesn't require specification of the utility and/or production functions. However, reduced-form models do not detect internal adjustments within the household.

A system of structural equations approach

If more than one endogenous variable is of interest, the whole system of structural equations of the household model need to be estimated (Kuiper, 2004). First-order conditions are then derived from the household maximisation problem to determine a system of equations that describe household's production and consumption decisions. If decisions are assumed to be separable, the model may be estimated recursively. Otherwise, the model should be solved simultaneously, using numerical techniques which may involve proceeding to econometric estimations (De Janvry et al., 1991). Non-separability implies indeed simultaneously choosing, on the producer's side, the allocation of labour and other inputs to production, on the worker's side, the allocation of income from farm profits and labour sales, and, on the consumer's side, the allocation of the budget between commodities and services.

Estimating structural equations of the household model requires selecting functional forms for the demand and supply functions. These may be derived from utility and production functions, or may be postulated (Kuiper, 2004). Estimation of the structural equations can be complicated because of the endogeneity of some variables and because of indeterminate signs of coefficients making it difficult to distinguish the true inference from spurious correlation (Kruseman, 2000). In addition, data necessary for estimation purposes may be difficult to gather.

Mathematical programming approach

Previous authors have derived systems of structural and reduced-form equations from the first order conditions (De Janvry et al., 1991). However, estimation of a household model in reduced-form or as a system of equations may not be possible. First, the structure of the household model may be too complex to derive a limited number of equations. This applies in particular in the case of non-separable household models, when it cannot realistically be assumed independence between utility and profit maximization. Second, Second, econometric estimation may be hindered by unobservable variables. Such cases can occur, for example, when households produce commodities for home use only and not for market sale. Third, econometric estimation sets requirements in terms of the number of observations, time horizon and variation in variables (Kuiper, 2004).

A third approach relying on Mathematical Programming has also been used in the last years (Omamo, 1998; Kruseman, 2000). The optimisation approach follows the general framework of an objective function maximised under constraints and solved the program through optimisation algorithms. Resting on numerical techniques, it does not require deriving first order conditions. However, a functional form to the objective utility function needs to be specified. Econometrically estimated parameters may be entered in the model to reduce data requirements.

A literature review shows an increased number of farm household programming models being used to address a multitude of questions. McGregor et al. (2001) reviewed studies using these kinds of model up to 2001. Major contribution is the Malian Farm Household Model developed by Ruben and Ruijven (2001) to assess farmers' responses to agrarian policies. It consists of a non-linear dynamic recursive optimization model working at household level and simulating biological processes by making use of meta-modelling principle. Okumu et al. (2000) developed the Ginchi Farm Household Model. It is a dynamic non-linear and multi-objective programming model which optimises a weighted utility function where three goals are incorporated: cash income, leisure and basic food production. Barbier and Bergeron (1999) built a recursive and dynamic linear programming model which maximizes full income as a proxy for utility where minimum consumption requirements are imposed. The farm households with different resource endowments are then aggregated to the regional level to assess the supply response and the potential price effects as they interact with demand. Shepherd and Soule (1998) developed a dynamic simulation model that incorporates household needs, constraints and financial flows. An interesting aspect of their work is that they consider households with different resource endowments and in different environmental contexts. Holden et al. (2004) take truly advantage of the household decision-making structure of programming models to integrate economic optimization in production and consumption with environmental feedbacks in a non-separable regime. This household model maximizes a welfare function measured as the discounted utility of a certainty equivalent full income. This full income is specified as a function of an expected income based on the probability of expected prices and expected outputs in drought years and years without drought. Dolisca et al. (2008) use a similar model to evaluate the role of various policy instruments on large-income farm households and low-income farm households' welfare and forest conservation in Haiti. Laborte et al. (2009) use a farm household model to evaluate the potential attractiveness to Philippine farmers of three innovative production technologies. In this optimization model, it was again assumed that utility could be replaced by discretionary income. Likewise, other farm household models were developed for different countries to investigate various questions. Among these countries/models one could mention: Zambia (Holden, 1993); Kenyan (Waithaka et al., 2006); Ghana (Yiridoe et al., 2006); Ethiopia (Babulo et al., 2008), Philippine (Walker et al., 2009).

The problem is that most of these programming models are, on the one hand, unable to exactly reproduce the observed behaviour and therefore to be suitable for policy analysis, and, on the other hand, they are used for a specific purpose and location and therefore cannot be easily adaptable and extendable to others contexts and conditions. Moreover, in most of these models household consumption is modelled through a minimum consumption constraint which is unable to capture household consumption decision correctly. The model presented in this report relies on this approach and attempts to overcome the above issues using the Positive Mathematical Programming approach (Howitt, 1995a) and a consumption function parameterized through Generalized Maximum Entropy estimation. Another model's novelty is that, because of non-separability assumption, the price at which the household values a commodity is generated by the model (i.e. endogenous) depending on household trading status.

2.7.2. Modelling farm household decisions in FSSIM-Dev

The aim of this section is to present the household modelling approach to implement in FSSIM-Dev for taking into account farm household supply and consumption decisions. Based on mathematical programming, this approach relies on both the general household's utility framework and the farm's production technical constraints, in a non-separable regime. However, before describing our approach, we discuss briefly some issues related to the specification of household utility function.

2.7.2.1. Discussion on household utility function

In Economics, utility refers to the perceived value of a good or service by a consumer. It is a measure of the relative satisfaction from consumption of goods and services. This concept of utility is essentially important for ranking the different consumption bundles. If consumer's behaviour satisfied axioms of completeness and transitivity, consumer can consistently rank all baskets of commodities in order of preference. With this measure, one may speak meaningfully of increasing or decreasing utility, and thereby explain economic behaviour in terms of attempts to increase one's utility. This kind of utility is referred to as "ordinal utility", as opposed to "cardinal utility" which treats the magnitude of utility differences as a significant quantity. Ordinal utility is the core assumption towards people's preferences and utility functions and is sufficient to model consumer behaviour.

Thus, given a certain preference ordering, we can assume a utility function to describe this ranking. Utility function is the mathematical expression that shows the relationship between utility values and every possible basket of goods. One of the major difficulties involved in using revealed preference approaches is the specification of functional forms. The most common utility functions found in the literature are:

Negative Exponential utility function

$$u(x) = -e^{-\alpha x}, \ \alpha > 0 \qquad (32)$$

with x, the consumption bundle and α, the coefficient of (absolute) risk aversion.

Logarithmic utility function:

$$u(x) = \log x \tag{33}$$

Power utility function:

$$u(x) = \frac{x^{\alpha}}{\gamma}, \gamma > 1 \tag{34}$$

with γ and α, constant terms. The power utility function is one of the most flexible forms.

Iso-elastic utility function (or CRRA or CES):

$$u(x) = \frac{x^{-1\rho}}{\rho}, \rho > 1 \tag{35}$$

with ρ, the coefficient of (relative) risk aversion.

Many efforts have been made to model functional forms which satisfy theoretical conditions and large sections of Demand Theory have been dedicated to deriving demand functions directly from maximizing a utility function. Three of them have received considerable attention because of their relative empirical expediency. They are the Linear Expenditure System (LES) developed by Stone (1954), the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980), and the combination of these two systems into a Generalized Almost Ideal Demand System (GAIDS) proposed by Bollino (1990). Other complete demand systems found in the literature but not as widely used are the Rotterdam model of Theil (1976) and Barten (1969) and the translog model of Christensen, Jorgenson, and Lau (1975) (cited by Sadoulet and De Janvry, 1995).

In FSSIM-Dev we opted for the Linear Expenditure System (LES) as it is the easier in term of parameterisation and calibration. However, this system can be easily substituted by a minimum consumption constraint if data on income and price elasticities are missing or if the number of observation is limited. In such case the user has just to provide data on minimum energy requirement per adult and the nutrient (energy) value per consumed goods.

2.7.2.2. Modelling farm household consumption decision

A linear expenditure system (LES) was used to describe the household's consumption behaviour. In this system, the set of demand functions is expressed in expenditure form and assumed to be linear in prices and incomes as follows:

$$c_{h,j}p_{h,j} = \beta_{h,j}(Y_h - \sum_{j'=j}\gamma_{h,j'}p_{h,j'}) + \gamma_{h,j}p_{h,j} \tag{36}$$

$$\begin{cases} 0 < \beta_{h,j} < 1 \\ \sum_j \beta_{h,j} = 1 \\ \gamma_{h,j} < c_{h,j} \end{cases} \tag{37}$$

where **p** is the (n×1) vector of prices of goods, **c** is the (n×1) vector of consumed quantity of goods, **Y** is the farm household full income (farm household expected income (**R**) plus the value of the household's land endowment), γ is the uncompressible consumption (interpreted as minimum subsistence or "committed" quantities below which consumption cannot fall) and β is the marginal budget share. is the subsistence expenditure and the term is generally interpreted as "uncommitted" or "supernumerary" income which is spent in fixed proportions β between the commodities (Sadoulet and De Janvry, 1995).

The Generalized Maximum Entropy (GME) method was used to estimate γ and β parameters for the sampled farm households, using information on income elasticities and the Frisch parameter[12] from literature (Seale et al., 2003). As stated by Golan et al (1996), the GME method permits the consistent and efficient estimation of a demand system with non-negativity constraints and a large number of goods without imposing restrictions on the error process. It also allows inclusion of prior knowledge in a technically straightforward way, making estimates potentially more efficient (Jansson, 2007).

12 The Frisch parameter is a ratio of the total expenditure and the discretionary (supernumerary) income. For further details see Dervis et al. (1982).

The application of the GME estimator to the linear expenditure system is based on the solution of the following problem:

$$\max H(w,w',w'') = -\sum_{h,j,k} w_{h,j,k} \ln w_{h,j,k} - \sum_{h,j,k'} w'_{h,j,k'} \ln w'_{h,j,k'} - \sum_{h,j,k''} w''_{h,j,k''} \ln w''_{h,j,k''} \quad (38)$$

Subject to:

Data-consistency constraints

$$c_{h,j}p_{h,j} = \beta_{h,j}(Y_h - \sum_{j'} \gamma_{h,j}p_{h,j}) + \gamma_{h,j}p_{h,j} + \mu_{h,j} \quad \forall h,j$$

$$\beta_{h,j} = \sum_{k} w_{h,j,k}Z_{k,j} \quad \forall h,j$$

$$\gamma_{h,j} = \sum_{k'} w'_{h,j,k'}Z'_{k',j} \quad \forall h,j$$

$$\mu_{h,j} = \sum_{k''} w''_{h,j,k''}Z''_{h,k'',j} \quad \forall h,j$$

Adding-up or normalization constraints

$$\sum_{k} w_{h,j,k} = 1 \quad \forall h,j$$

$$\sum_{k'} w'_{h,j,k'} = 1 \quad \forall h,j$$

$$\sum_{k''} w''_{h,j,k''} = 1 \quad \forall h,j$$

Accounting restriction

$$\sum_{j} \beta_{h,j} = 1 \quad \forall h$$

$$\gamma_{h,j} < c_{h,j} \quad \forall h,j$$

$$\sum_{j} \mu_{h,j} = 0 \quad \forall h$$

Non-negativity conditions

$$\beta_{h,j} > 0; \ \gamma_{h,j} > 0; \ \mathrm{w}_{h,j,k} \geq 0; \ \mathrm{w}'_{h,j,k'} \geq 0 \ ; \ \mathrm{w}''_{h,j,k''} \geq 0$$

where μ is the error term which is specific to each good *j* and farm household *h*, **K, K'** and **K''** are the numbers of support points associated to both the unknown parameters and the error vector, **Z**, **Z'** and **Z''** are the values of support points set exogenously, and **w, w'** and **w''** are their unknown probabilities, respectively.

The principle of Generalized Maximum Entropy consists of selecting the values of γ**,** β and μ whose distributions **w, w'** and **w''** maximize the function **H** in (8), subject to the data-consistency constraint (8.1), the adding-up or normalization constraints (8.5-7) which ensures that probabilities appropriately sum to one, the accounting constraint (8.8-10) and the non-negativity condition (8.11). The accounting restriction (8.8) is imposed in order to ensure that total household expenditure and total household income at farm household level are equal. This procedure ensures that all (agricultural and non-agricultural) goods are taken into account *simultaneously*. This is achieved by introducing an additional category of goods ***m*** "market goods", as suggested by Brooks et al. (2011), with corresponding expenditure equals to the difference between household income and household agricultural consumption.

$$p_{h,m}c_{h,m} = Y_h - \sum_{j' \neq m} \gamma_{h,j'}p_{h,j'} \quad (39)$$

To make the GME estimation operational, we need to define the support points for the unknown parameters as well as for the error vector. As pointed out by several studies, the choice of support points in the context of GME is an important issue, as it can strongly affect model outcomes (Golan et al., 1996). To define the number of support points, their bounds, spacing, and the implied prior expectation, we have made the following assumption:

- for the β parameters of agricultural food products (rice, cassava, groundnuts, sweet potatoes, palm oil and fruits), 11 support points (i.e., K=11) are chosen, centred around the income elasticity times the average budget share at district/region level as follows:

$$Z_j = za_j \eta_j avs_j$$

where

$$za_j = [0.01, 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, 3] \quad \forall j \neq m \quad (40)$$

$$avs_j = \frac{\overline{p_j c_j}}{Y}$$

where η is the income elasticity and **avs** is the average budget share devoted by households to good *j* (average across sample households within each district/region). We assume that all farm households have the same income elasticity for each good and the same Frisch parameter (Seale et al., 2003).

- for the β parameter of the additional good "market goods", 11 support points are also chosen bounded between zero and one, and equally spaced with a distance of 0.1 (i.e., we assume a priori expectation of 0.5 because this category incorporates the expenditure for all non-agricultural goods which can easily account for up to fifty per cent of the total household income).

$$Z_j = [0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1] \quad \forall j = m \quad (41)$$

for the γ parameter, 5 support points are chosen (i.e. K' = 5), ranging between ± 100% times the average uncompressible consumption across farm households for each good. It is given by:

$$Z'_j = zb_j \overline{\gamma_j}$$

where

$$zb_j = [0, 0.5, 1, 1.5, 2] \qquad \forall j \qquad (42)$$

$$\overline{\gamma_j} = \frac{\overline{Y}}{p_j}\left(avs_j + \frac{\eta_j avs_j}{\varphi}\right) \quad \forall j$$

where is the average uncompressible consumption across sample households within each district/region, η is the income elasticity, φ is the Frisch parameter and **avs** is the average budget share across (Savard, 2003).

- For the error term μ we use the common assumption where three support points (i.e., K" = 3) are symmetrically defined around zero and bounded by the so-called "three-sigma rule" (Pukelsheim, 1994).

$$Z''_j = [-3\hat{\sigma}_j,\ 0,\ +3\hat{\sigma}_j] \qquad \forall j \qquad (43)$$

where

$\hat{\sigma}$*: Sample standard deviation of consumption and expenditure in good j*

2.7.2.3. Transformation of the FSSIM objective function

In order to take into account both farm household production and consumption decisions, in a non-separable regime, the FSSIM utility function was transformed from a famer's expected utility function which focus mainly on agricultural (farm) income to a household's expected utility function based on incomes from all economic activities of a family living in the same household. This new expected utility function in FSSIM-Dev is defined as a farm household income (i.e. full income) minus its standard deviation due to risk averse towards price and yield variation:

$$U_h = R_h - \phi_h \sigma_h \qquad (44)$$

where **U** is the expected farm household utility function, **h** denotes farm households, **R** is the farm household expected income, ϕ is the risk aversion coefficient and σ is the standard deviation of agriculture income due to price and yield variation.

Farm household income **R** is defined as the income earned from all economic activities of a family living in the same household and is composed of three components: agricultural income **z**, income from marketed factors of production (non-farm wages, rent of land and equipment) and off-agricultural/farm incomes. The off-farm incomes are exogenously defined and can originate from different sources such as non-farm salaries, petty trading, self employed craftsmanship, pensions, transfer, donations, etc.

The farm household's income **R** is defined as follows:

$$R_h = z_h + \sum_{tf} s_{h,tf} p_{h,tf} - \sum_j b_{h,j} p_{h,j} + exinc_h \qquad (45)$$

where **Z** is the agricultural income, **s** the (n×1) vector of sold quantities of goods *j* or tradable factors *tf* (land, labour and equipment), **p** is the (n×1) vector of prices of goods *j* or tradable factors *tf*, $\mathbf{c^s}$ is the (n×1) vector of self-consumed quantities of goods, **b** is the (n×1) vector of bought quantities of goods or rented-in tradable factors and $\mathbf{exinc_h}$ is the exogenous off-farm incomes for households.

Agricultural (farm) income **z** is defined as the value that farm-households have earned by selling or consuming their own agricultural products (i.e. self-consumption). It is calculated according to the following formulation:

$$z_h = \sum_j (s_{h,j} + c^s_{h,j}) p_{h,j} + \sum_i sb_{h,i} x_{h,i} - \sum_i a_{h,i} x_{h,i} - \sum_i (d_{h,i} + 0.5 Q_{i,i'} x_{h,i}) x_{h,i} - \sum_{tf} (b_{h,tf} + \lambda'_{h,tf}) p_{h,tf} - fc_h \qquad (46)$$

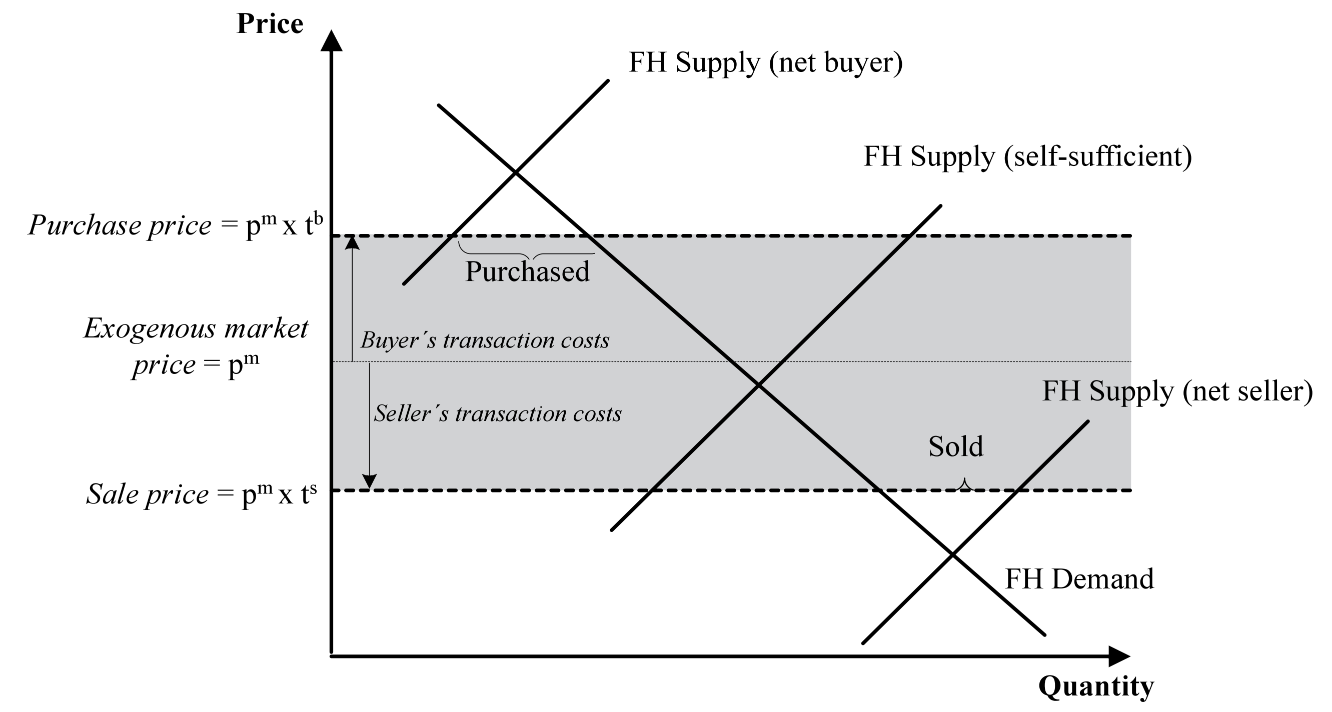
where **x** is the (n×1) vector of the simulated levels of the agricultural activities *i*, **sb** is the (n×1) vector of production subsidies, **a** is the (n×1) vector of accounting cost, **fc** is the fixed cost, is the (m×1) vector of implicit unit costs of tradable factors (i.e. the difference between the market price and the effective unit cost of a tradable factor), **d** is the (n×1) vector of the linear part of the activities' implicit cost function and **Q** is a (n x n) symmetric, positive (semi-) matrix of the activities' implicit cost function. **Q**, **d** and are estimated using Positive Mathematical Programming approach.

Agricultural commodity prices (i.e. market prices) are exogenously fixed for households participating in markets. We assume that those farm households are price takers on commodity markets. However, the price at which the household values a commodity will be generated by the model depending on household trading status (net buyer, net seller or self-sufficient) which in turn is related to transaction costs. This means that the commodity prices are endogenously determined by the model and not exogenously given as it was the case in FSSIM.

2.7.2.4. Modelling market participation decision

The decision for a farm household to participate in the market depends hardly on transaction costs. Transaction costs are any costs that an agent incurs in order to perform a market transaction. They are caused by, for example, long distances to markets, high transportation costs, poor

Figure 4: Non-separable production and consumption decisions



Source: adapted from Sadoulet and De Janvry (1995)

infrastructure, non-competitive market structures, and incomplete information. A buyer facing transaction costs perceives the effective price of commodities he wants to buy as higher than the market price. Similarly, a seller facing transaction costs perceives the effective sale price as lower than the market price (Brooks et al., 2011). Due to these costs, production and consumption decisions become non-separable[13] and the household may choose to live in partial or total autarky (Henning and Henningsen, 2007). As long as markets are perfect for all goods, farm-households are indifferent between consuming own-produced and market-purchased goods and allocate indifferently production between consumption and market sales. However, if there are market failures, a household approach might be necessary depending on whether the good for which market fails is important in household production (Singh et al., 1986). As this situation is very common in many low income economies, FSSIM-Dev was designed to take transaction costs into account and to endogenously capture market participation decisions. This is achieved using the concept of price band, based on market price (p^m) and multiplicative transaction costs (t). Figure 4 illustrates this situation.

As shown in Figure 4, the wedge between buying price and selling price generated by transaction costs leads to discontinuous behaviour in which the household could be a net buyer, a net seller, or self-sufficient. The price at which the household (h) values a commodity *j* will thus generated by the model depending on the household trading status.

- If the household's marginal cost (supply) curve crosses its demand curve above the price band, then the household is a net buyer and its buying price will be ($p_{h,j} = p^m_j t^b_{h,j}$) higher than market price $(t^b_{h,j} \ge 1)$
- If the household's marginal cost (supply) curve crosses its demand curve below the price band, then the household is a net seller and its selling price will be ($p_{h,j} = p^m_j t^s_{h,j}$) lower than market price $(t^s_{h,j} \le 1)$
- If the household's marginal cost (supply) curve crosses its demand curve within the price band, then the household does not participate in the market (self-sufficient) and its internal shadow price will be used to values the consumed quantities of goods. The shadow price is determined by the intersection of household supply and demand and varies among households according to their resource endowment and socio-economic conditions (i.e. households use their own internal shadow price if and only if they do not participate in the market).

$$p^m_j t^s_{h,j} \le p_h \le p^m_j t^b_{h,j}$$

13 Non-separability can result from other factors as well, such as market power, risk, and imperfect substitutability between home goods and purchased goods (see Roe and Graham-Tomasi, 1986; Sadoulet and De Janvry, 1995).

For modelling market participation decision in FSSIM-Dev three blocks of equations are included:

- The first block for setting an upper and a lower bounds for commodity prices

$$p_{h,j} \le p_j^m t_{h,j}^b \qquad p_j^m t_{h,j}^s \le p_{h,j} \tag{47}$$

The second block, so-called complementary slackness conditions, is used to guarantee that a farm household use its own internal shadow price if and only if it does not participate in the market for goods.

$$s_{h,j}(p_{h,j} - p_j^m t_{h,j}^s) = 0 \qquad b_{h,j}(p_{h,j} - p_j^m t_{h,j}^b) = 0 \tag{48}$$

The third block to ensure that a farm household can be either a buyer or a seller but not both (households can also be self-sufficient, i.e. neither buying nor selling goods).

$$s_{h,j} b_{h,j} = 0 \tag{49}$$

where **s** is the (n×1) vector of sold quantities of goods, **b** is the (n×1) vector of bought quantities of goods, $\mathbf{p^m}$ is the (n×1) vector of market prices of goods, **p** is the (n×1) vector of farm household prices of goods and $\mathbf{t^b}$ et $\mathbf{t^s}$ are (n×1) vectors of multiplicative buyer and seller transaction costs, respectively.

Having transaction costs in the model requires that we explicitly express a cash constraint for households. The following cash constraint, imposed in FSSIM-Dev, states that the total value of inputs, goods and tradable factors that a household can purchase is constrained by its total cash income from the market sales of goods and tradable factors plus production subsidies and (exogenous) off-farm incomes if they exists.

$$\sum_j s_{h,j} p_{h,j} + \sum_j s_{h,tf} p_{h,tf} + \sum_i sb_{h,i} x_{h,i} + exinc_h \ge \sum_j b_{h,j} p_{h,j} + \sum_j (b_{h,tf} + \lambda'_{h,tf}) p_{h,tf} + \sum_j a_{h,i} x_{h,i} \tag{50}$$

where **s** the (n×1) vector of sold quantities of goods *j* or tradable factors *tf* (land, labour and equipment), **p** is the (n×1) vector of prices of goods *j* or tradable factors *tf*, $\mathbf{c^s}$ is the (n×1) vector of self-consumed quantities of goods, **b** is the (n×1) vector of bought quantities of goods or rented-in tradable factors, **sb** is the (n×1) vector of production subsidies, **a** is the (n×1) vector of accounting costs and **exinc** is the exogenous off-farm incomes for households.

To ensure commodity balance at household level (h) after the inclusion of this consumption function, a new constraint was embedded in the FSSIM-Dev constraint system. This constraint implies that the sum of production and market demand for each good must be equal to consumption plus market sales.

$$q_{h,j} + b_{h,j} = s_{h,j} + c_{h,j} \tag{51}$$

where **q** is the (n×1) vector of produced quantities of goods, **b** is the (n×1) vector of bought quantities, **s** is the (n×1) vector of sold quantities and **c** is the (n×1) vector of consumed quantities.

According to this new specification, the general mathematical formulation of the FSSIM-Dev, at farm household level, can be presented as follows:

$$Max\ V = \sum_{h=1}^{H} w_h U_h \qquad U_h = R_h - \phi_h \sigma_h \tag{1}$$

S.t.

- Resource constraints

$$A_h x_h \le B_h + b_h - s_h \tag{2}$$

- Linear expenditure system (LES)
- Price bands & complementary slackness conditions
- Market clearing conditions
- Cash constraint

where **V** is the value of the objective function, **h** denotes representative farm household and **w** its weight within the village, region or region, **U** is the farm household utility**,** **R** is the farm household expected income, ϕ is the risk aversion coefficient and σ is the standard deviation of farm agricultural income due to price and yield variation, **p** is a (n×1) vector of prices of goods *j* and **x** is the (n×1) vector of the simulated levels of the agricultural activities *i*. **A** is a (n×m) matrix of technical coefficients, **s** is a (m×1) vector of rented-out tradable factors, **b** is a (m×1) vector of rented-in tradable factors and **B** is a (m×1) vector of initial available resources and upper bounds to policy and cash constraints.

2.7.3. Conclusion

This section presented the main structure of the FSSIM-Dev household module. The main efforts were focused on developing a generic, computable modelling of farm-household consumption decisions, and easily implementable within the FSSIM-Dev framework. Apart its consistency with theoretical literature, this household formulation requires little information on households' consumption behaviours. Elasticities of demand and Frisch parameter suffice to parameterize the model. Furthermore, this approach accounts for the existence of a price-band which offers guidance for analysing the effects of transaction costs on household's production and consumption responses.

2.8. Trend and policy modules

2.8.1. Outlook parameters for building baseline scenario

FSSIM-Dev structure offers the possibility of building a specific baseline scenario to use as reference for the interpretation and analysis of different policy scenarios. The baseline scenario (also known as 'reference' or 'benchmark' or 'non-intervention' scenarios) is interpreted as a projection in time covering the most probable future development in term of technological and market changes. In some case, the baseline may be a simple projection of the current situation assuming no changes (the expression *"Business as Usual"* scenario is generally used to specify this kind of baseline) and in other cases, the baseline may change drastically. The principal outlook parameters predefined in the FSSIM-Dev trend module that can be used to build the baseline scenario are the following: inflation rate, price projection, yield growth and farm structure change. These parameters are accessible from FSSIM-Dev GUI (see section 3.7) and can be manipulated easily by the user without going through the GAMS code.

2.8.1.1. Inflation

Regarding inflation the user has to precise through the GUI the inflation rate and the model inflates automatically all monetary values (i.e. all input out puts prices as well as premiums and PMP terms) using the following inflation coefficient:

$$Inflation = (1 + \inf/100)^{(Ybl\_Yby)} \qquad (52)$$

- Ybl is the year in which baseline was performed
- Yby is the year in which base year was performed
- inf represents the inflation rate (in %)
- Inflation represents the inflation coefficient

2.8.1.2. Price projection and yield growth

FSSIM-Dev offers the possibility of varying market prices and yields between base year and baseline in order to take into account technological innovation and market changes. This can be performed through the GUI using data from others sources/studies or by simply assuming a certain percent change. The baseline default value of market price (i.e. price projection) and yield changes (i.e. yield growth) are equal to zero and changing them for example to +10 and +20 will increase price and yield by +10 and +20 percent, respectively. Note that negative percent (i.e. -10 and -20) are also possible.

$$p_j^{bl} = p_j^{by}\left(1 + \Delta p_j/100\right) \qquad (53)$$

- p_j^{by} is a vector of average market prices used in the base year
- p_j^{bl} is a vector of average market prices used in the baseline scenario
- Δp_j is a vector representing the percentage change of average market prices between base year and baseline. This vector, expressed in percent, is given by users through FSSIM-Dev GUI.

$$Y_{j,i}^{bl} = Y_{j,i}^{by}\left(1 + \Delta y_j/100\right) \qquad (54)$$

- $Y_{j,i}^{by}$ is a vector of average yield of each crop product within agricultural activity used in the base year
- $Y_{j,i}^{bl}$ is a vector of average yield of each crop product within agricultural activity used in the baseline scenario
- Δy_j is a vector representing the percentage change of average crop yield between base year and baseline. This vector, expressed in percent, is related to crop and not to activity and it is given by users through FSSIM-Dev GUI.

2.8.1.3. Farm structure change

Users can also assume that farm structure could change between base year and baseline due to market and policy changes or because of new resource availability. In such case, it is necessary to change farm resource endowments especially, land, labour and equipments. This can be achieved by varying either the weight of each representative farms or the Right-Hand Side (RHS) coefficients of resource constraints (i.e. increases or decreases farm size, available irrigable land, available labour, available water ...) using the structure change parameters (Δr_f) stored on the FSSIM-Dev database and accessible from the FSSIM-Dev GUI. The baseline default values for these parameters are zero and are implemented as follow:

$$B_{h,f} = B_{h,f}^{by}\left(1 + \Delta r_{h,f}/100\right) \qquad (55)$$

- $B_{h,f}^{by}$ is a vector of RHS coefficients of resource constraints used in the base year
- $B_{h,f}$ is a vector of RHS coefficients of resource constraints used in the baseline scenario
- Δr_f is a vector representing the percentage change of RHS coefficients between base year and policy scenarios. This vector, expressed in percent, is given by users through FSSIM-Dev GUI.

2.8.2. Policy parameters

In addition to representing farmer behaviour in the base year and forecasting his/her reaction under baseline scenario, FSSIM-Dev structure provides the possibilities of simulating the impact of market change, technological innovation and water pricing policies. This makes it possible thanks to a set of policy parameters included in the FSSIM-Dev GUI and which can be easily handled by users.

2.8.2.1. Market price change

The change in market prices can be performed through the GUI using exogenous assumption or data from others sources/studies. This would concern either output (j) or input (k) prices. In case of missing data on disaggregated account costs per input categories, user can simulate the impact of varying total account costs.

$$p_j = p_j^{bl}\left(1 + \Delta p_j / 100\right) \qquad (56)$$

- p_j^{bl} is a vector of output market prices used in the baseline
- p_j is a vector of output market prices used in the policy scenario
- Δp_j is a vector representing the percentage change of output prices between baseline and policy scenarios. This vector, expressed in percent, is given by users through FSSIM-Dev GUI.

$$p_k = p_k^{bl}\left(1 + \Delta p_k / 100\right) \qquad (57)$$

- p_k^{bl} is a vector of input market prices used in the baseline
- p_k is a vector of input market prices used in the policy scenario
- Δp_k is a vector representing the percentage change of average input prices between baseline and policy scenarios. This vector, expressed in percent, is given by users through FSSIM-Dev GUI.

2.8.2.2. Transaction costs change

The user can also change, through the FSSIM-Dev GUI, the value of transaction costs expressed as the difference between the farm household selling/buying prices and the market prices. In the absence of transaction costs (i.e. transaction costs equal to zero), the multiplicative buyer and seller transaction costs (t) are equal to one and the farm household prices are equal to market prices (i.e. separable regime). In such situation, the farm household model is collapsed to a farm supply model working with exogenous prices and an additional constraint of consumption. In contrary, in the presence of transaction costs (i.e. transaction costs are positives), farm household's prices are different to market prices and production and consumption decisions are non-separable and the household may choose to live in partial or total autarky.

$$\begin{aligned} p_{h,j} &\le p_j^m t_{h,j}^b \\ p_j^m t_{h,j}^s &\le p_{h,j} \end{aligned} \qquad (58)$$

where $\mathbf{p^m}$ is the (n×1) vector of market prices of goods, $\mathbf{p}$ is the (n×1) vector of farm household prices of goods and $\mathbf{t^b}$ et $\mathbf{t^s}$ are (n×1) vectors of multiplicative buyer and seller transaction costs, respectively.

2.8.2.3. Technological change

FSSIM-Dev provides the possibility of simulating the impact of alternative activities if they are explicitly defined and included in the list of agricultural activities. These alternative activities could be new crops, new variety, new crop rotations, new management practices … This option exists already within the FSSIM, but what is new here is that they can be easily switched on/off from FSSIM-Dev GUI.

2.8.2.4. Water tariff policies

Water resource plays a central role in the sustainability of agricultural systems of many economies, both developing and developed. Because of its scarcity and inefficiency use, it has been the focus of many intervention policies which seek multiple objectives, including income transfer, food production, environmental sustainability, and resource conservation. These policies are based on a plethora of policy instruments, namely water pricing, quotas, water right assignments…

Because water is a common problem of many economies, the template of FSSIM-Dev was designed to allow the simulation of different water pricing policies and to help policy makers and research in assessing their impacts. Among the set of water tariff that can be tested through the FSSIM-Dev GUI are:

- Fixed tariffs (independent to water consumption)
- Volumetric tariffs proportional to water consumption (linear tariffs)
- Volumetric tariffs increase with water consumption (increasing-block-rate tariffs)
- Binomial tariffs where a volumetric tariff is combined with a fixed tariff
- These water tariff policies are handled in FSSIM-Dev using three equations:
- The first equation expresses that the sum of water requirement for irrigated activities cannot exceed the water availability.

$$\sum_i \left(A_{h,i,\text{"water"}} x_i\right) \le B_{h,\text{"water"}} \qquad (59)$$

where

- $A_{h,i,\text{"water"}}$ is a vector of water requirement for each agricultural activity *i*
- $B_{h,\text{"water"}}$ is a vector of water availability

- The second equation is related to the upper bound of each water block and expresses that the consumed water in each block cannot exceed the water availability per block.

$$Qw_{h,wb} \leq Aw_{h,wb} B_{h,"irland"} \quad (60)$$

where

- wb indexes water blocks (3 blocks are included: w1, w2 and w3)
- $Qw_{h,wb}$ is a vector of consumed water per block
- $Aw_{h,wb}$ is a vector of available water per block and per hectare of irrigable land
- $B_{h,"irland"}$ is a vector of available irrigable land

- The last equation is used to compute water costs to be included in the objective function

$$Qw_{h,wb} \leq Aw_{h,wb} B_{h,"irland"} \quad (61)$$

where

- fp is a vector of fixed water price per hactare of irrigable land
- vp_{wb} is the block-rate water price per unit (i.e. m3).
- $QW_{h,wb}$ is a vector of consumed water per block
- $B_{h,"irland"}$ is a vector of available irrigable land

2.9. Transition from farm to aggregated levels

This section presents the required adjustments in the existing modules as well as the set of new variables and equations to develop for facilitating the transition of impact analysis from farm to village/regional and national levels. These adjustments and new equations make it easy, on the one hand, the inter-linkage of all individual farm household models into one aggregate model and, on the other hand, the modelling of interaction among farm households for market factors (land, labour and equipments) which are very common in developing countries. The development of this part of the model has started within the BECRA project[14], however only from technical point of view. Most of the conceptual issues linked to aggregation process are investigated within this study. Among this, we can recall the aggregation bias, such as unrealistic product specialization or/and excessive resources exchange, which may arise if farms are not properly aggregated. In addition to traditional methods for reducing aggregation bias, likely grouping farms with similar characteristics (Buckwell and Hazell, 1975), assuming multiple crop production activities (Heady and Srivastava, 1975) and using rotations instead of single crops (Heady and Srivastava, 1975) which are already taken into account in FSSIM, a calibration procedure based on PMP (Paris et al., 2011) has been implemented in order to estimate transaction costs and eliminate (or at least reduce) aggregation errors.

2.9.1. Adjustment of existing modules to facilitate aggregation

2.9.1.1. Simultaneous optimisation of farm level models

It consists of including three new dimensions (i.e. index positions) on data and variable structure in all the existing modules in order to make it easy the simultaneous solve of several farm models reproducing the behaviour of different farm types. These dimensions are (Ms,Re,Ft), where Ms indexes Member state (or country or region), Re indexes region (or zone or sub-region or village) and Ft indexes farm household type. Thanks to this technical specification, it will be possible to simulate the interactions among farms for factor markets (land, labour and capital) as well as for common resources (e.g. common pasture), which are very important in developing countries. It permits as well the aggregation of results from farm household to village, regional or national levels.

With this new specification, the FSSIM-Dev objective function, implemented in the common module, becomes the maximization of the weighted sum of representative farm households' utility. Utility is defined as farm household expected income minus its standard deviation due to risk averse towards price and yield variation. The general mathematical formulation of the model is now the following:

$$Max\ V = \sum_h w_h U_h \quad \text{with} \quad U_h = R_h - \phi_h \sigma_h \quad (62)$$

where **V** is the value of the objective function, **h** denotes representative farm households and **w** their weight within the village/region, **R** is the farm household expected income, ϕ is the risk aversion coefficient and σ is the standard deviation of agriculture income due to price and yield variation.

In addition to changing the model's objective function, a set of adjustments have to be included within the aggregation process for reflecting competition among farms for factor markets and common resources. This implies that a set of new equations has to be included to balance the demand and supply for goods and tradable factors at the aggregated (regional, district or village) level. This is expressed by the clearing conditions explained below.

14 BECRA: Bio-Economic analysis of climate change impact and adaptation of Cotton and Rice based Agricultural production systems in Mali and Burkina Faso (2010, CE).

2.9.1.2. Modelling the possible exchange of tradable factors among farm households

Land, labour and equipment (i.e. capital) are assumed to be tradable factors and can be exchanged among farms within the same region (or village). For modelling the possible exchange of tradable factors among farm households, a new variable was included in the right Right-Hand Side (RHS) of resource constraints. That is to say that for each farm household (h) and for each tradable factor (tf), the required quantity of factor should be less or equal to initial available quantity plus quantity rented-in minus quantity rented-out (i.e. traded quantities)[15].

$$\sum_i A_{h,i,tf} x_{h,i} \le B_{h,tf} + s_{h,tf} - b_{h,tf} \qquad (63)$$

where **h** indexes farm household, **i** indexes agricultural activities, **tf** indexes tradable factors (land, labour and capital), **A** is a (m x n) matrix of input coefficients (i.e. input use of factor tf into activity i), **B** is (n×1) vector of initial resources endowment and **s** and **b** are (n×1) vectors of rented-out and rented-in tradable factors, respectively.

The second adjustment is by adding into the FSSIM-Dev objective function the cost/benefit from trading production factors.

$$Tradefactors\_outcome = \sum_{tf} w_h (s_{h,tf} - b_{h,tf}) p_{h,tf} \qquad (64)$$

where **s** and b are (n×1) vectors of rented-out and rented-in tradable factors (tf) in each farm household (h) and **p** is a (n×1) vector of tradable factor prices.

2.9.2. Aggregation module

This module includes two market clearing conditions working at regional level: the first one for tradable factors and the second one for agricultural goods.

2.9.2.1. Regional balance for tradable factors

This balance equation implies that, for each region and for each tradable factor (tf), agricultural demand for factor plus the export of factor from other sectors should be equal to agricultural supply for factor plus the import of factor from other sectors, assuming a close regional market for tradable factors. This means that any surplus of tradable factors can be exported outside the agricultural sector at market prices. Conversely, any excess demand for tradable factors can be satisfied by importing from the others sectors within the same region (e.g. exchange of land and equipment among sectors are not allowed).

15 To facilitate understanding, we switch-off from the resource constraint the parameters used to capture seasonality and labor skills.

Regional tradable factors balance

$$\sum_h w_h s_{h,tf} + M_{tf} = \sum_h w_h b_{h,tf} + E_{tf} \qquad (65)$$

- *h* indexes representative farm household
- *tf* indexes tradable factors
- w is the weight of representative farm households within the region
- s is the quantities of tradable factors rented-out
- b is the quantities of tradable factors rented-in
- M is the imported quantities of tradable factors from other sectors within the region
- E is the exported quantities of tradable factors to other sectors within the region

2.9.2.2. Regional balance for commodity

Similar to the previous one, this balance equation expresses that for each trading region and for each agricultural good (j), the demand and the supply for goods should be in equilibrium at regional level, assuming a close regional market for goods.

Regional tradable factors balance

$$\sum_i A_{h,i,tf} x_{h,i} \le B_{h,tf} + s_{h,tf} - b_{h,tf} \qquad (66)$$

- h indexes representative farm household
- j indexes goods
- w is the weight of representative farm households within the region
- s is the sold quantities of goods
- b is the bought quantities of goods
- M is the imported quantities of goods from other sectors within the region
- E is the exported quantities of goods to other sectors within the region

The main question arising from this step is how to ensure that the model reflects correctly the exchanged production factors between farms and how to capture transaction costs if they exist. The following section present a new calibration procedure developed in Paris et al (2011) which can be used for answering such kind of questions.

2.9.3. Calibrating aggregate farm household models

Aggregation is an important issue when modelling the agricultural sector using mathematical programming. Serious error, such as unrealistic product specialisation and excessive resource exchange, may arise if farms are not properly aggregated (Onal and McCarl, 1991). Apart from the fact that mathematical programming models suffer from over-specialization of the optimal solution, the main cause of this discrepancy often originates in the transaction costs linked to the trade of market factors across farms. In general, this piece of crucial information is measured with a degree of imprecision.

This section presents a calibration procedure which exploits all available information to make aggregate model generate solutions that perfectly reproduce the supply and demand of goods at individual level as well as the trade flows for a given base year. Based on PMP approach this procedure attempts (i) to calibrate the model and guarantees exact reproduction of observed production and consumption levels of the base year; and (ii) to estimate the effective marginal cost of tradable factors. As explained in the previous section, PMP application is performed through three steps: in the first step a set of calibration constraints is added. This set of constraints binds production (q) and rented-in (b) tradable factors to their observed levels (q^0 and b^0) at the base year period. The mathematical formulation of the PMP first step is the following:

$$Max\ V = \sum_h w_h \begin{bmatrix} \sum_j (s_{h,j} + c^s_{h,j}) p_{h,j} + \sum_i sb_{h,i} x_{h,i} - \sum_i a_{h,i} x_{h,i} \\ - \sum_{tf} b_{h,tf} p_{h,tf} - \sum_j b_{h,j} p_{h,j} - fc_h - \varphi_h \sigma_h \end{bmatrix}$$

$$\begin{aligned} & s.t. \\ & A_{h,f} x_{h,f} \leq B_{h,f} + b_{h,f} - s_{h,f} \quad [\rho_{h,f}] \\ & q_{h,j} \leq q^0_{h,j}(1+\varepsilon) \quad [\lambda_{h,j}] \\ & b_{h,tf} \leq b^0_{h,tf}(1+\varepsilon') \quad [\lambda'_{h,tf}] \\ & x \geq 0 \end{aligned} \tag{67}$$

where and are vectors of small positive numbers for preventing linear dependency between the resource and the calibration constraints. The dual values of the first calibration constraints represent the implicit (i.e. unobserved) costs related to production process (Howitt, 1995a). The dual value of the second calibration constraint, which may be either positive or negative, can be interpreted as the implicit unit costs (i.e. unit transaction costs) linked to exchange of tradable factors (for further details on this procedure see Paris et al., 2011). The same calibration procedure could be applied for the other tradable factors (land, capital) if data on observed traded quantity is available.

In the second step the dual valuesis employed to estimate the parameters **d** and **Q** of the non-linear implicit costs (the procedure for estimating these parameters are explained in the section dealing with calibration module).

In the third and last step, the calibration constraints of the first stage are removed and the estimated non-linear implicit cost functions as well as the implicit labour costs are embedded into the objective function. The model is now calibrated and can be used for assessing farm household's response to parameter variations of interest from a policy viewpoint. The final mathematical structure of the FSSIM-Dev is presented in Appendix 1.

2.10. Conclusion

This section presented a detailed description of the template of the FSSIM-Dev model to be used for ex-ante assessment of agri-food and rural policies on the livelihood of farm-households in developing countries. In addition to the set of improvements included within the existing FSSIM modules such as crops, calibration, trend and policy modules, this version involves three new modules which are indispensable for representing farm-household behaviours in developing countries: household, perennial and aggregation modules. Moreover, FSSIM-Dev involves advanced technical aspects which can increase model re-usability and applications for different case studies and policy scenarios.

The next section describes the components of FSSIM-Dev newly developed under the current project framework, such as the electronic survey, the database and the Graphical User Interface of the FSSIM-Dev. After a detailed technical description of these components, the first application of the FSSIM-Dev model is illustrated via an example in Sierra Leone to ex-ante assess the impacts of new cropping managements in the livelihood of a set of representative farm households.

3. FSSIM-Dev Components & Technical Implementation

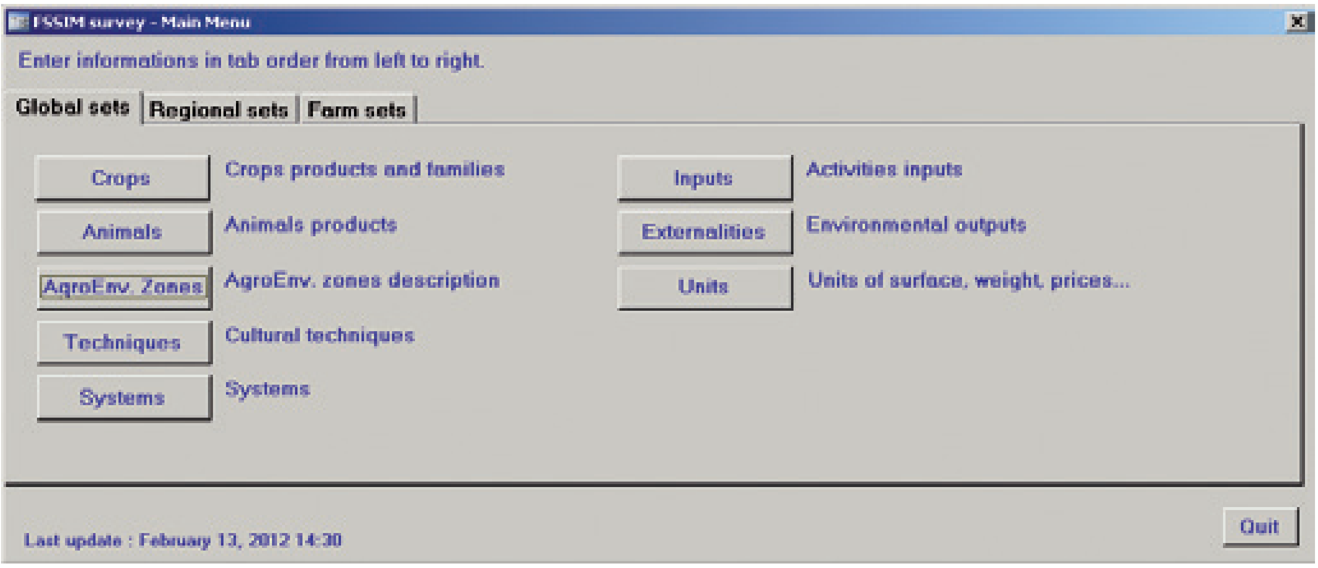
3.1. Introduction

FSSIM-Dev, described in the previous section, is developed using GAMS (General Algebraic Modelling System) software which is a high-level modelling system for mathematical programming and optimization technique. It is solved using a well suited solver for non-linear programming model, namely CONOPT. An Electronic survey was used to enter, visualize and manage data in the FSSIM-Dev Database. A friendly User Interface was developed on the Windev (PC-Soft©) programming environment to extract data from the Database into text files readable by GAMS. This interface is also used for setting/defining policy scenarios, selecting calibration methods, the switching on/off modules & constraints, running policy scenarios and visualizing model results. This section gives a detailed description of these three FSSIM-Dev components: Electronic Survey, Database and Graphical User Interface. This could serve as a manual for users of FSSIM-Dev.

3.2. FSSIM-Dev Electronic Survey

The FSSIM-Dev Electronic survey is a User Interface developed in MS Visual Basic (VBA) to enter, visualize and manage data in the FSSIM-Dev Database. In order to launch the electronic survey, double-click on the *FSSIM-Dev Electronic survey.mdb* file should be made, the MS-Access will open, load the file and the main menu (Figure 5) will appear. This main menu allows access to the FSSIM-Dev data which can be grouped into 3 specific categories: global data, regional data and farm data. In the first category, the user defines (or selects from existing list) the set of crops, production technique and agri-environmental zone linked to his/her application. In the second category, after defining the set of agricultural activities (rotation, technique, agri-environmental zone and system) at regional level, he/she fills the data on input output coefficients linked to these activities. In the last category, the user fills farm data such as resources endowment and calibration data.

Figure 5. The main menu of FSSIM-Dev electronic survey



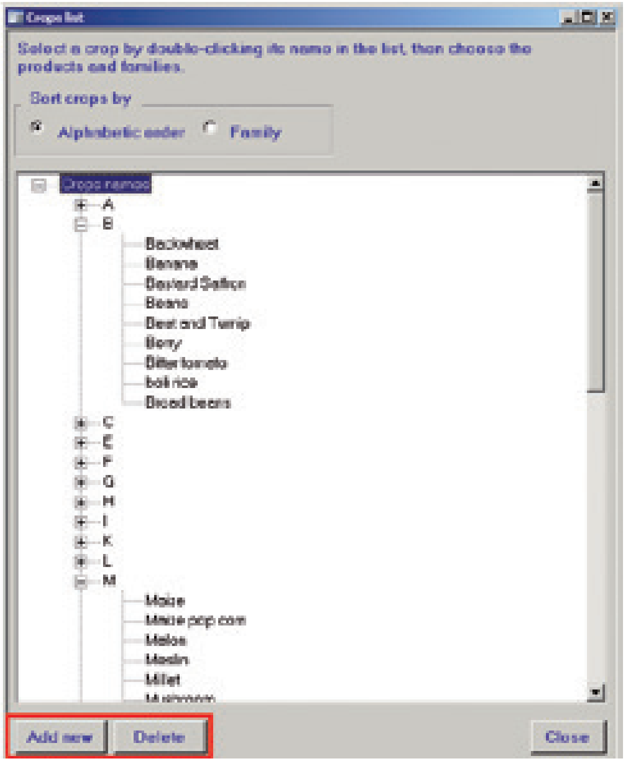
3.2.1. Global data

The global data includes all the information that can be used to define the set of agricultural activities, such as the lists of crops, agri-environmental zones (or soil type), production technique (agro-management) and production system. It includes as well the set of environmental indicators that can be computed by the model and their units. They are called Global because most of them are not region or farm specific.

3.2.1.1. Definition of crops

This button gives access to the list of crops (Figure 6) that already contains the main crops as defined by the FAO. The list can be sorted in alphabetic order or by crop families. By clicking on the 'Add new' button, the user can define a new crop. Selecting a crop in the list and clicking the 'Delete' button allows the user to delete a crop in the list.

Figure 6. Crop list form

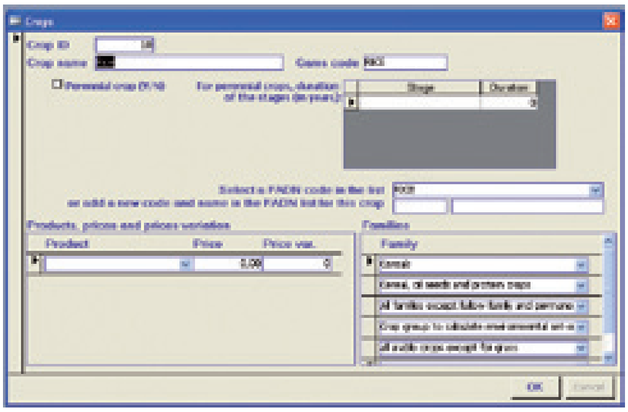


By double-clicking on the name of a crop, the crop form opens (Figure 7a) in which the crop data are defined:

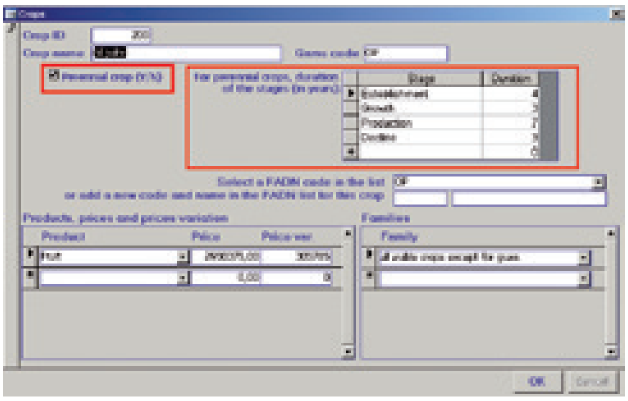
- *Crop name*: the full name of the crop
- *GAMS code*: the code used in the GAMS model to manipulate the crop
- *Perennial (Y/N):* the user has to specify if the crop is perennial or not. If yes, he/she has to define the duration (in years) of the different stages along the crop life: Establishment, Growth, Production, Decline (Figure 7b).
- *FADN code:* this combo box contains the list of crops retained in the European FADN database. The FADN crops list is more aggregated than FSSIM crops list and in some cases due to data missing, model calibration could be based on FADN list rather than on FSSIM list. In such case, the user must create a relational mapping between the two lists of crops.
- *Products, prices and prices variation:* each crop can produce different products (for example, rice can produce grain and straw). The combination set of crops-products are chosen from a list and then for each combination crop-product, the average price per unit and the price variation (the price variation is usually the standard deviation of the prices across several years) have to be defined.
- *Families:* each crop can be associated with one or more crop families/groups.

Figure 7. Arable and perennial crops forms

(a) Arable crop



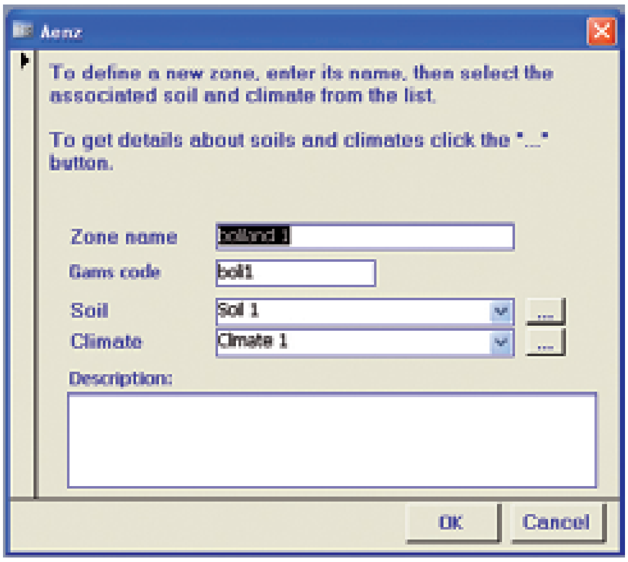
(b) Perennial crop



3.2.1.2. Definition of agro-environmental zones

This button gives access to the predefined list of agro-environmental zones. By clicking on the 'Add new' button, the user can define a new zone in the Agro-environmental zones form (Figure 8). In such case, it has just to give a name and a GAMS code to this new zone, to specify the soil and climate associated to this zone and if necessary a short description. The '...' buttons give access to the soil and climates lists, through which soils and climates can be defined in the same way.

Figure 8. Agro-environmental zones form



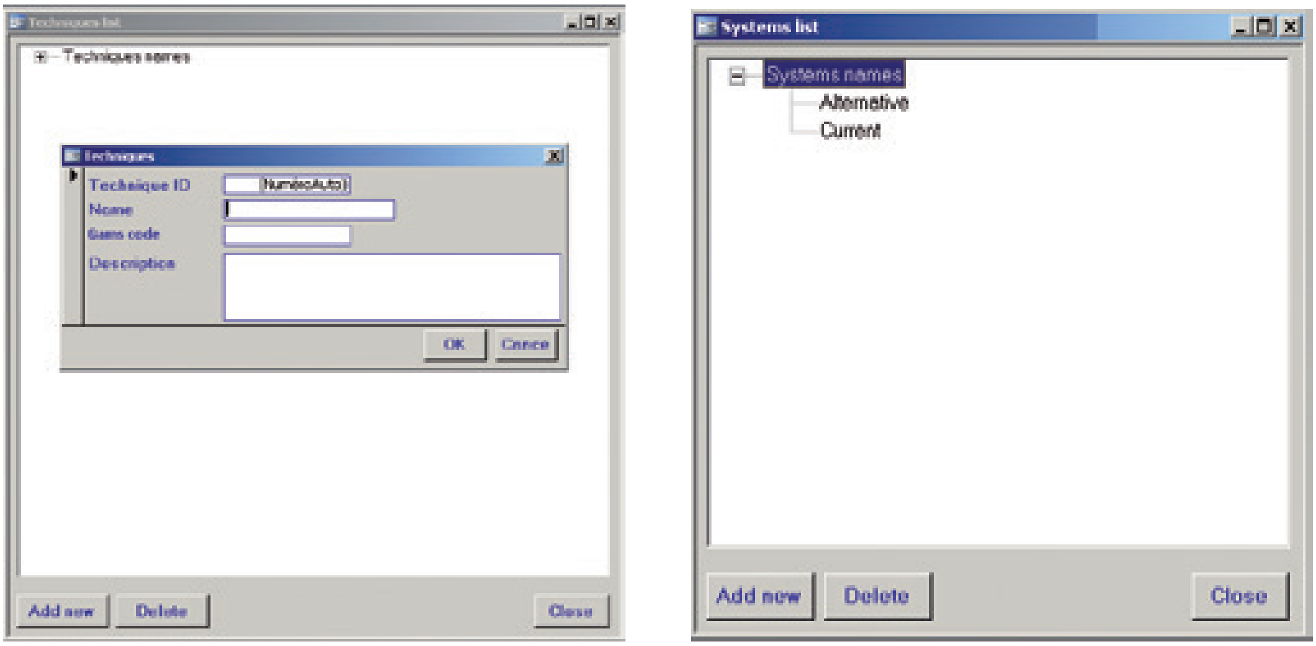
3.2.1.3. Definition of production techniques and production systems

These two buttons work in the same way and are used to define the production techniques and the production systems (Figure 9). Two production systems are already predefined and must not be deleted, i.e. current and alternative systems. The first one is linked to current agricultural activities and the second one to alternative activities.

Figure 9. Production techniques & Production Systems forms

(a) Production techniques

(b) Production systems

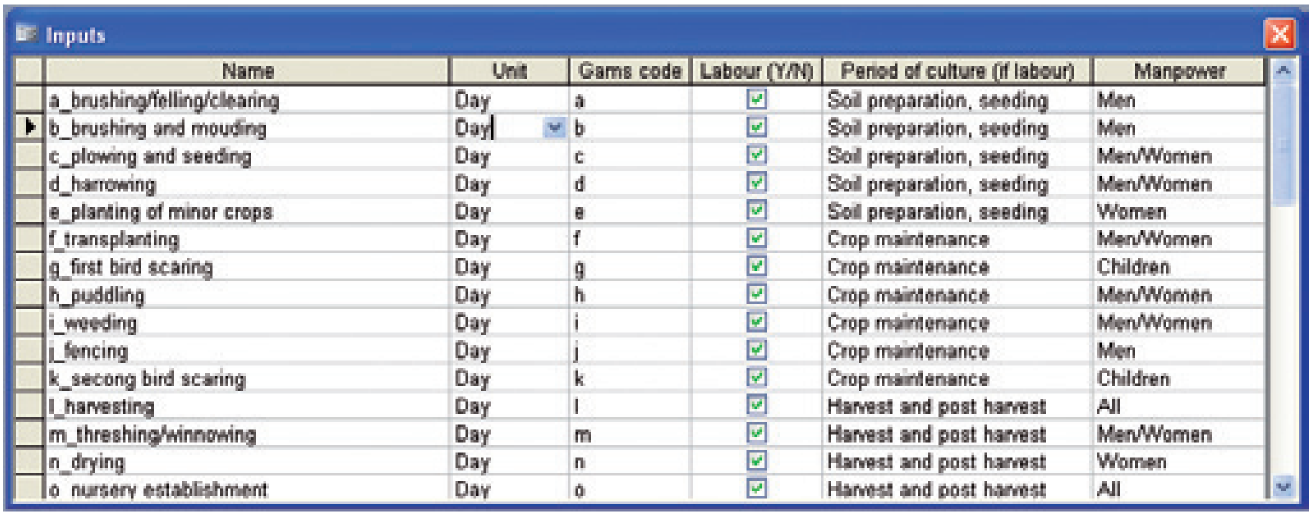


3.2.1.4. Specification of Input categories

In this screen, the user defines the different categories of inputs that will later be associated with each crop within the agricultural activities (rotations). For each input category the following information are needed:

- Input name.
- *Unit:* a combo box gives access to the units that are defined by the user (see 2.7, below).
- *Gams code:* a short code that refers to the input in the GAMS model.
- *Labour (Y/N):* checked if the input consists of labour (different from inputs like fertilizers, seeds, water etc.). For these inputs, the unit is 'Day'.
- *Period of cropping (if labour):* a combo box gives access to a list of periods in the cultural cycle of the crop, i.e. 'Soil preparation, seeding', 'Crop maintenance' and 'Harvest and post-harvest'. If necessary, the user can associate each labour input with one of these periods.
- *Manpower:* again for labour inputs, the user can associate a kind of manpower needed to accomplish that kind of work. From the combo box, the user can choose 'Men', 'Women', 'Children', 'Men/Women' or 'All'.

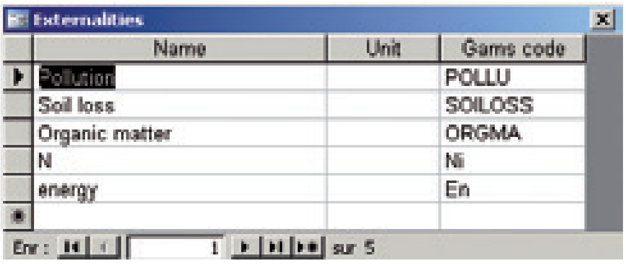
Figure 10. Inputs form


Inputs

Name	Unit	Gams code	Labour (Y/N)	Period of culture (if labour)	Manpower
a_brushing/felling/clearing	Day	a	☑	Soil preparation, seeding	Men
b_brushing and mouding	Day	b	☑	Soil preparation, seeding	Men
c_plowing and seeding	Day	c	☑	Soil preparation, seeding	Men/Women
d_harrowing	Day	d	☑	Soil preparation, seeding	Men/Women
e_planting of minor crops	Day	e	☑	Soil preparation, seeding	Women
f_transplanting	Day	f	☑	Crop maintenance	Men/Women
g_first bird scaring	Day	g	☑	Crop maintenance	Children
h_puddling	Day	h	☑	Crop maintenance	Men/Women
i_weeding	Day	i	☑	Crop maintenance	Men/Women
j_fencing	Day	j	☑	Crop maintenance	Men
k_secong bird scaring	Day	k	☑	Crop maintenance	Children
l_harvesting	Day	l	☑	Harvest and post harvest	All
m_threshing/winnowing	Day	m	☑	Harvest and post harvest	Men/Women
n_drying	Day	n	☑	Harvest and post harvest	Women
o_nursery establishment	Day	o	☑	Harvest and post harvest	All

3.2.1.5. Definition of environmental outputs

Figure 11. Externalities form



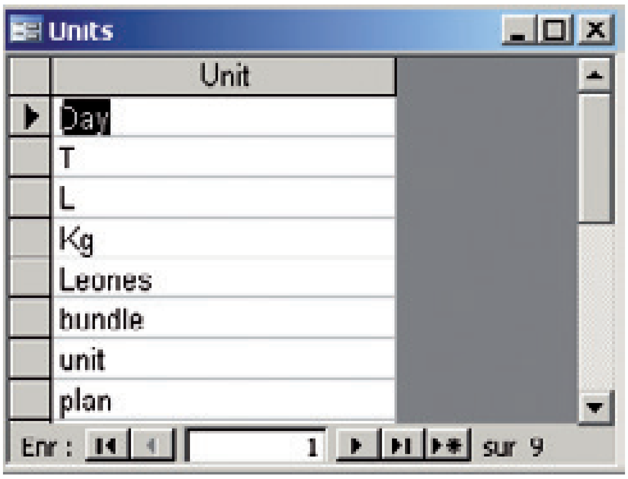
This form allows defining the set of environmental externalities (i.e. environmental outputs) to be computed by the model (Figure 11). Only the name, the unit and the GAMS code of the environmental outputs are included in this form.

- Name
- Unit
- Gams code

3.2.1.6. Definition of Unit

In this form, the units of different inputs and outputs can be defined.

Figure 12. Units form



3.2.2. Regional data

3.2.2.1. Definition of the study Region/Country

First, the user will choose in the combo boxes the State (i.e. Country) and the associated regions in which the survey takes place. If necessary, a new country (Figure 13a) or/and new regions (Figure 13b) can be defined.

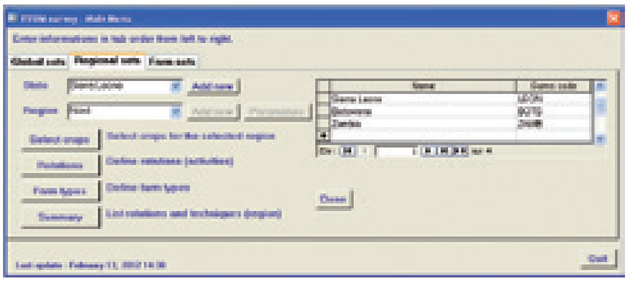
Each country has to be defined by its full name and GAMS code. By clicking on the 'Done' button, the sub-form will be closed and the data saved.

A new region is defined in the same way, but it has to be associated to a specific country. Clicking the 'Done' button will again close the sub-form and save the data.

The 'Parameter' button allows the user to enter the market prices of labour and water at regional scale (Figure 14).

Figure 13. Country and Region forms

(a) Defining Country



(b) Defining Region for the selected Country

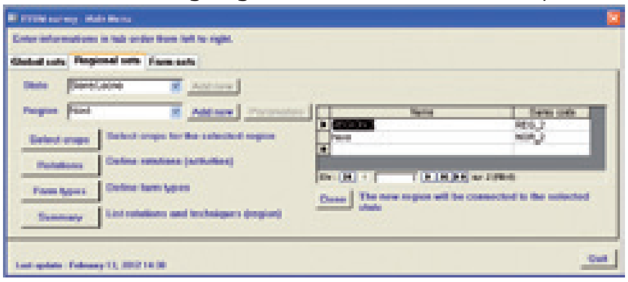
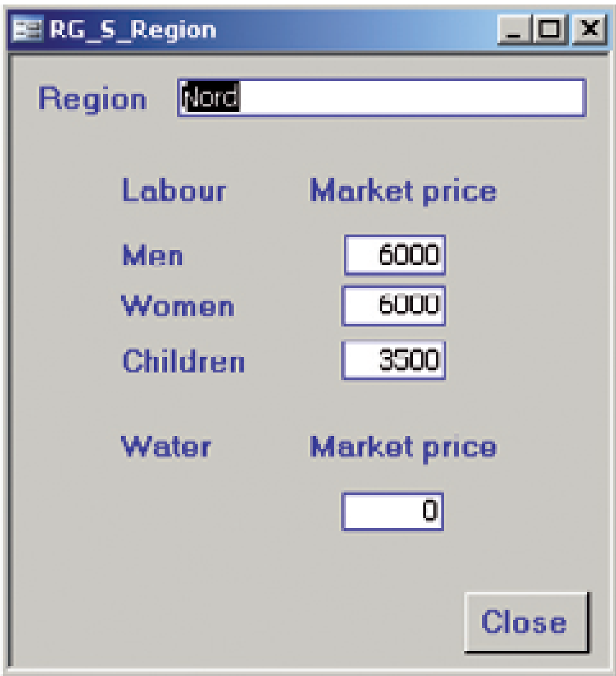


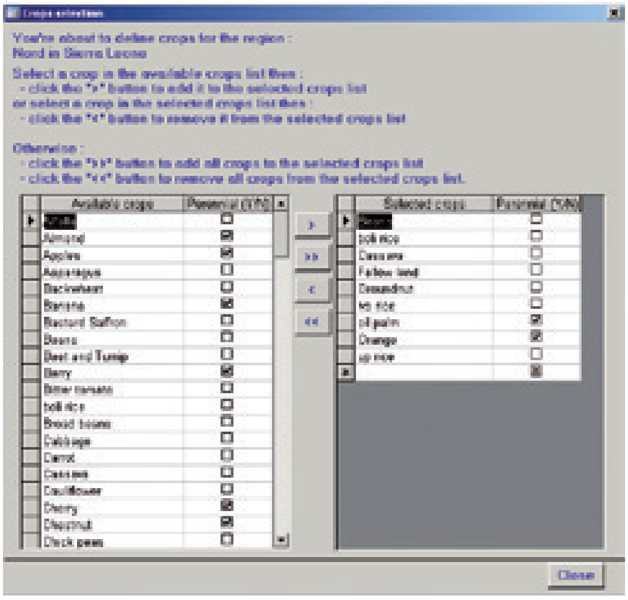
Figure 14. Input unit costs form



When a Country and a region have been selected, the user will then select, from a predefined list, the set of crops that can be cultivated in this region and define as well the set of crop rotations and farm types existing in this region.

3.2.2.2. Selection of relevant crops

Figure 15. Crops form



The set of crops that can be grown in the selected region are chosen from the list of all the crops (Figure 15) using one of these two buttons: '>' or '>>'. The '<' button is used to remove a crop; the '<<' button to remove all crops from the selected crops list.

3.2.2.3. Definition of crop rotations and agricultural activities

First, the user has to define the set of agricultural activities one by one by specifying for each of them its crop rotation and the agro-environmental zone in which it is grown (Figure 16). Then, for each crop within the rotation, it has to specify its order in the rotation, its production technique using the 'Technique' combo-box, and its growth stage if it as a perennial crop (Establishment, Growth, Production or Decline).

Each time a crop is added/deleted to/from the rotation, the rotation description is modified to reflect the succession of crops in the rotation.

If needed, the 'Duplicate' button will copy all information (including inputs/outputs) in a new line in the same rotation.

The buttons on the bottom-left of the form (▮◂▸▸▮▸*) are used to navigate between the set of agricultural activities that have been defined for the selected region and create a new activity.

3.2.2.4. Quantification of Input Output coefficients

IO coefficients are defined in FSSIM-Dev at regional level and they are not farm specific. To fill the data on labour requirement, input use, yield and environmental externalities associated to each crop within agricultural activity (Figure 17 to 20), the user has to click on the button 'Inputs/Outputs' to open a window with the following Tables.

Labour requirement:

In this screen the labour requirement for each crop within the rotation have to be defined. The user has to choose first the different input categories (planting, seeding, harvesting,

Figure 16. Rotations form

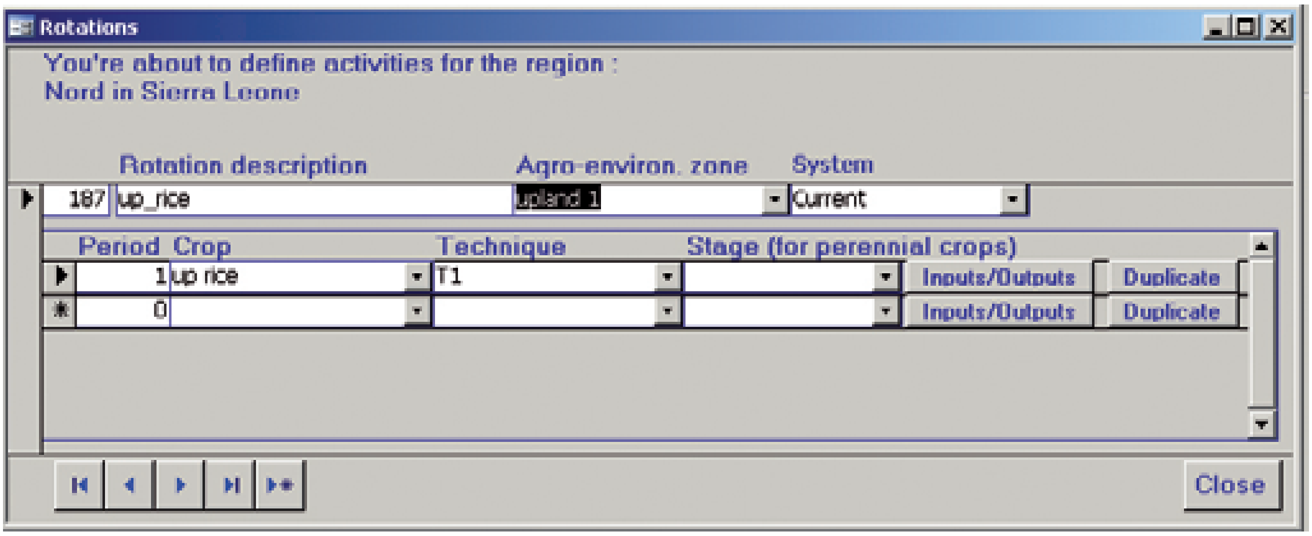
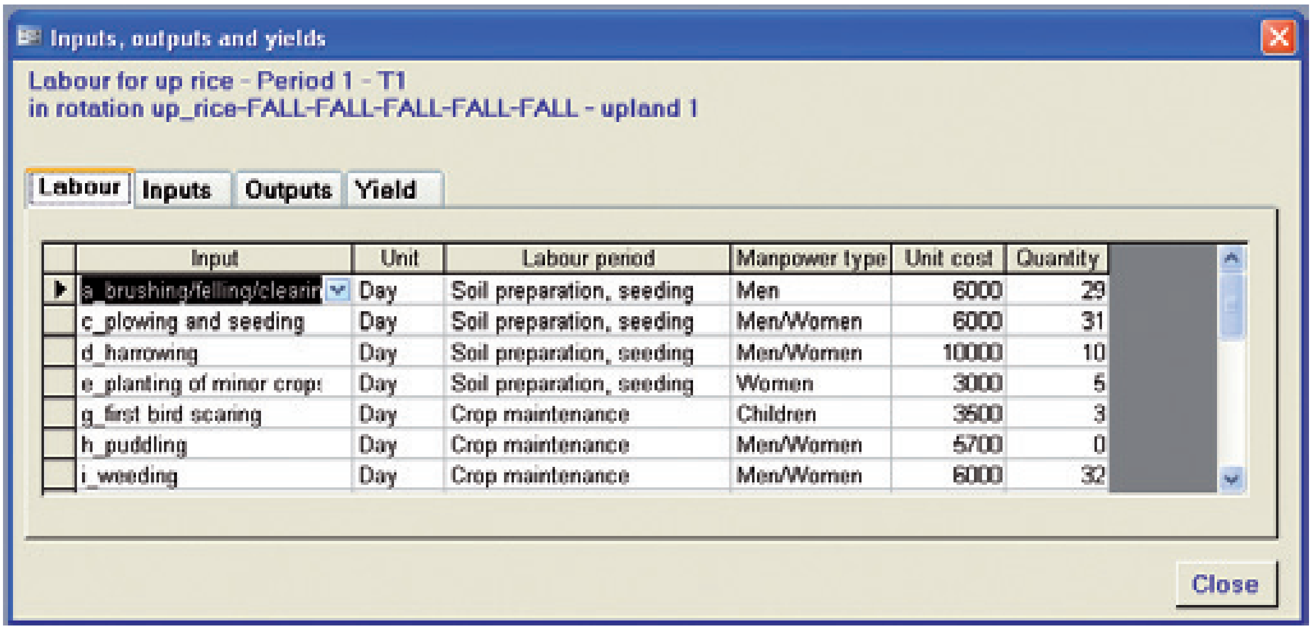


Figure 17. Labour requirement form



Inputs, outputs and yields

Labour for up rice - Period 1 - T1
in rotation up_rice-FALL-FALL-FALL-FALL-FALL - upland 1

Labour | Inputs | Outputs | Yield

Input	Unit	Labour period	Manpower type	Unit cost	Quantity
a_brushing/felling/clearin	Day	Soil preparation, seeding	Men	6000	29
c_plowing and seeding	Day	Soil preparation, seeding	Men/Women	6000	31
d_harrowing	Day	Soil preparation, seeding	Men/Women	10000	10
e_planting of minor crops	Day	Soil preparation, seeding	Women	3000	5
g_first bird scaring	Day	Crop maintenance	Children	3500	3
h_puddling	Day	Crop maintenance	Men/Women	5700	0
i_weeding	Day	Crop maintenance	Men/Women	6000	32

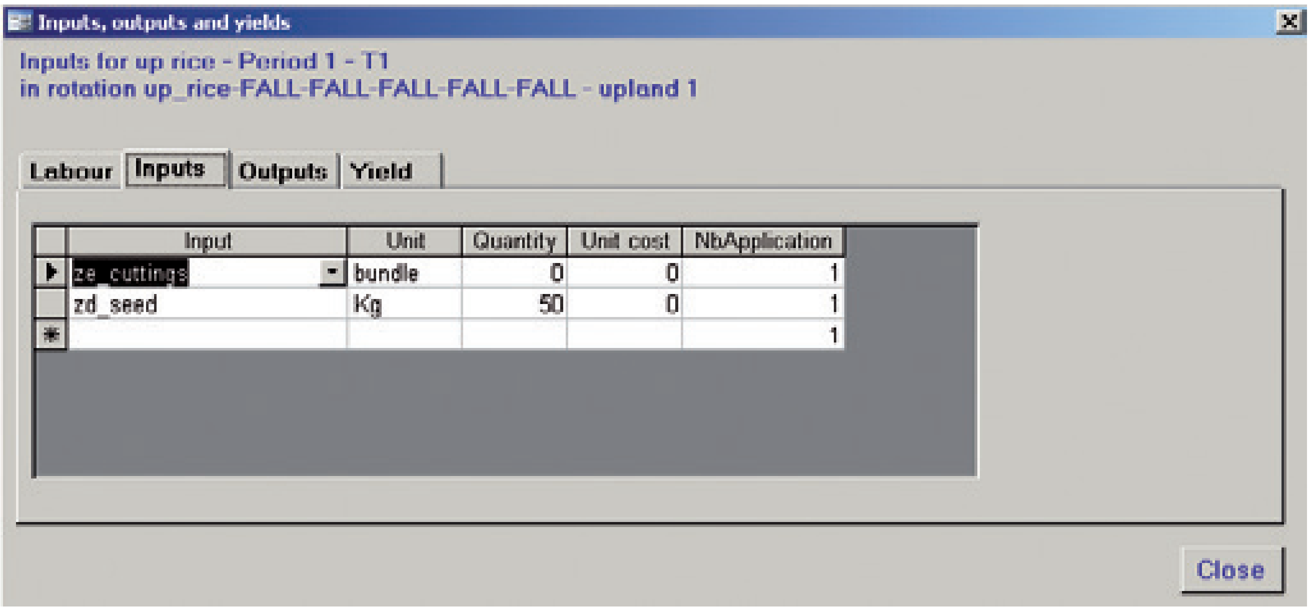
Close

etc.) from the combo box and then to set the unit cost and the quantity of labour (number of days required to execute the work) required by crop and by input category as well as the type of labour (men, women and children) that can do the work.

Input use:

For all input categories, the user has to select from the combo box the type of inputs (seed, fertiliser, water etc.) and to set the unit cost, the used quantity and, if necessary, a number of applications of this input for each crop within the rotation (for example in the case of water).

Figure 18. Inputs form



Inputs, outputs and yields

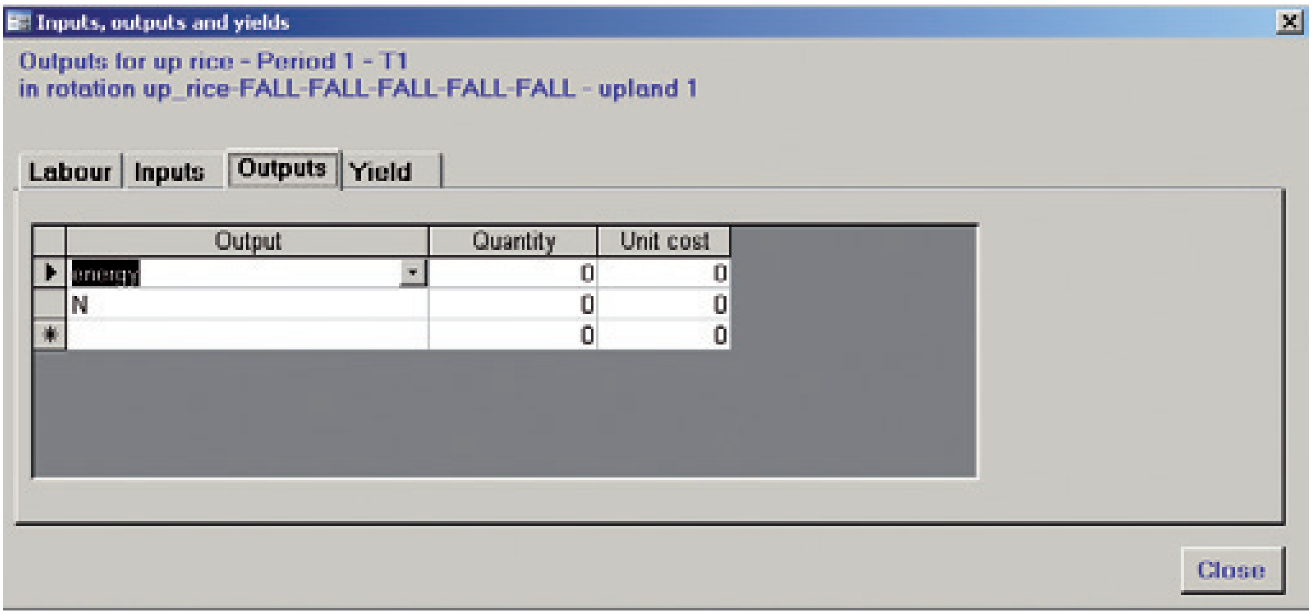
Inputs for up rice - Period 1 - T1
in rotation up_rice-FALL-FALL-FALL-FALL-FALL - upland 1

Labour | Inputs | Outputs | Yield

Input	Unit	Quantity	Unit cost	NbApplication
ze_cuttings	bundle	0	0	1
zd_seed	Kg	50	0	1
				1

Close

Figure 19. Outputs form



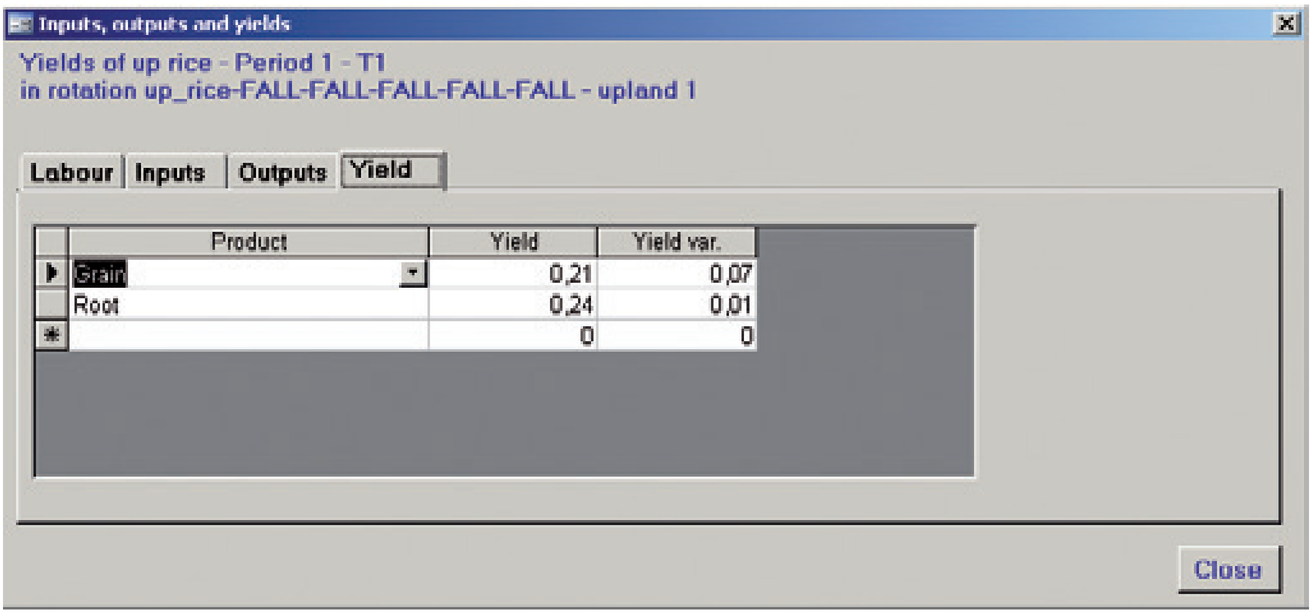
Environmental outputs:

The definition of outputs is made in the same way as input data (Figure 19).

Crop yield:

To define the yield of one crop, first the user has to choose from a combo box the set of products that can be associated to such crop and then to specify, for each crop product, the average yield and the yield variability defined by unit surface (usually 1 ha). (Figure 20).

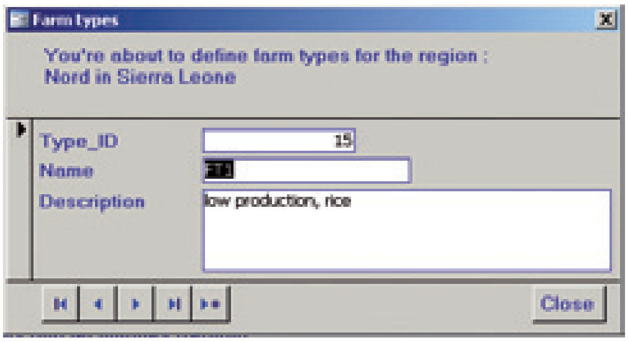
Figure 20. Crop yield form



3.2.3. Farm data

3.2.3.1. Definition of farm types

Figure 21. Farm types form



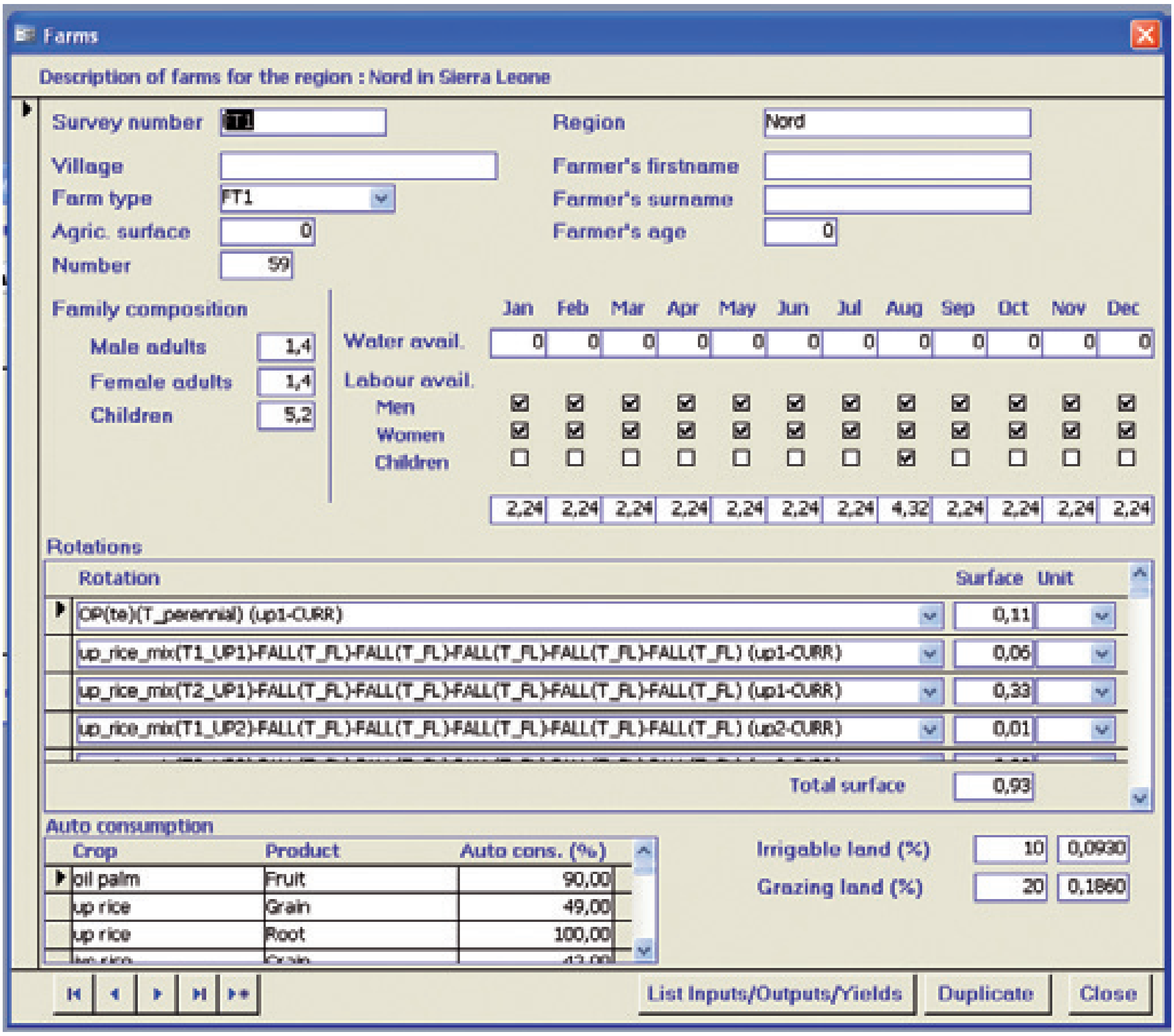
In this screen, the user defines the set of farm types representative of relevant farming systems on the study region. For each type, the user gives a name and a short description (Figure 21).

3.2.3.2. Setting Farm Data

This form (Figure 22) will allow the user to specify all the characteristics of each farm type mainly in terms of farms endowments (e.g. land, labour availability) and observed activity levels. Note that these farms can be real ones or virtual 'farm types' resulting of a typology. Note also that the farm is automatically linked to the selected region. The information to be added to the model is the following:

- *Survey number:* it can be a number or a short name that will be used as a GAMS code.
- *Farm type:* in case of real farms, they can be associated with a farm type as defined previously.

Figure 22. Farm data form



- *Number:* this number indicates how many farms in the region belonging to that type of farms.
- *Family composition:* the number of men, women and children in the family.
- *Active male adults, active female adults, active children:* the number of men, women and children available in each month for working in and off-farm.
- *Water availability*: the monthly water available for irrigation.
- *Observed activity levels:* here the user choose from the combo box the set of agricultural activities (rotations) that are grown in the base year (the year in which the survey was performed) and to set their respective areas.
- *Self-consumption:* for each crop produced during the base year a line is automatically added to set the percentage of production used for self-consumption.
- *Irrigable land, Grazing land:* for each farm type, the user gives the share of irrigable/grazing land in total area and then the corresponding area is calculated automatically.

3.3. FSSIM-Dev Database

Databases and data integration procedures are increasingly important in mathematical programming modelling applications, especially in the case of generic models which have been designed to assess numerous scenarios. The manual introduction of data either directly in the model or in text files is particularly error prone, difficult, and user hostile, and therefore infeasible for large models or multiple scenario simulations. FSSIM-Dev has been developed as a generic model aiming at increased model re-usability and applications of different case studies and scenarios. For reaching this aim, a model-specific Data Management Facility (DMF) was created. The DMF serves two purposes: it is used as a database for storing, manipulating and interfacing the FSSIM-Dev data (database module – DM), and as a tool for retrieving the data from the DM and transforming them into text files readable by GAMS (integration code module - ICM).

A number of approaches are available regarding data management and data integration into economic modelling. Typically used data management approaches for mathematical programming models written in GAMS involve the use of MS Excel, MS Access, and My SQL. My SQL is a well-established and free of charge database management system, but it is less wide-spread compared to MS Access or MS Excel. MS Excel is a widely used tool, lacking however the data management properties of a specialised database product, such as i) easier and faster data control, ii) possibility of using structured procedures for database population, iii) maintenance of data integrity, and iv) possibility of linking the database tool to other external databases and/or models. MS Access is a user-friendly easily accessible database management system, offering the above MS Excel capabilities. Additionally, the use of MS Access, as opposed to MS Excel, is advantageous for the retrieval of the data and their writing into text files. The loading of files into GAMS is significantly faster when using MS Access, compared to using MS Excel. The system is also more generic and re-usable, since one has to specify the range of cells to be imported. This means that for each application the range of data to be imported would have to be re-specified, depending on the number of records of each input file. Thus, MS Access has been used for the development of the DMF.

3.3.1. Database Module

The Database module was structured according to FSSIM-Dev GAMS requirements. The inputs required by FSSIM-Dev can be distinguished into data concerning the definition and specification of the agricultural system, and into data describing characteristics of this system. These data correspond to set elements or parameter values within the model. There is a clear analogy between the two types of data and what is specified as a set or a parameter in the model. The sets usually act as the data on system definition, while the parameters associated to the sets act as the data on the description of characteristics of this system. In a model written in GAMS, sets are defined as "the basic building blocks of a GAMS model, corresponding exactly to the indices in the algebraic representations of models" (Rosenthal, 2008). Sets can be one-dimensional or multi-dimensional. The parameters are the core data of a model and they can be scalars or dimensional parameters. A scalar is a parameter of zero dimensionality, thus there are no associated sets and there is exactly one number associated with it (ibid). The dimensional parameters are associated to one or more sets of the model. For the design of the DM, special attention was given so that the actual relationships between sets and parameters that exist in FSSIM-Dev are also used for establishing the relationships between the different DM fields.

The building blocks of any database are the database tables. Each table is characterised by i) a table name: a unique identifier for the relation defined in the table; ii) a primary key: a unique identifier assigned to one of the table attributes, enforcing that no row will be duplicated; and iii) columns with their headings and value types: each column represents an attribute which should be related to the primary key and it is assigned a specific value type e.g. string, numerical, boolean, etc. The table names signal the contents of the table in terms of type of data and specific relation. Specifically, the name consists of a prefix, which identifies the data type, and a root which describes the relation contained in the table. The referential integrity constraints follow the conceptual and technical links of the FSSIM-Dev input data for the establishment of one-to-many relationships, as implicitly established by the dimensions of the set and parameter domains in the model.

3.3.2. Integration Code Module

The Integration Code Module (ICM) is a tool that retrieves data from the MS Access database into text files readable by GAMS. ICM is based on the specification of the source database, the SQL query for each data field to be extracted, and the data destination files. The advantage of the VB application is that it allows replicating exactly the data text files used in FSSIM-Dev. Moreover, it allows keeping the same structure as FSSIM components (Figure 23). The execution of this module is handled through the FSSIM-Dev Graphical User Interface (FSSIM-Dev GUI) presented below.

Figure 23. Link between database and GAMS files

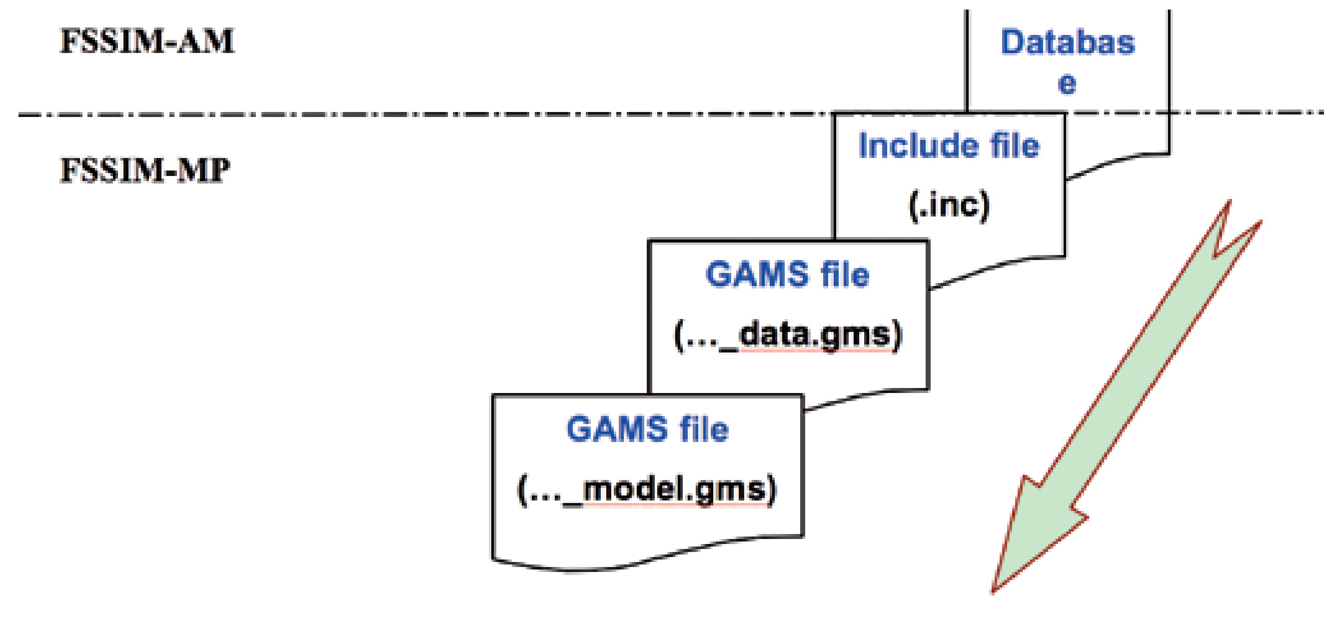
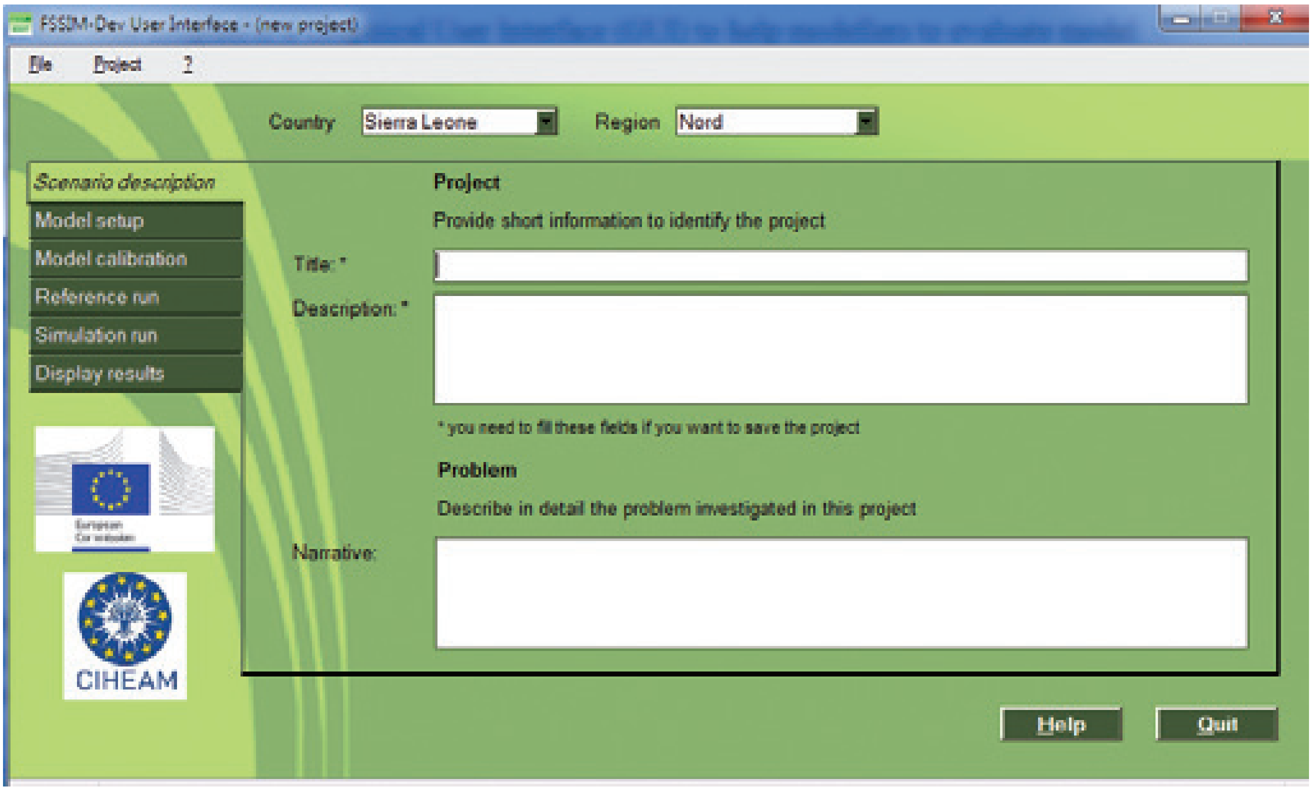


Figure 24. Scenario description in FSSIM-Dev GUI



3.4. FSSIM-Dev Graphical User Interface

FSSIM-Dev has been coupled to a Graphical User Interface (GUI) to help modellers to evaluate model performance and policy makers to simulate policy scenarios. This GUI was targeted at users who would like to apply FSSIM-Dev without having a deep knowledge of GAMS programming languages. It involves a set of screens which provides different functionalities going from scenario description to display results.

Scenario description: through this screen (Figure 24), the user may build up a project that specifies an assessment exercise. A project is characterized by the definition of the problem it tries to solve or study, and it incorporates at least one experiment configuration, that is, the configuration of the models to be executed during the analysis. An experiment, in turn, is associated with a specific set of modules and constraints, a single calibration method and is parameterized by the specification of a context and a policy option. Through a single project, several alternatives can be investigated and compared. Based on the results of the computation, the calculated model outputs become available and can be visualized under different formats accessible from the *display results* screen.

Model setup: from this screen (Figure 25) the user can select the set of modules to be included in the simulation run and their corresponding constraints. Certain modules and constraints such as the crops and aggregation modules are selected by default and cannot be switch off (Figure 25).

In the perennial module, the user can choose between three different modelling approaches: short, medium and long-term approaches (Figure 26).

- In the short term, we assume a constant area for perennial crops, that is, no land competition between annual and perennial crops are depicted.
- In the medium term, an innovative modelling approach is used to take into consideration sunk cost and adjustment cost effects of investment decisions. This modelling framework provides the mid-term response of perennial producers to changes in incentives. Basically, we make a distinction between the existing stock of perennial crops and new plantations in terms of input-output coefficients.
- In the long term, we adopt a steady state approach, allowing for adjustments in the area allocated to perennial activities and, therefore, modelling the competition for land between annual and perennial crops.

Figure 25. Model setup in FSSIM-Dev GUI: livestock module

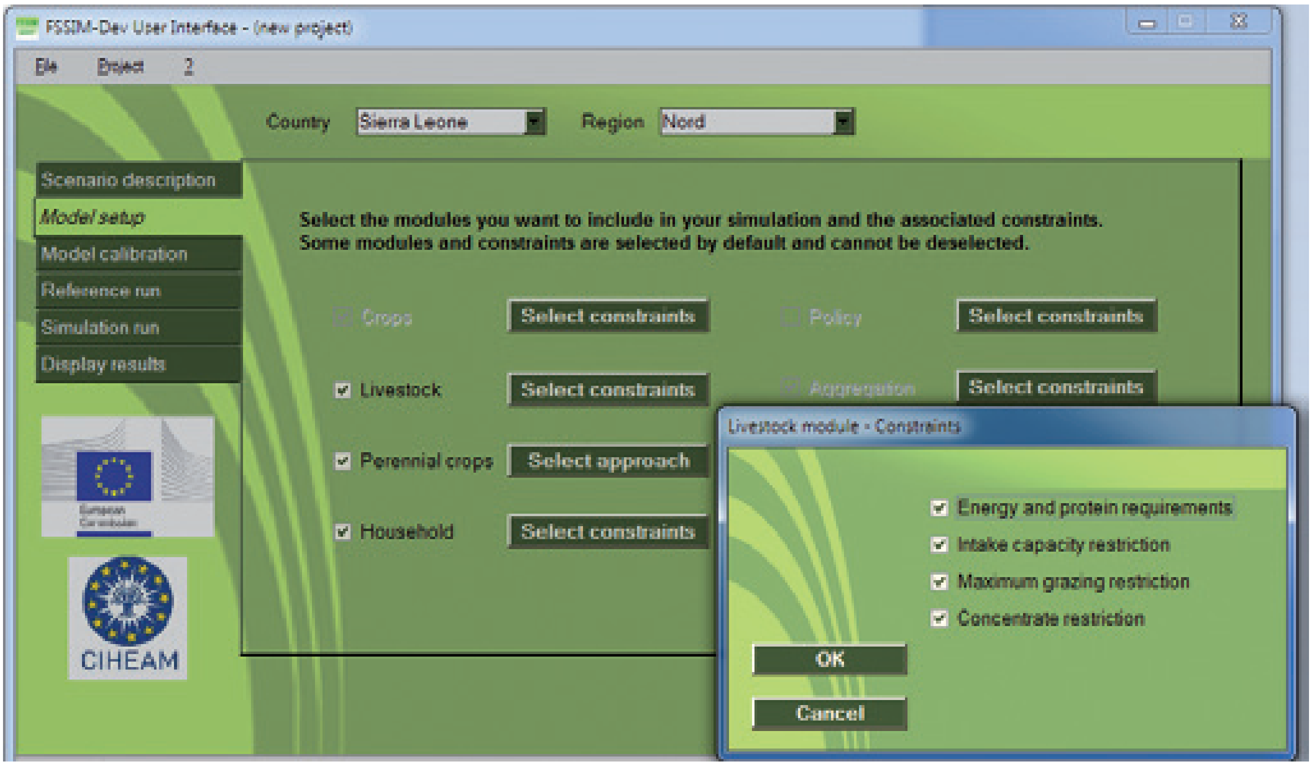


Figure 26. Model setup in FSSIM-Dev GUI: perennial module

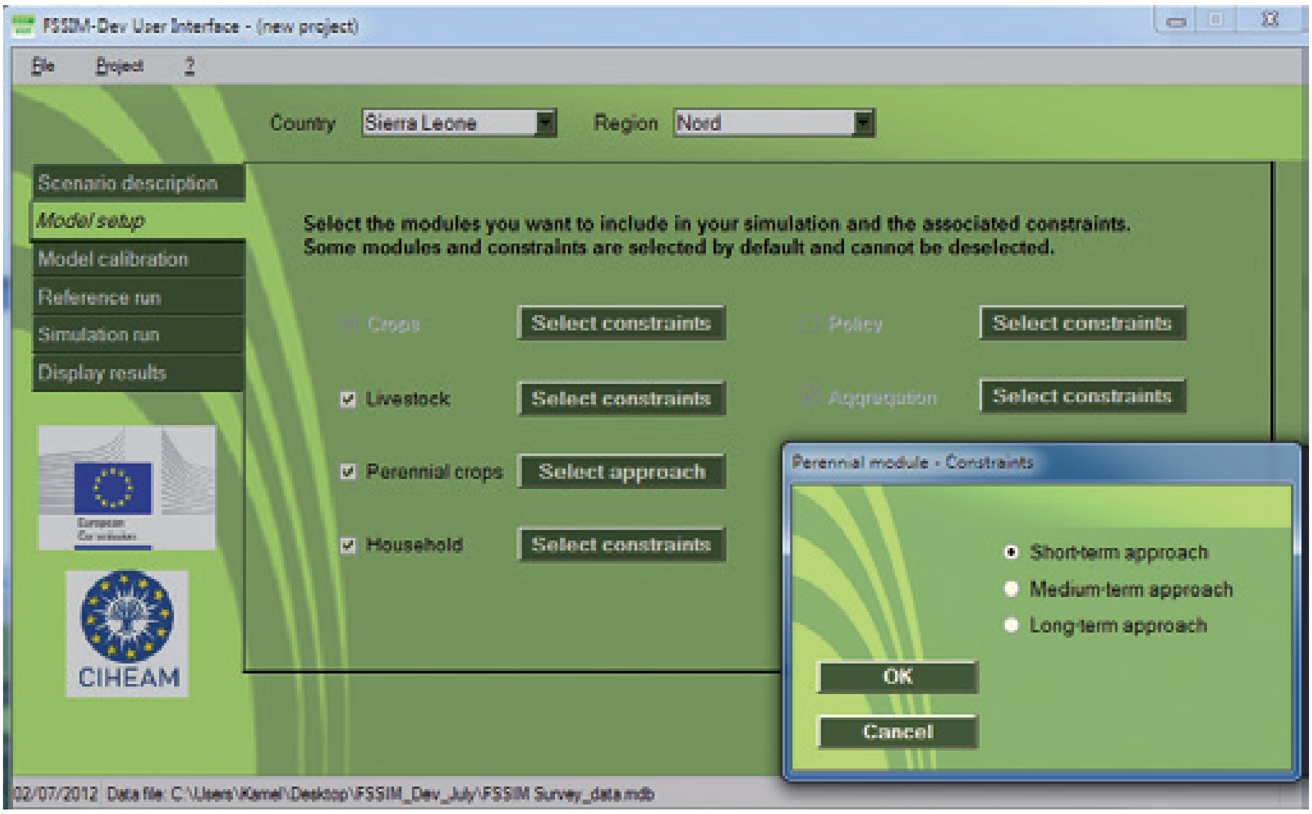
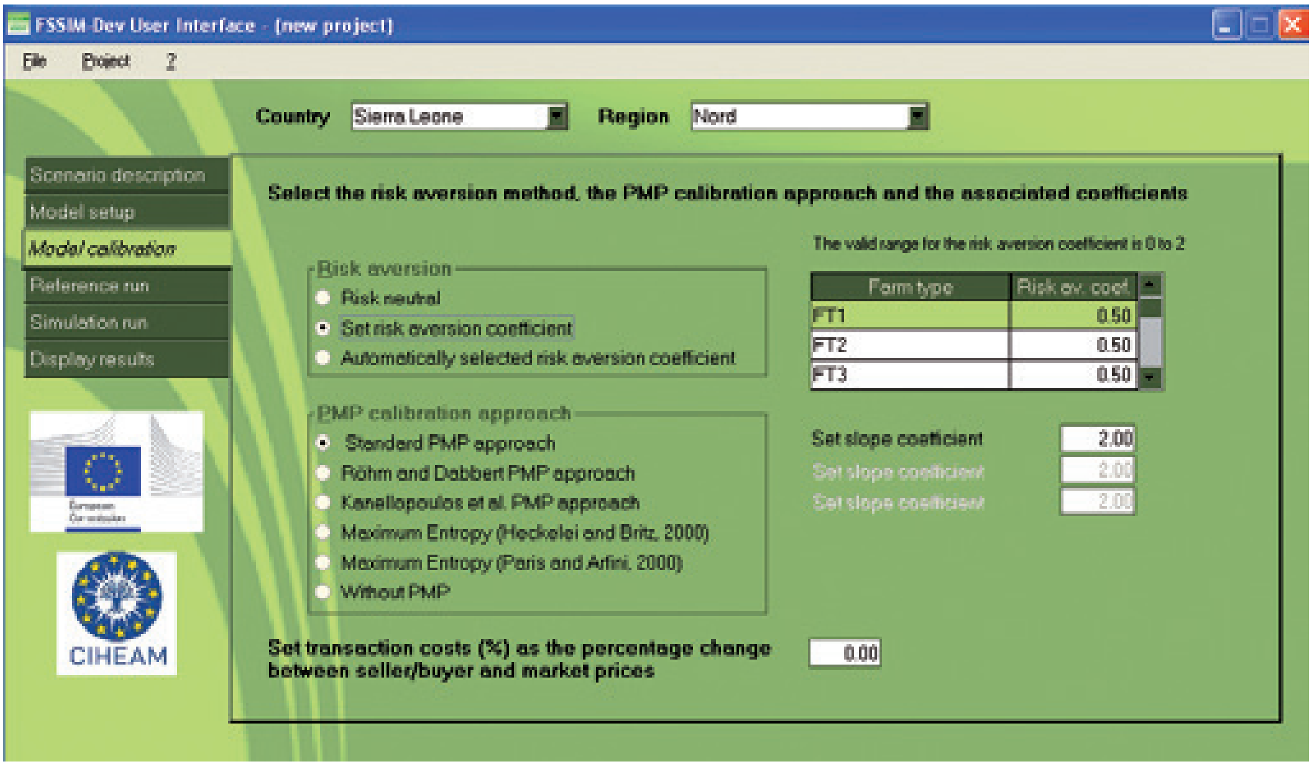


Figure 27. Model calibration in FSSIM-Dev GUI



Model calibration: this screen (Figure 27) allows selecting the method to use for calibrating the model during the base year. It provides several functionalities such as the:

- switching on/off risk (i.e. switching between profit and utility maximization problems)
- choosing between different methods for setting risk aversion coefficients [0-2].
- switching on/off calibration with PMP approach

Figure 28. Reference run in FSSIM-Dev GUI

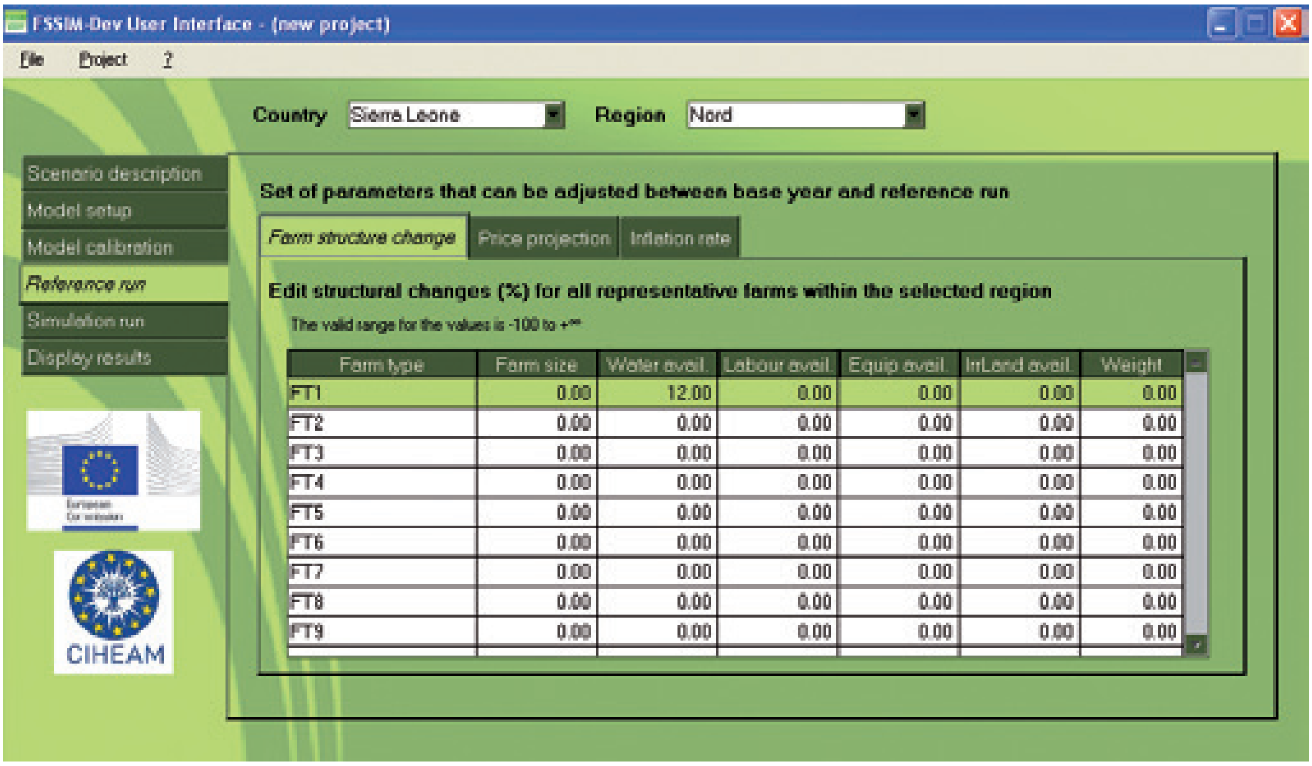
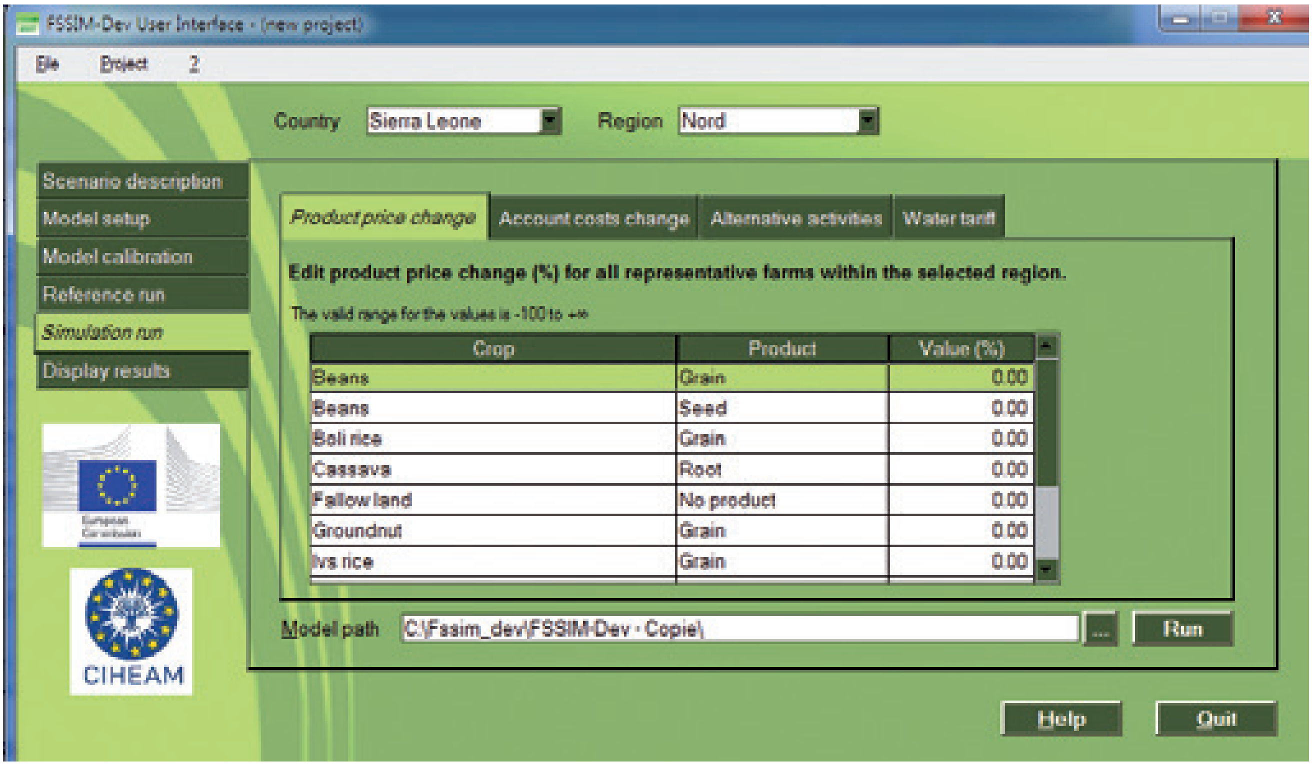


Figure 29. Simulation run in FSSIM-Dev GUI



- choosing between different PMP approaches (Standard PMP approach by Howitt; Röhm and Dabbert PMP approach; Kanellopoulos et al. PMP approach; Maximum Entropy-PMP approach by Heckelei and Britz; and Maximum Entropy-PMP approach by Paris and Arfini) as well as between diverse PMP variants based on different weights of the linear and the non-linear terms of the cost functions (i.e. standard, average cost and almost-linear).
- Setting the transaction costs as the percentage change between seller/buyer and market prices.

Figure 29. Simulation run in FSSIM-Dev GUI

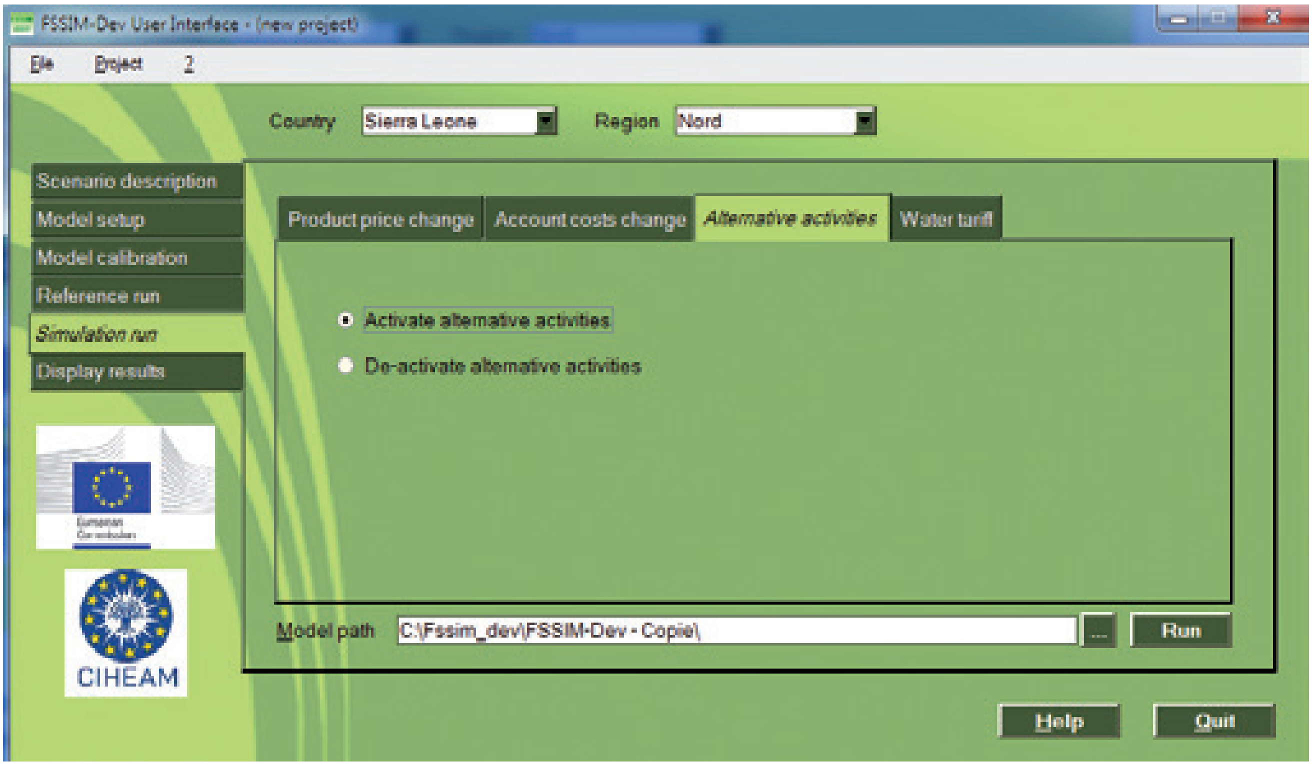
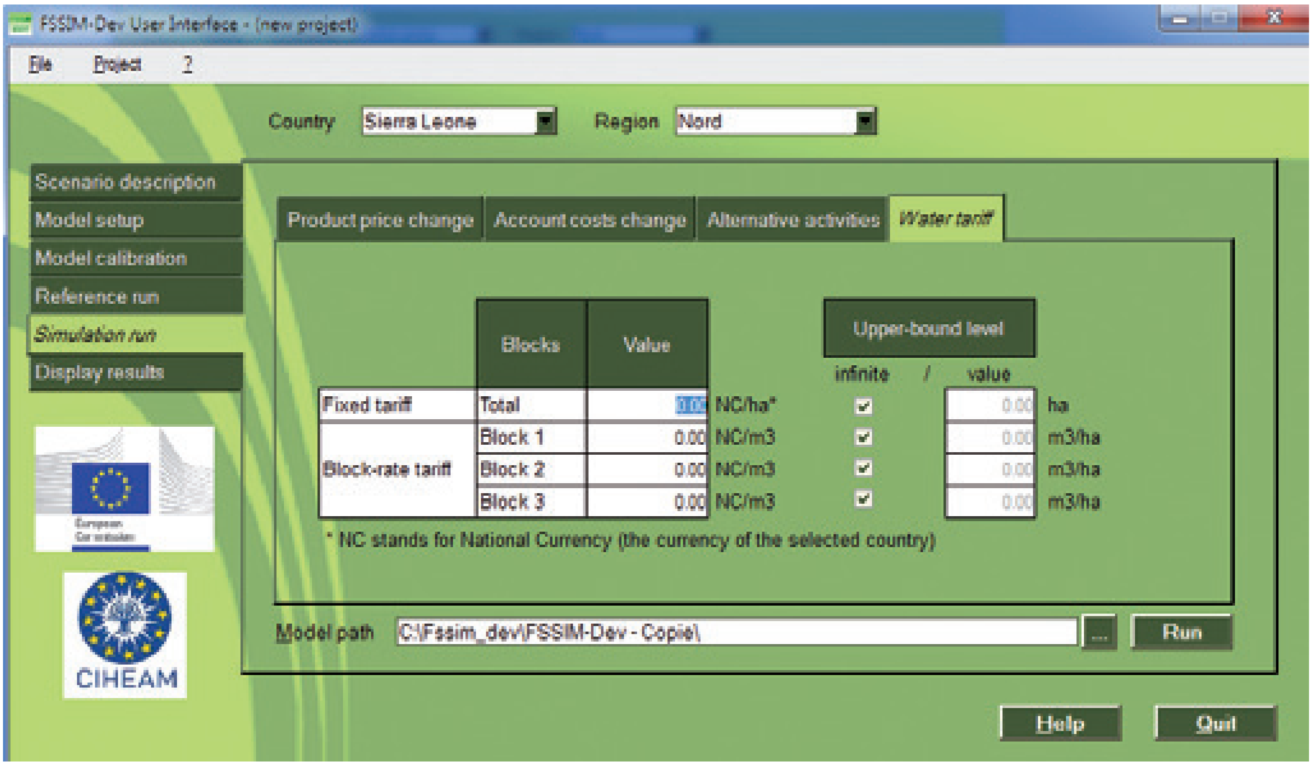


Figure 29. Simulation run in FSSIM-Dev GUI



Reference run: through this screen (Figure 28), the user build the baseline (i.e. reference run) scenario to be used as reference for comparing simulated policy scenarios. It includes the set of parameters that can be changed between baseyear and baseline such as the inflation rate, the initial farm resources endowment (land, labour, capital and water availabilities), the market commodity prices and the average

Figure 30. Display results in FSSIM-Dev GUI

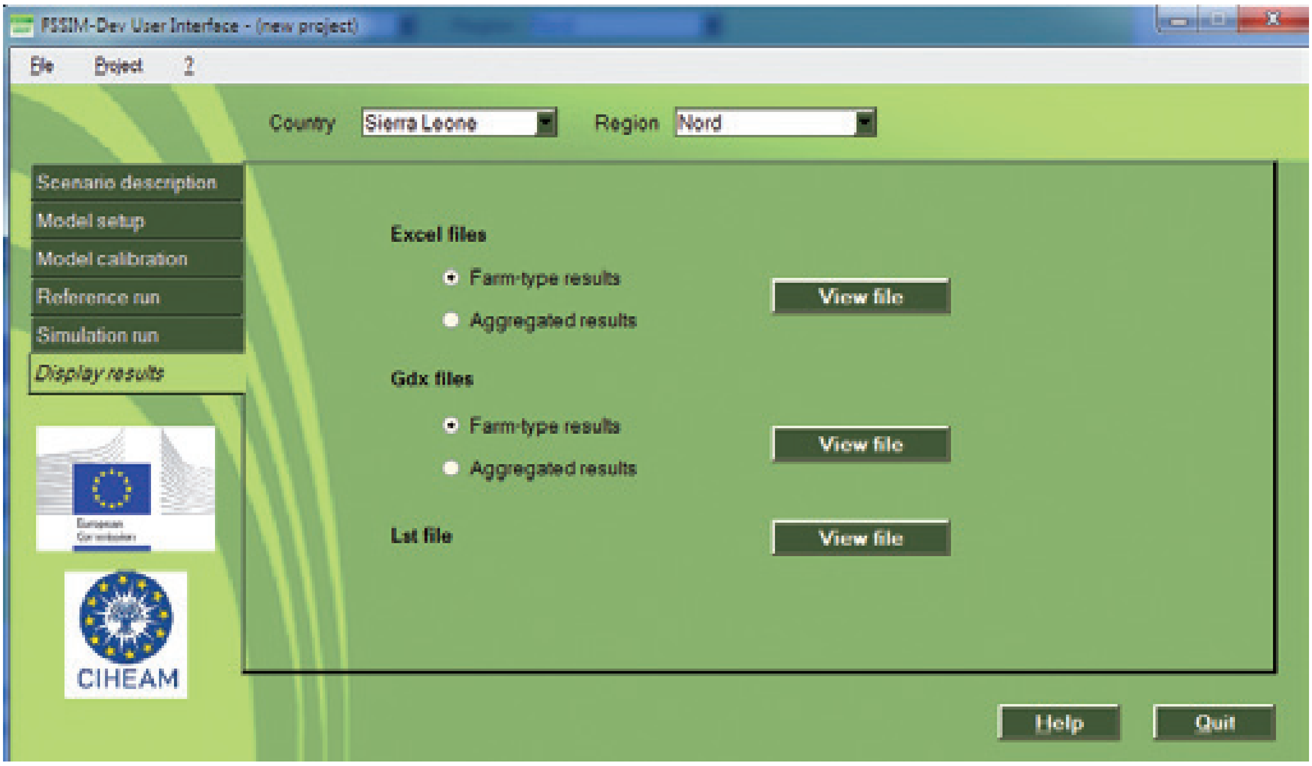
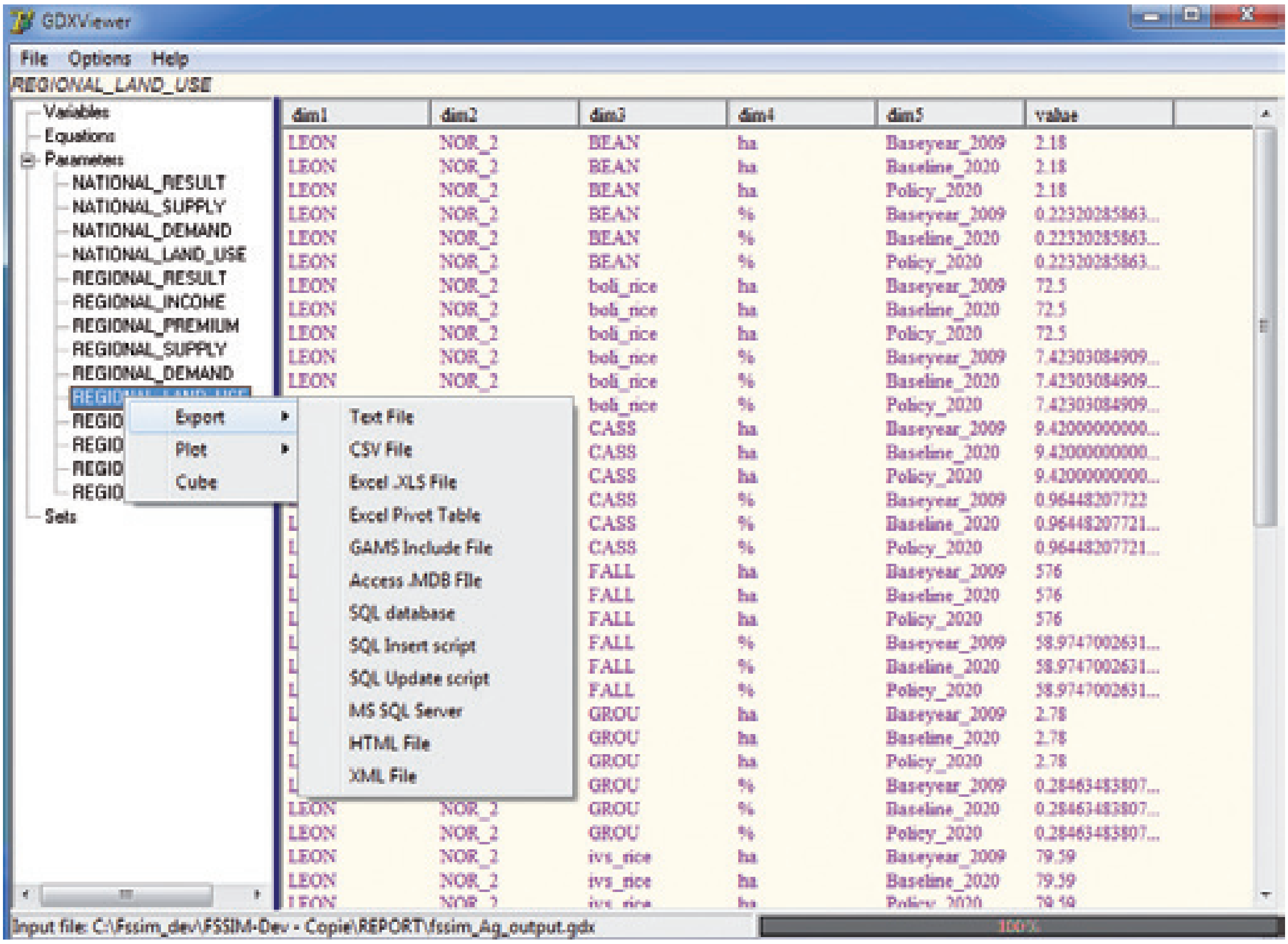


Figure 31. Display results using GDXVIEWER



transaction costs between farm household and market prices.

- **Run simulation**: through this screen (Figure 29) it is possible to simulate a set of policy scenarios related to the change in market commodity prices, the change in accounting costs, the switch on/off of alternative (new) activities and the implementation of water pricing policies (more detail about these policies are given in the section describing the policy module). This screen involves also the required button for running the model, namely "run". By clicking this button, the input data required by FSSIM-Dev are generated from the Database into text files and, then, GAMS program uses this input files to run the so-called "FSSIM.experiment.gms" file which control all the FSSIM-Dev GAMS files.

- **Display results**: this screen (Figure 30) allows visualizing FSSIM-Dev results stored under Excel, Gdx and List files. These results are reported at both farm and aggregated levels.

Gdx files are displayed with a GDXVIEWER tool distributed freely with the GAMS software to view and convert data contained in GDX files. After loading a GDX file in GDXVIEWER the content of the file is displayed in list view (Figure 31). The left-hand side of the window shows the index of the GDX file organized in a tree structure. When clicking on an identifier, the right-hand-side will display the actual data for the identifier. When the right mouse button is clicked on an identifier a pop-up menu is presented that allows exporting an identifier to a number of target formats. GDXVIEWER has a built-in facility to quickly plot data. It includes LINE, BAR and PIE charts, examples are shown below. The plots can be made through the menu *File|Plot*.

3.5. Conclusion

This section gives a detailed technical description of the FSSIM-Dev components, especially their specification, structure and inter-linkages. It shows the transparency, the flexibility and the usefulness of these components for entering, visualising and managing data as well as for setting/defining policy scenarios, selecting calibration methods, switching on/off modules & constraints, running policy scenarios and visualizing results. Thanks to these specifications, FSSIM-Dev could be used to simulate and to assess the effects of different policy options on the performances and characteristics of different farming (and farm household) systems.

4. Application of FSSIM-Dev in a Sierra Leone case study for assessing rice support policy

4.1. Introduction

In order to illustrate the applicability of the newly developed FSSIM-Dev model, it is applied to a representative sample of farm households belonging to the Northern Region of Sierra Leone, more precisely on the Bombali region, in order to assess the combined effects of input (fertiliser) subsidy policy and improved rice cropping managements.

Sierra Leone is a West African country, bordered by Guinea in the Northeast, Liberia in the Southeast, and the Atlantic Ocean to the Southwest. It is divided into four Regions (Northern, Southern, Eastern and Western) with a total surface of 71 740 km² and a population estimated at 6.7 million in 2008 (World Bank, 2009). In addition to a favourable environment for tropical agriculture with abundant rain (2000-4500mm per annum) and high biodiversity, the country has rich marine resources and minerals including diamonds, gold, rutile and iron ore (Jalloh, 2006). In terms of economic prospects, Sierra Leone is one of the poorest countries in the world. Its gross domestic product (GDP) per capita was estimated to be only slightly more than 300 US dollars (USD) in 2010. The agricultural sector plays a very important role in the economy. It contributed around 46% to the GDP in 2008 and employed 75% of the population (MAFFS, 2009). The agricultural sector is made up of crops, livestock, forestry and fisheries sub-sectors. Arable land represents 74% of the total area of the country (around 5.365,000 ha). However, due to several reasons among them the inadequate tools and limited access to markets and inputs only 36% of this area is under cultivation. The average farm household cultivates 1.56 hectares. 56% of the farms have less or equal to 1 ha and the majority of holdings range from 0.5 to 2 cropped hectares while keeping potential arable land under fallow (FAO, 2005). In most of cases, farmers manage different plots, of which 60-80% are located in the upland, and 20-40% are in the lowlands (Inland Valley Swamps (IVS), Bolilands, Mangrove Swamps and Riverain Grasslands – see in Annex XX the description of the West African ecosystems). Rice yield in the upland is however generally lower than in the lowlands (MAFFS, 2009).

The Northern and Eastern regions are considered the most productive regions in the country due to the larger agricultural areas under cultivation. Most of the land under cultivation is dedicated to rice which represents the staple food of the population and is grown by over 95% of the farmers. It is commonly cultivated under mixed cropping with cassava, maize, millet, groundnuts and sweet potatoes in varying proportions (MAFFS, 2009). However, due to very low productivity, most of the farms are for subsistence or semi-subsistence purposes, and the produced outputs are mainly for family consumption.

To contribute to the improvement of food security and the economic development of Sierra Leone's agricultural sector, both national governments and the international community[16] have developed different agri-food and rural policies. The promotion of domestic rice production is a key element in this respect, since it directly contributes to improvement of food security, stimulates economic growth and increases rural income. Sierra Leone's agricultural development policy has been focused on the achievement of rice self-sufficiency among other objectives, which has been already supported by governmental and donor organizations with limited success (JICA, 2009). The current policy related to the rice production is described in the National Rice Development Strategy (NRDS), where a framework is laid down aiming at significant increase of rice production. One of the ways to achieve this objective is to ensure an increase in the sustainable productivity and production of rice in Sierra Leone (JICA, 2009).

16 The European Union has made a donor since 2005 through the Stabilisation of Export Earnings (STABEX) funds – the 8th European Development Fund. The main goal of this intervention is the improvement of rice production and the rehabilitation of cocoa and coffee plantations to achieve its food security goals and improve the agricultural export sector of the country. Most of the support provided between 2007 and 2009 by these projects (which reached a value of 4,378,000 EUR) focused on increasing yields through a set of measures and technical assistance which mainly dealt with factors hampering or/and increasing (i) smallholder agricultural productivity, (ii) current and potential farm income and, more generally, rural poverty.

The aim of this case study is to assess through the FSSIM-Dev model the combined effects of input (fertiliser) subsidy policy and improved rice cropping managements on the livelihood of farm households in the poorest region (Bombali) of Sierra Leone. In order to achieve this objective the following steps are taken:

1 Identification and analysis of the current cropping and farming systems: this step seeks to identify the set of representative farm households in the region as well as their main cropping systems. It is achieved using two different face-to-face interviews: i) in the first one, more than 190 smallholders have been interviewed in summer 2009, in order to collect data on their resources as well as on their socio-economic conditions, and ii) in the second one, a set of regional experts has been interviewed during December 2011 in order to collect agronomic data for major crops in the regions (i.e. experimental data, statistical data, etc.). The Principal Component Analysis was used to elaborate the farm typology and define the most representative farming systems.

2 Identification of alternative rice production systems: performed using expert knowledge (including bibliography analysis), this step seeks to identify a set of rice activities with higher yields (than the existing ones) using better management practices (N fertilization, adjusting sowing date…). The main idea from this step is to avoid the use of complex models (e.g. CropSyst, APES …), which are developed to be used for plot analysis with a large quantity of observed data. Expert knowledge is also used to determine the relationships between agricultural practices, crop yields and environmental effects in a context of high soil quality variability.

3 Definition and implementation of the simulated scenarios: in this step two policy scenarios were implemented, based on a literature review and interaction with smallholders and policymaker, and their results are presented and discussed in comparison to a reference scenario (i.e. baseline).

This section describes in details these three steps. It starts with the identification of major agricultural activities in the studied area, then, it shows the results of the farm household typology, and finally, it provides a brief description of the simulated scenarios and discusses their results in comparison to the reference scenario.

4.2. Selection of current agricultural activities

In order to identify the main current activities in the targeted region (crop rotations and crop practices: fertilization, irrigation, seeding, etc.) the survey, carried out during 2009 in the Bombali region was analysed. The survey itself and the details about the collected data are described in the Gomez y Paloma *et al.*, (2012) report. One of the targets of this survey was to identify at regional scale the current cultivated crops and rotations in the studied area.

The principal crops in the Bombali region are rice, vegetables, palm oil, sorghum, maize and vegetables crops. Combined with the results of surveys on management information, these crops were defined as the current agricultural activities in this region.

Concretely, the method used to identify the main current activities in the Bombali region is divided in two steps: i) first the main activities by ecosystem (Upland, IVS and Boliland) are identified, then, ii) the variables on yield and on the total requested labours for each activity are used to cluster the main activities by using the Principal Component Analysis (PCA). The palm oil activity is classified only based on the yield information. Table 2 presents the calendar of the rice cropping systems.

Table 2. Rice cropping calendar by ecosystem

	Upland rice	IVS rice	Boliland rice
Brushing/Felling/Clearing	February- April	-	-
Brushing and Mounding	-	April	April
Plowing and seeding	Mid-Jun	-	/
Puddling	-	July	July
Transplanting	-	July	July
Weeding	Mid-July	-	-
Harvesting	November-December	November-December	November-December

4.2.1. Classification by ecosystem

The first classification is realized based on the three ecosystems: upland, IVS and Boliland. By analysing the surveyed data, we can show that the upland rice is the dominant activity grown by 117 farms (42%), followed by the IVS rice activity cultivated by 115 farms (41%) and then the Boliland activity observed only in 49 farms (17%) (Table 3). The Boliland soil is often heavy clay, making it very hard to work, especially during the dry season for soil tillage and weeding.

By looking to rice production, the highest yield is observed for the IVS activity (0.38 t/ha), followed by the Boliland (0.31 t/ha) and then the upland rice (0.28 t/ha). For yield variability, the IVS system presents the highest variability (standard deviation = 0.2 t/ha) by comparison to the rice grown on Boliland or upland. This could be explained by the problem of water management under the IVS system. In fact, in such a context, farmers have not the requested equipments to manage adequately the rainfall water distribution within the rice field.

Table 3. Average and standard deviation of rice yield by ecosystem

	Numbers	Percentage (%)	Average yield (t/ha)	Standard deviation (t/ha)
Upland rice	117	42	0,28	0,11
Ivs rice	115	41	0,38	0,20
Boliland rice	49	17	0,31	0,15
Total	**281**	**100**	**-**	**-**

4.2.2. Cluster analysis

For each ecosystem, a cluster analysis was undertaken by considering the total farm labour and yield criteria. For each type of rice and for each criterion (labour, yield) two classes are identified: low and high yield and low and high labour. Rice classes are created automatically by using the PCA analysis. This analysis was performed using TANAGRA (Rakotomalala, 2005), which helped to create for each criteria (yield, labour) two statistically different classes. Thus, 12 rice patterns (cropping systems) were identified as shown in Table 4.

Overall, the rice cropping systems producing the low yields are characterized by a high yield variability compared to the rice cropping systems with a high yields. This variability is almost the same for the three types of rice (around 30%). However, for the highest yield, the upland rice shows the lowest yield variability, followed by the IVS and then the Boliland.

By combining the ecosystems and the total labour classification, four rice cropping systems are identified for each ecosystem (Table 4). For each rice cropping system a type of soil and a percentage of organic matter are also associated based on expert knowledge and bibliography analysis (Saito et al., 2010).

The results obtained from this classification were presented and validated by the local experts in one day meeting held in the Ministry of Agriculture in Freetown (December, 2011). The list and the function of the expert pool are presented in Table 15.

Overall, the detailed analysis of the three dominant rice cropping systems (upland, IVS and Boliland) showed that:

1- Upland rice: for the same yield, the actual labour requirement could be twice as much from one farm to another. This statement is the same for all the tasks from sowing to harvesting. This result could be explained mainly by the crop cycle duration and the soil type and quality. Generally, the performance should be for a relatively flat land (with less than 10% slope) and short crop cycle (2 to 3 months). Where relatively flat land is not available, land with steep slope (>30%) should be contour-bunded to reduce excessive run off and erosion. This operation is very

Table 4. Set of selected rice cropping systems

Ecosystem	Classes	Cropping systems	Yield (t/ha)	Standard deviation	Labour (day/ha)	Type of soil	Organic matter (%)
Upland	Low yield low labour	CS1	0,21	0,06	174	Ultisol	0,60
	Low yield high labour	CS2	0,23	0,07	318	Oxisol	0,60
	High yield low labour	CS3	0,40	0,04	162	Ultisol	0,90
	High yield high labour	CS4	0,44	0,08	267	Oxisol	0,90
IVS	Low yield low labour	CS5	0,27	0,09	157	Sandy-clay	0,90
	Low yield high labour	CS6	0,33	0,11	248	Sandy-clay	0,90
	High yield low labour	CS7	0,71	0,12	178	Sandy-clay	2,10
	High yield high labour	CS8	0,50	0,12	333	Sandy-clay	2,10
Boliland	Low yield low labour	CS9	0,19	0,08	85	Sandy-clay	0,60
	Low yield high labour	CS10	0,20	0,06	225	Sandy-clay	0,60
	High yield low labour	CS11	0,35	0,06	145	Sandy-clay	0,90
	High yield high labour	CS12	0,47	0,12	217	Sandy-clay	0,90

time consuming (Rhodes, 2005). Table 5 shows that the soil preparation (brushing, plowing and seeding) and the weeding practices are very labour consuming.

2- IVS rice: similarly to the upland rice, in the IVS system the soil preparation and the transplantation are the two tasks that requested the highest labours (Table 5).

3- Boliland rice: here also the soil preparation (plowing and seeding) and the weeding events are very labour consuming (Table 5). In the Boliland ecosystem, the brushing operation is less time consuming than in the upland because this type of ecosystem (Boliland) is not suitable for the development of shrubs as for upland ecosystems.

Table 5. Labour requeriment for rice cropping systems

Ecosystem	Classes	Cropping systems	Brushing	Brushing and Mounding	Plowing and seeding	Harrowing	Planting of minor crops	First bird scaring	Puddling	Transplanting	Weeding	Fencing	Second bird sscaring	Harvesting	Threshing/ Winnowing	Drying	Total labour
Upland	Low yield low labour	CS1	29	-	31	10	5	3	-	-	32	2	13	30	15	4	**175**
	Low yield high labour	CS2	46	-	45	21	13	5	-	-	55	5	21	38	41	28	**319**
	High yield low labour	CS3	28	-	28	10	5	3	-	-	26	3	10	29	16	5	**163**
	High yield high labour	CS4	37	-	49	12	10	7	-	-	45	3	33	42	21	9	**268**
IVS	Low yield low labour	CS5	1	27	11	1	0	1	20	19	2	0	15	29	23	8	**158**
	Low yield high labour	CS6	13	32	22	5	1	2	29	33	3	1	19	44	29	15	**248**
	High yield low labour	CS7	2	32	6	0	0	1	20	27	4	3	19	30	23	11	**178**
	High yield high labour	CS8	31	34	40	3	1	2	42	40	6	12	19	59	30	14	**334**
Boliland	Low yield low labour	CS9	0	0	9	12	0	2	7	0	23	0	2	21	7	2	**85**
	Low yield high labour	CS10	7	22	29	38	0	2	8	4	44	0	11	40	14	7	**225**
	High yield low labour	CS11	1	0	22	23	1	3	7	0	36	0	3	42	5	2	**145**
	High yield high labour	CS12	3	4	39	33	3	1	10	6	38	0	12	46	14	6	**218**

4.3. Farm household typology

In order to give a representative picture of the current farming systems in the selected region and to capture heterogeneity among farms households, a typology was performed using the data collected in 191 farms through a face-to-face interview. These farms are mainly arable and cultivate particularly rice, vegetables (such as groundnuts, manioc and beans), cassava and orchards (mainly palm oil). A segmentation analysis followed by a clustering analysis is undertaken for selecting the more relevant farm household types in the studied region. The segmentation analysis was based on two structure criteria (farm size and specialization). Two steps are, thus, taken in order to characterise each farm: i) first, calculating the total standard production, which expresses the economic size of farms and, ii) second, determining the share of the main crop in the total production, in order to define the farm specialization. Based on these criteria, farms were divided into different clusters using the clustering analysis.

For representing the farm household type two approaches are generally used: the average or the typical farm household. The average farm household could be defined as a virtual (not observed in reality) farm household which is derived by averaging data from farm households that are grouped in the same farm household type. A typical farm household is an existing (observed) farm household with representative, for a certain farm household type, properties and characteristics. Different approaches could be used when trying to identify a representative typical farm household (e.g. selecting the farm household that is close to the average farm household or the one with the median profit).

In this study, the average farm household was selected to represent all farm households that belong to the same farm household type. By simulating the behaviour of average farm households, we ensure that all important crop products that are produced by farm households will be part of the simulated production plan. This is very important for up-scaling results from farm to regional level. However, simulating the average farm household has also important drawbacks. First, an average farm household does not exist, and consequently, an average crop/activity pattern also does not exist. Second, the crop/activity pattern of the average farm household is much more diversified than the one of individual farms (for further details on advantages/disadvantages of each approach see Louhichi et al. 2010).

4.3.1. Farm economic size

The total standard production is used to determine the economic size of farms. It is expressed via the "economic unit dimension" (EUD) (RICA, 2010), i.e. the farm income of each farm. The farm income has been calculated for each farm household in the survey.

The total farm income is calculated as follows:

Farm income = Price (rice) * Production (rice) – labour costs

Where:

- Price (rice): is the average rice price in the Bombali region calculated from the survey. The average price includes the three rice types (Upland, IVS and Boliland) and it is equals to 1701903 Leones/ton.
- Production (rice): is the average rice production by farm type calculated from the survey. The rice production at farm level is calculated as the sum of production of the three rice types.
- Labour costs: this includes only the cost of hired labour. The unit costs of hired labour are different according to labour category: men (6000 Leones/day), women (3600 Leones/day) and children (400 Leones/day). Those costs are established by the experts of the Ministry of Agricultural during the field visit to Sierra Leone (December, 2011).

Regarding rice seeds, most of small households, as in Bombali, self produce their own seed, i.e. seeds for sowing in a given year are stoked from the harvest of the previous year. Other farmers get, for free, their rice seeds at the Ministry of Agriculture or NGOs. For this reason, we consider in this application, the cost of seeds as zero.

The same formula and assumptions are used for calculating the crop income of other crops (such as palm oil, vegetables). All calculation details are presented in Appendix 3.

The total standard production is the total farm income expressed in term of "equivalent rice". The total standard income is then defined as the number of hectare of rice that ensures the same total income.

More specifically, in order to calculate the rice equivalence of the farm income for each surveyed farms the following four steps are taken:

1- Calculating the total rice production for all the farms.
2- Calculating the average rice production (Prodaverage rice).
3- Associating the equivalent EUD units for the average rice production. In this application, 1 EUD rice is equal to 552533 Leones (the income of 1 tonne of rice).
4- Determining the farm EUD by dividing the total farm income by the rice equivalent EUD.

By using the total standard production (i.e. production standard (PS)), a Principal Component Analysis has been undertaken. As a consequence, three classes are obtained:

1- Farms with low income standard. There are 69 farms, representing 36% of the total farms surveyed in the Bombali region. Those farms are characterized by a low EUD, comprises between 0.2 and 0.88 EUD (110507 and 442026 Leones).
2- Farms with medium income standard. They are represented by 84 farms (44% of the total farms

in Bombali). They are characterized by an EUD that comprised between 0.9 and 2.23 (497280 and 1232148 Leones).

3- Farms with high income standard. There are 38 farms, representing 20% of the total farms surveyed in the Bombali region. Their EUD exceeds 2.27 (more than 1 252 250 Leones).

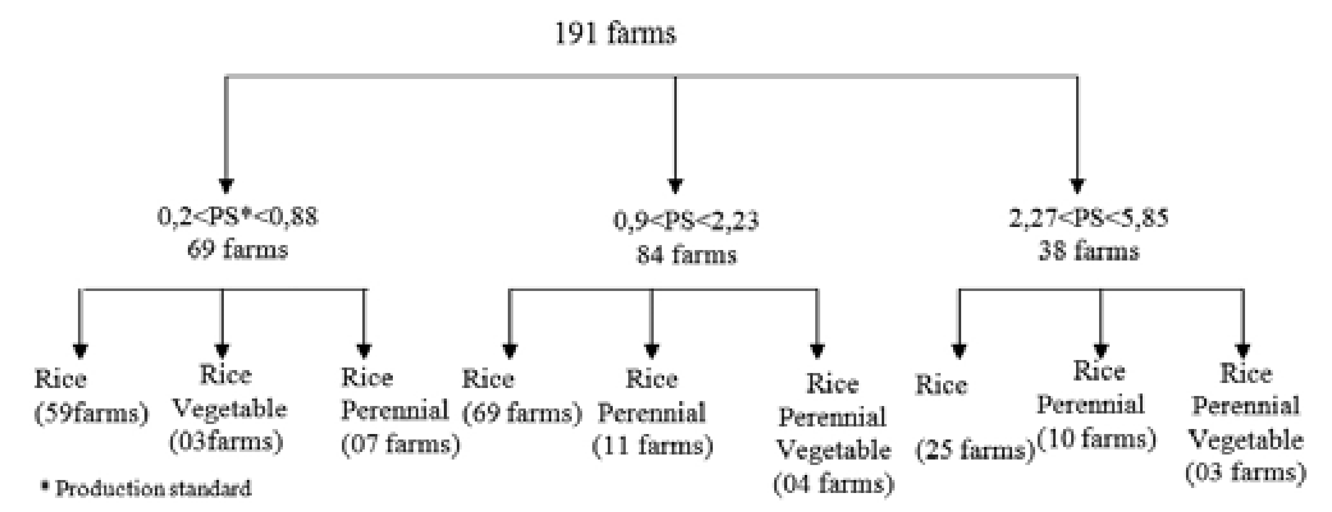
4.3.2. Farm specialization

A second farm typology is undertaken with the focus on farm specialization. For this, the share of production of the main crop in the total farm income is determined. Four types of crop specializations are identified: rice farms, mixed farms (rice and vegetable), rice and perennial crops farms, and diversified farms (rice, vegetables and perennial).

Based on these four specializations and the production standards (PS) 9 farm household types can be identified. The specification of these 9 farm household types is illustrated in Figure 32.

- In the small farms (with low production standard), 59 farms produce exclusively rice, 3 are mixed farms (rice and vegetables) and 7 are cultivating rice and perennial crops (mainly palm oil).
- For the medium farms (with medium production standard), 69 farms are producing mainly rice, 11 farms are cultivating rice and perennial crops and only 4 farms cultivating rice, perennial and vegetables (diversified farms).
- For the big farms (with high production standard), most of the farms are producing mainly rice (59 farms), followed by the rice and perennial farms (10 farms) and then 3 farms are identified as diversified farms (rice, perennial and vegetables).

Figure 32. Farm typology



4.3.3. Description of farm household types

For this study, 9 farm household types are retained (Figure 32) which represent more than 190 surveyed farms in the region (see section 4.3.2). The section provides a detailed description of these farm household types.

Rice_small: it's a small farm with rice as a main production. The area of this farm type is 0.92 ha in which the rice represents 84% of the total area followed by the perennial crops (12%) and vegetables (4%). The three types of rice are cultivated in this farm type. The perennial crops are represented only by palm oil. Manioc, groundnuts and beans represented the main vegetable crops. The rice ensures 96% of the total farm production estimated at 432209 Leones (0.78 UDE). The rice activity consumes 94% of the total farm labour (Table 6).

Rice_veg_small: it's a mixed farm type cultivating mainly rice and vegetables. The average area of this farm type is about 1.08 ha in which the vegetable crops occupy 50% of the total area. The three types of rice are cultivated: upland rice with low yield and low labour, IVS rice with high yield and high labour, and Bolilandrice with low yield and high labour. Despite the important area of vegetable crops (50% of the total farm area), they produce only 29% of the total farm production. In fact, rice ensures 71% of the total production and consumes 56% of the total farm labour (Table 7).

Table 6. Main characteristics of the "rice_small" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	0,92	100	432209	100	203	100
Perennial crop	**0,11**	**12**	**8299**	**2**	**8**	**4**
Palm oil (establishment)	0,11	12	8299	2	8	4
Rice	**0,78**	**84**	**413582**	**96**	**191**	**94**
Upland1	0,06	6	24143	6	10	5
Upland 2	0,33	36	162221	38	105	52
Upland 3	0,01	1	4922	1	1	1
Upland 4	0,03	3	23563	5	7	4
IVS 1	0,20	22	89258	21	31	15
IVS3	0,02	3	27474	6	4	2
IVS4	0,07	7	54342	13	22	11
Boliland 1	0,02	2	5298	1	2	1
Boliland 2	0,01	1	1878	0	2	1
Bolilandi3	0,02	3	11592	3	3	2
Boliland 4	0,01	1	8891	2	3	1
Vegetable	**0,04**	**4**	**10328**	**2**	**5**	**2**
Cassava	0,02	3	5843	1	3	1
Groundnuts	0,01	1	1211	0	1	1
Beans	0,01	1	3274	1	1	0

Table 7. Main characteristics of the "rice_veg_small" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	1,08	100	397368	100	194	100
Rice	**0,54**	**50**	**284087**	**71**	**108**	**56**
Upland 1	0,13	13	55861	14	24	12
IVS 3	0,13	13	154374	39	24	12
Boliland 2	0,27	25	73853	19	61	31
Vegetable	**0,54**	**50**	**113281**	**29**	**86**	**44**
Cassava	0,27	25	65663	17	32	17
Groundnuts	0,27	25	47617	12	54	28%

Rice_per_small: it's a small mixed farm cultivating mainly rice and palm oil. The average area of this farm type is about 1.56 ha divided almost equally between rice (41% of the total farm area) and palm oil (57% of the total farm area). The orange trees represent only 2% of the total area. The three types of rice are cultivated as described in Table 8. The rice remains the main crop in terms of production (76% of the total farm production) and labour use (72% of the total farm labour use) (Table 8).

Rice_med: it's a medium farm type cultivating mainly rice. The average area of this farm type is about 2.08 ha represented mainly by rice (75%), palm oil (22%) and vegetables (3%). Two types of palm oil are cultivated in this farm type: palm oil at established and full production stages, 12 types of rice (upland, Bolilandand IVS combined with low yield and labour and high labour and yield) and vegetables represented by groundnuts and Manioc. The rice remains the main crop in terms of production (94% of the total farm production) and labour use (89% of the total farm labour use) (Table 9).

Table 8. Main characteristics of the "rice_per_small" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	1,56	100	508703	100	241	100
Perennial crop	**0,92**	**59**	**120510**	**24**	**67**	**28**
Palm oil/ establishment	0,69	44	52460	10	48	20
Palm oil /full production	0,20	13	61096	12	19	8
Orange	0,03	2	6955	1	0	0
Rice	**0,64**	**41**	**388193**	**76**	**174**	**72**
Upland 4	0,14	9	124126	24	39	16
IVS 4	0,23	15	192852	38	77	32
Boliland 2	0,26	17	71215	14	59	24

Table 9. Main characteristics of the "rice_med" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	2,08	100	888360	100	392	100
Perennial crop	**0,46**	**22**	**41833**	**5**	**32**	**8**
palm oil /establishment	0,42	20	32107	4	29	7
palm oil/ début production	0,03	2	9726	1	3	1
Rice	**1,56**	**75**	**832415**	**94**	**351**	**89**
Upland 1	0,02	1	9701	1	4	1
Upland 2	0,45	22	222190	25	144	37
Upland 3	0,18	9	130286	15	30	8
Upland 4	0,04	2	35208	4	11	3
IVS 1	0,30	15	135340	15	48	12
IVS 2	0,04	2	21817	2	10	3
IVS 3	0,02	1	23458	3	4	1
IVS 4	0,12	6	102602	12	41	10
Boliland 1	0,13	6	33924	4	11	3
Boliland 2	0,08	4	20841	2	17	4
Boliland 3	0,07	3	32522	4	10	2
Boliland 4	0,10	5	64526	7	22	6
Vegetable	**0,06**	**3**	**14112**	**2**	**10**	**2**
Cassava	0,04	2	9978	1	5	1
Groundnuts	0,02	1	4135	0	5	1

Rice_per_med: it's a medium farm type cultivating rice and palm oil. The average area of this farm type is about 2.76 ha represented exclusively by rice (45%) and palm oil (55%). Almost all the types of rice are cultivated and contribute to 70% of the total farm production and consume almost 72% of the total farm labour use (Table 10).

Rice_mix_med: it's a medium farm type cultivating rice, palm oil and vegetables. The average area of this farm type is about 2.83 ha. Those crops occupied 48%, 23% and 29% respectively for palm oil, rice and vegetables. In this farm the palm oil is mainly in the establishment stage and the IVS rice and the Boliland rice are the only types of cultivated rice. The rice ensures almost the half of the total farm production and consumes 39% of the total farm labour use (Table 11).

Table 10. Main characteristics of the "rice_per_med" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	2,76	100	895407	100	416	100
Perennial crop	**1,52**	**55**	**266099**	**30**	**116**	**28**
Palm oil /establishment	0,98	36	74121	8	67	16
Palm oil /début production	0,41	15	122852	14	38	9
Palm oil /full production	0,07	3	55777	6	11	3
Orange	0,06	2	13349	1	0	0
Rice	**1,24**	**45**	**629308**	**70**	**299**	**72**
Upland 1	0,04	1	15317	2	6	2
Upland 2	0,52	19	255146	28	165	40
Upland 4	0,04	1	31767	4	10	2
IVS 1	0,22	8	99586	11	35	8
IVS 4	0,13	5	107964	12	43	10
Boliland 1	0,18	7	47612	5	16	4
Boliland 4	0,11	4	71917	8	24	6

Table 11. Main characteristics of the "rice_mix_med" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	2,83	100	775013	100	368	100
Perennial crop	**1,37**	**48**	**149076**	**19**	**99**	**27**
Palm oil /establishment	1,16	41	87980	11	80	22
Palm oil /début production	0,20	7	61096	8	19	5
Rice	**0,66**	**23**	**321711**	**42**	**176**	**48**
IVS 4	0,25	9	210932	27	84	23
Boliland 2	0,40	14	110779	14	91	25
Vegetable	**0,81**	**29**	**304227**	**39**	**93**	**25**
Cassava	0,51	18	123118	16	60	16
Beans	0,30	11	181109	23	33	9

Rice_big: it's a big farm type cultivating mainly rice. The average area of this farm type is about 3.56 ha represented mainly by rice (73%) and palm oil (27%). The palm oil is mainly in the establishment stage. All the types of rice are cultivated except for the upland rice with low yield and low labour. The total farm production is mainly produced by rice (95%) which uses almost 88% of the total farm labour (Table 12).

Rice_mix_big: it is a big farm type cultivating rice, palm oil and vegetables. The average area of this farm type is around 3.57 ha. Three types of crops are observed: palm oil (45%), rice (34%) and vegetables (21%). Only two types of rice are cultivated (IVS and Boliland). Rice and palm oil ensure respectively 38% and 44% of the total farm production (Table 13).

Table 12. Main characteristics of the "rice_big" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	3,56	100	1492887	100	542	100
Perennial crop	**0,96**	**27**	**79547**	**5**	**67**	**12**
Palm oil /establishment	0,92	26	69772	5	63	12
Palm oil /début production	0,03	1	9775	1	3	1
Rice	**2,61**	**73**	**1413339**	**95**	**475**	**88**
Upland 2	0,19	5	91721	6	59	11
Upland 3	0,66	19	476274	32	108	20
Upland 4	0,14	4	118168	8	37	7
IVS 1	0,32	9	141642	9	50	9
IVS 2	0,22	6	116298	8	54	10
IVS 3	0,06	2	74100	5	12	2
IVS 4	0,06	2	47249	3	19	3
Boliland 1	0,52	15	133355	9	44	8
Boliland 2	0,16	5	44312	3	36	7
Boliland 3	0,08	2	39082	3	12	2
Boliland 4	0,20	6	131139	9	44	8

Table 13. Main characteristics of the "rice_mix_big" farm household type

Characteristic	Size		Production		Labour	
Unit	ha	%	Leones	%	Days	%
Total	3,57	100	1266912	100	513	100
Perennial crop	**1,62**	**45**	**555200**	**44**	**123**	**24**
Palm oil /establishment	0,67	19	51003	4	46	9
Palm oil /début production	0,00	0	0	0	0	0
Palm oil /full production	0,54	15	406833	32	77	15
Orange	0,40	11	97364	8	0	0
Rice	**1,21**	**34**	**483478**	**38**	**303**	**59**
IVS 4	0,27	8	224994	18	90	18
Boliland 2	0,94	26	258484	20	213	41
Vegetable	**0,74**	**21**	**228235**	**18**	**87**	**17**
Cassava	0,61	17	147742	12	72	14
Beans	0,13	4	80493	6	15	3

Table 14. Main characteristics of the "rice_per_big" farm household type

Characteristic	Size		Production		Labour	
Unit	ha		Leones		Days	
Total	4,84	100	1720386	100	738	100
Perennial crop	2,43	50	494892	29	202	27
Palm oil /establishment	1,46	30	110166	6	100	14
Palm oil /début production	0,77	16	232163	13	73	10
Palm oil /full production	0,20	4	152563	9	29	4
Rice	2,33	48	1205795	70	527	71
Upland 2	0,83	17	408757	24	264	36
Upland 3	0,12	3	87123	5	20	3
IVS 1	0,36	8	163433	9	58	8
IVS 2	0,06	1	32305	2	15	2
IVS 4	0,10	2	84373	5	34	5
Boliland 1	0,12	3	31255	2	10	1
Boliland 3	0,45	9	214954	12	65	9
Boliland 4	0,28	6	183595	11	62	8
Vegetable crop	0,08	2	19699	1	10	1
Cassava	0,08	2	19699	1	10	1

Rice_per_big: big farm type cultivating mainly rice and palm oil. The average area of this farm type is about 4.84 ha. Those crops occupied 50 and 48 for palm oil and rice, respectively. The rest is cultivated with vegetables. The main characteristic of this farm type is that palm oil is defined as being under different stages of development: establishment, growth and full production. The rice ensures almost the 70 of the total farm production (Table 14).

4.3.4. Conclusion

The Principal Component Analysis was used to elaborate the farm typology and define the most representative farming systems in the Sierra Leone Bombali region. Apart from the biophysical endowments, two socio-economic criteria are used to capture farm heterogeneity: the economic farm size and specialization. Overall, 9 types of farm household are selected. Each farm household type represents a given number of real farms. All farm household types produce rice with different share according to the ecosystem and the majority of them cultivate the three types of rice (Upland, IVS and Boliland) but with a large diversity in term of cropping systems. We observed also that for the same cropping system labour requirement can be very different among farm household types leading to a high variability of labour productivity and farm profitability.

4.4. Definition and implementation of the simulated scenarios

In this section, we describe the two selected policy scenarios (Policy scenarios 1 and 2) by comparison to business as usual scenario (baseline scenario). These scenarios are designed to assess the combined effects of input (fertiliser) subsidy policy and improved practices (i.e. better management) on rice productivity and farm household viability in the Sierra Leone's northern region. The main idea is to analyse the interactions between agro-ecological conditions, improved technology and policy measure at field scale and then to assess their overall socio-economic impacts at farm and regional scales.

4.4.1. Baseline scenario

The base year information for which the model was calibrated stems from the year 2009, the year in which the survey was carried out. To define a suitable time horizon for farming systems scenarios analysis, the temporal scale may be chosen from a wide range according to the nature of the external driving forces and the intensity of the perturbing shocks. In several studies, for the expected shocks at the medium-term (as opposed to particular intermittent shocks), a period of at least 10-15 years is recommended, when studying the issue of external driving forces (Ross et al., 2008). However, it is clear that the greater the time horizon, the greater is the uncertainty of the market behaviour. The volatility of the product prices and possible agricultural policies that could be applied are the main reasons for such uncertainty. Thus, the year 2020 (time horizon of 11 years) is taken as the time horizon for running simulations (i.e. the baseline scenario). Apart from inflation, all the parameters are assumed to remain unchanged up to 2020. The other modelling assumptions are:

- Due to the lack of reliable information, no exogenous assumptions in terms of technological and market changes are adopted between the base year and the baseline;
- The exchanges of labour between farms are allowed, while the exchanges of land and equipment are not;
- Only current production activities are considered in the baseline.

4.4.2. Policy scenarios

4.4.2.1. Procedure for identification of policy scenarios

In this study the identification of policy scenarios was done through consultation with local experts, stakeholders and agents of the agricultural extension service (Table 15). The identification of policy scenarios was accomplished in two 2 steps:

1- Presentation of the study's objective: a first document describing the study area and the objective of the study was presented to all experts (Ministry of Agricultural, Free Town). This presentation gave also a summary of the modelling approach to use in this policy analysis.

Table 15. List of interviewed local experts and stakeholders

Name	Position	Institution	Email adress
Alpha Lakoh	Professor/Reasercher	Njala University	alphalakoh@yahoo.co.uk>
Jessie Olu John	President	NAFFSL	NaFFSL2009@yahoo.fr
Andrea RC Conteh	Diretor	NAFFSL/ FAAS	Claudacenter@yahoo.fr
Joseph S. Banguri	Assit director	MAFFS/SD	kabileh@yahoo.fr
B.J. Bangura	Director	MAFFS	Bjbangusa01@yahoo.fr
J.A Jalloh	Asst. Director extension	MAFFS	jajalloh@yahoo.com
Nazir. A Mohmood	R.O.SLARI	SLARI	nazirnadie@yahoo.com
Mohamed A Sheriff	Assistant director	MAFFS/PEMSD	mohamedjuba@yahoo.com
Foday S.Kanu	PME specialist	MAFFS/SCP	Fodaymot/cay@yahoo.fr
Mohamed T.Lahui	School of agriculture	Njala University	drmtlalai@yahoo.fr

2- Identification of policy scenarios: as a next step a meeting of half day with all experts was held in December, 2011 at the Ministry of Agricultural. The aim of the meeting was to identify the main biophysical and socio-economic constraints/ problems of rice production in the Bombali region and a list of potential solutions to overcome these constraints. To achieve this objective, experts were asked to answer the following two main questions:

- What are the main biophysical, agro-environmental (soils, sensitivity to pests and diseases, sensitivity to excess and deficit of water etc.) and technical (sowing, harvesting, etc.) problems faced by farmers to cultivate rice?
- What are the main technological innovations that could be applied to improve rice production?

From the meeting discussion and a large bibliography analysis, we conclude that even if Sierra Leone is naturally endowed with sufficient land, water, human resources and favourable climatic conditions, crop productivity remains very low and its improvement seems to be a big challenge due to several barriers such as: (i) the low-quality of seeds; (ii) the deficient access and use of fertiliser (less than 4kg/ha); (iii) the limited use of improved planting materials and production methods (FAO, 2005), especially for cocoa and coffee (low densities, age of the orchards, use of old cultivars, lack of maintenance, inadequate cultivation methods, etc.), (iii) the lack use of mechanisation; (iv) the limited access to agricultural financial services and to micro-credits facilities; and last but not least (iv) the fallow land constraint; usually after a crop cycle of 2-3 years, the land is often left, for a long idle/fallow period in order to regenerate organic matter, soil structure and nutrients stock.... Currently, the idle/fallow duration (bar soil) has progressively been shortened from an average of 20 years in the 1960s to a mere 4-7 years currently (MAFFS, 2009). The inadequacy or ineffectiveness of government support programmes and the slow adoption of improved technologies by farmers have also contributed to the poor crop productivity in Sierra Leone (MAFFS, 2009).

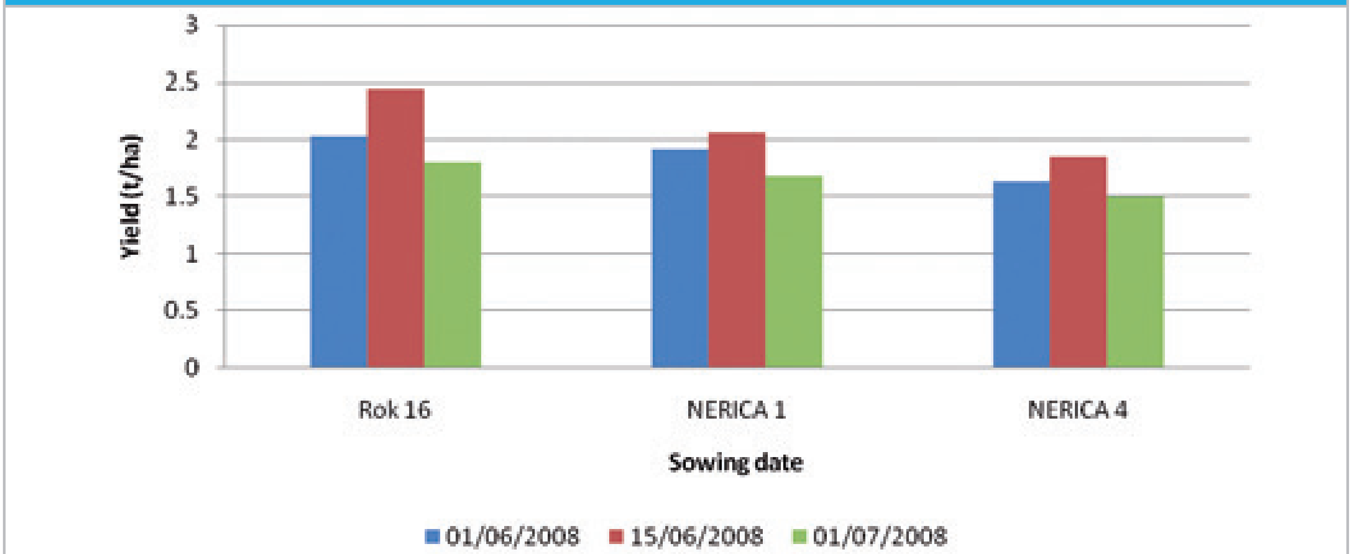
After a large discussion with local experts and an extensive literature review, two scenarios based on better rice managements are selected: (i) the adjustment of sowing date and amount of seeds; and (ii) the application of subsidized mineral fertilizer. The aim of this scenario analysis is to answer the following questions: how many farmers could adopt these new cropping systems, taking into account the current large cropping diversity and the local agro-ecological conditions and what are their likely impacts on rice productivity and farm profitability?

4.4.2.2. Policy scenario 1 (PS1): Baseline & Adjustment of sowing date and amount of seeds

One of the ways for improving rice production in Sierra-Leone would be the selection of appropriate sowing date enables to increase rice production and to take into account the arrival date of the monsoon. In fact, the standard deviation of average yield due to the variation in the sowing date is estimated to be between 17 and 68 (RARC, 2010). The Upland and the Bolilandrice are more sensitive to this variation then the IVS rice. Figure 33 shows this variation for the upland rice according to three varieties (Rok 16, Nerica 1 and Nerica 4) and three sowing dates. Form this Figure 33 it appears clearly that:

- The optimal date for the three varieties is the 16th of June. A delay or an anticipation of the sowing date by 15 days due to the arrival date of the monsoon or the not availability of labours could reduce yield by 28.
- The delay of the sowing date reduces more the final yield then the early sowing date. The observed difference in term of yield between the two dates could reach 11. In fact, the delay of the sowing date makes the rice more sensitive to drought in the reproductive phase.
- The more productive variety (Rok 16) is the most sensitive cultivar to the sowing date.

Figure 33: Effect of sowing date on rice yield



Source: RARC, 2010

In this scenario, we consider that the farmer is able to adjust the planting dates of rice in the different ecosystems (Upland, Boliland and IVS) as well as the seeding amount. The yield and the costs of these improved rice activities (by adjusting seedling rates and sowing dates) are estimated based on interactions with the interviewed local experts during the meeting held in Agricultural Ministerial in December 2012. The estimated costs and yields are reported in Table 16 and are related mainly to the local variety, RoK16, which is the more used one in the Bombali region. The yields expressed by experts in Table 16 (alternative yield) are, however, lower than those in Figure 33 which are well fertilized.

Table 16. Costs and yield of current and alternative rice activities

Rotation	Soil*	Technique	Current costs (Leones/ha)	Alternative costs (Leones /ha)	Current yield (t/ha)	Alternative yield (t/ha)
up_rice_mix-FALL	Upland 1	T1_UP1	293150	377666	0.22	0.35
up_rice_mix-FALL	Upland 1	T2_UP1	310300	341330	0.23	0.35
up_rice_mix-FALL	Upland 2	T1_UP2	293150	322466	0.39	0.6
up_rice_mix-FALL	Upland 2	T2_UP2	310300	341330	0.44	0.67
ivs_rice	IVS1	T1_IVS1	276000	276000	0.28	0.28
ivs_rice	IVS1	T2_IVS1	276000	276000	0.33	0.33
ivs_rice	IVS2	T1_IVS2	276000	276000	0.71	0.71
ivs_rice	IVS2	T2_IVS2	276000	276000	0.52	0.52
boli_rice	Boliland 1	T1_BOLI1	276000	276000	0.19	0.19
boli_rice	Boliland 1	T2_BOLI1	276000	276000	0.2	0.2
boli_rice	Boliland 2	T1_BOLI2	276000	276000	0.36	0.36
boli_rice	Boliland 2	T2_BOLI2	276000	276000	0.48	0.48

Source: Farm survey 2009 & expert knowledge

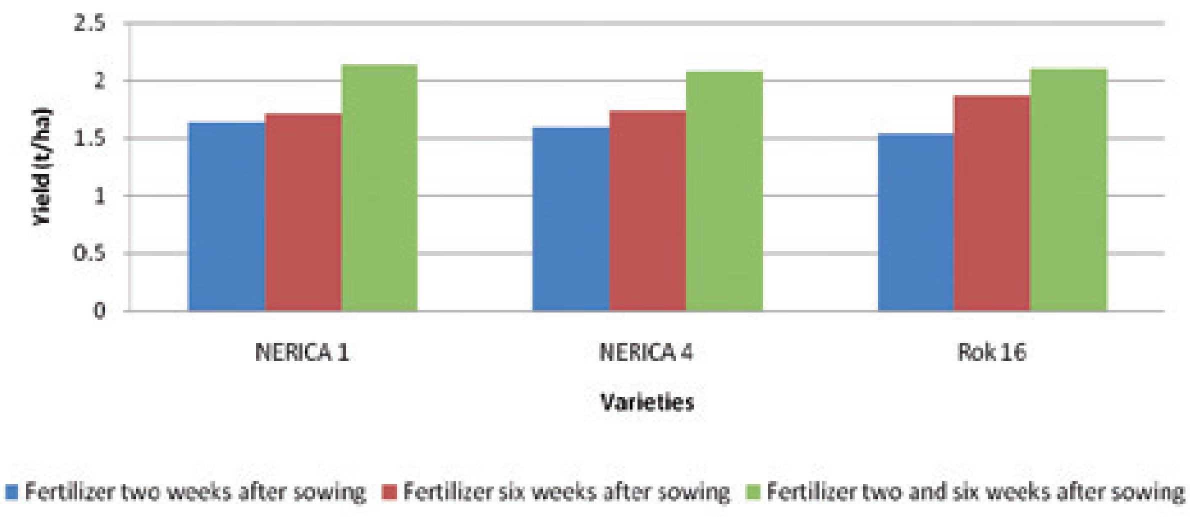
** upland 1: low soil fertility, upland 2: high soil fertility; T1: low labour use, T2 high labour use*

4.4.2.3. Policy scenario 2 (PS2): Policy scenario 1 & application of nitrogen fertilizer

The development of rice cultivars that are adapted to fertilization is also one of proposed solutions to promote rice production in Sierra Leone. In fact, the current traditional varieties which are still grown in an extensive way are known to be highly weed competitive, resistant to local biotic and abiotic stresses and adapted to low fertilization. However, it has a low yield potential due to poor resistance to lodging and grain shattering. In fact those cultivars (the traditional ones) are generally tall and low-yielding with few tillers and panicles. In this context, the N and P fertilization is seen as important and crucial alternative to improve the current rice cropping systems. Figure 34 gives an overview on the effects of N fertilizer on three rice varieties. This Figure shows also that the timing of application of N fertilizer can strongly affect the rice yield.

In this scenario, we attempt to assess the effects of nitrogen fertilizer on rice production and on whole-farm profitability. We assume that the farmer will receive within the STABEX program a fully subsidised fertiliser for producing rice. The amount of subsidies will be distributed directly to farmer depending on the applied quantity of N fertilizer which, in turn, varies according to the ecosystem. Table 17 reports the estimated yield and costs of the alternative rice activity (i.e. rice with fertiliser) based on expert knowledge as mentioned in previous section. The rice yields expressed in Table 17 concerns the traditional variety (i.e. Rok16) cultivated in the Bombali region.

Figure 34: Effect of N fertilizer and seed varieties on rice yield



Source: RARC, 2010

Table 17. Rice yield and costs after application of N fertiliser

Rotation	Soil	Technique	Yield (T/ha)	Costs (Leones/ha)
up_rice_mix-FALL	Upland 1	T1_UP1	0.44	2185641
up_rice_mix-FALL	Upland 1	T2_UP1	0.46	2149305
up_rice_mix-FALL	Upland 2	T1_UP2	0.71	2130441
up_rice_mix-FALL	Upland 2	T2_UP2	0.81	2149305
ivs_rice	IVS1	T1_IVS1	0.41	2083975
ivs_rice	IVS1	T2_IVS1	0.48	2083975
ivs_rice	IVS2	T1_IVS2	0.92	2083975
ivs_rice	IVS2	T2_IVS2	0.68	2083975
boli_rice	Boliland 1	T1_BOLI1	0.25	2083975
boli_rice	Boliland 1	T2_BOLI1	0.26	2083975
boli_rice	Boliland 2	T1_BOLI2	0.53	2083975
boli_rice	Boliland 2	T2_BOLI2	0.7	2083975

Source: expert knowledge

4.5. Results and discussion

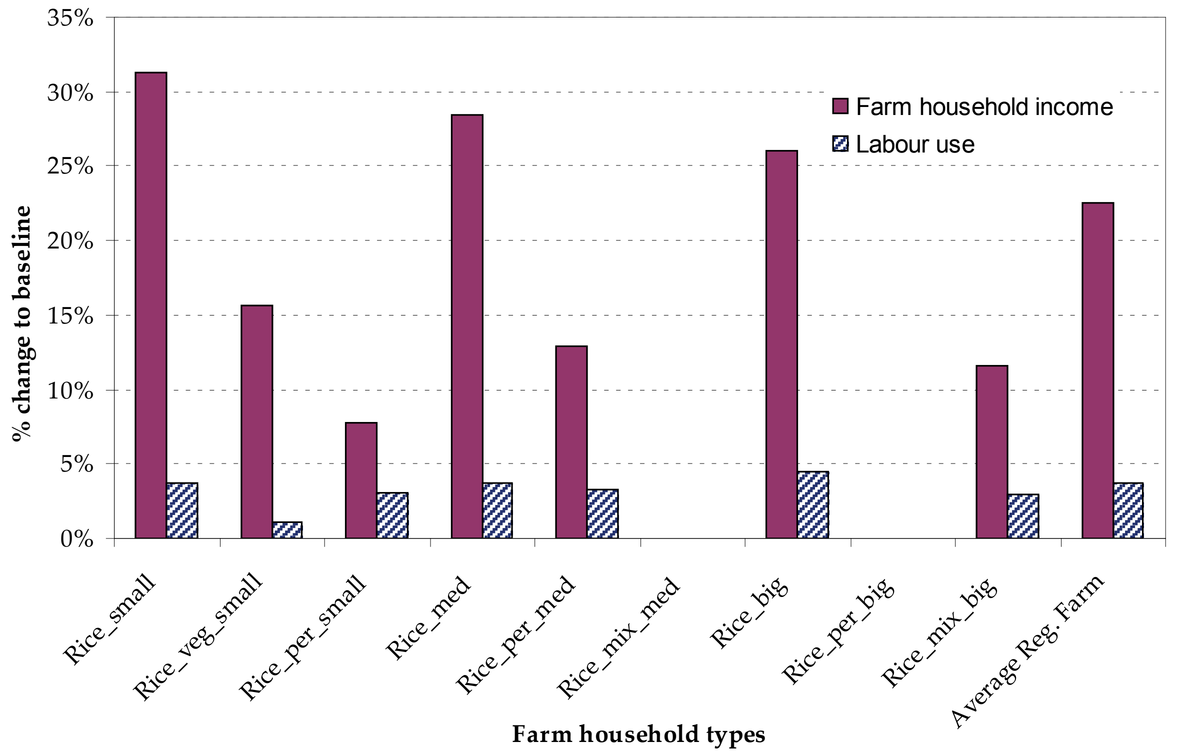
The objective of this section is to analyze and discuss the results of the simulated scenarios (baseline vs. PS 1 and PS 2) using a set of structural and economic indicators computed at the individual (i.e. farm household) and regional levels: land use, cropping pattern, supply and demand of rice and farm household income. In order to ease the interpretation of results and their comparison across scenarios, most impacts were measured as percentage changes to the baseline (i.e. reference run). The results in absolute terms are reported in Appendix 4.

4.5.1. Policy scenario 1 (PS1)

Figure 35 presents the variation of farm household income and labour use between baseline and policy scenario PS1 in the nine farm household types as well as in the average regional farm. As expected, the adjustment of rice sowing date and of seed amount (i.e. policy scenario 1) would boost household income of most arable farms and make farmers feel more secure. The majority of the farm household types would be positively affected and their farm household income would rise, in different degrees, according to agro-climate, resource endowment and socio-economic conditions. The biggest percentage increase would occur in specialised rice farms such as rice_small, rice_med and rice_big farm household types, followed by mixed farms combining rice and vegetable or rice and perennial crops. The lowest increase is observed for farms dominated by perennial crops (palm oil) such as rice_per_big farm type. The average percentage increase at regional level would be also significant at around 23% (i.e. average regional farm) and it is mainly driven by the high share of specialised rice farms within the studied region.

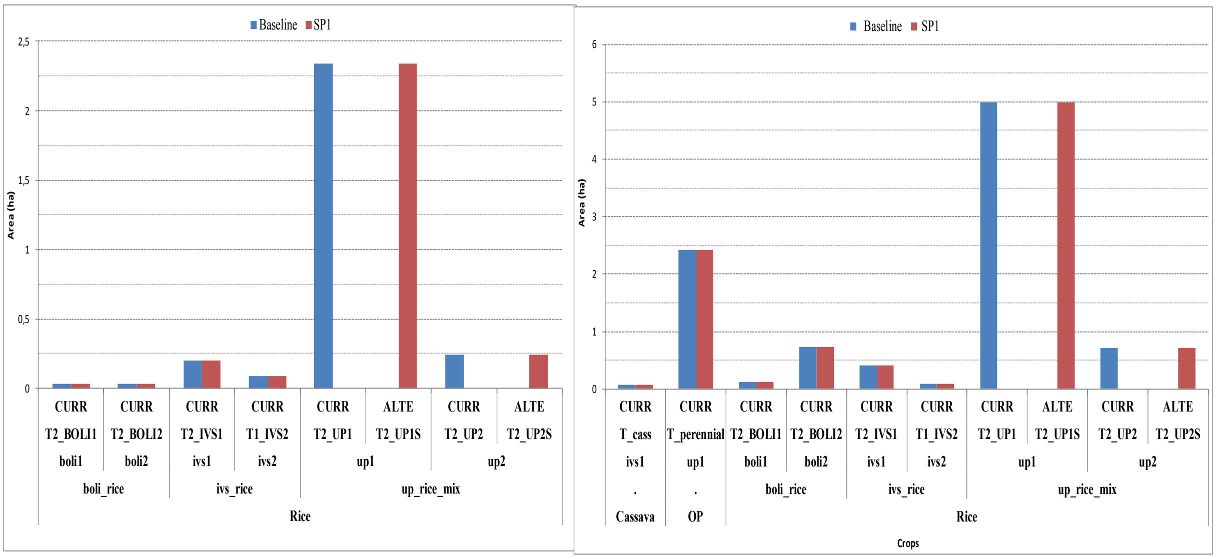
The implementation of this policy scenario would also induce an increase of labour use in most of the farm household types rounding the 4% explained by the high labour requirement of alternative rice practices, in comparison to current ones.

Figure 35: Socio-economic impacts of policy scenario 1 (PS1) on different farm household types



To understand those socio-economic results, a deep analysis of the change in land use, crop allocation, production and consumption of main activities provoked by this policy scenario is required. The first outcome from this deep analysis is that the implementation of the policy scenario PS1 does not affect at all the current crop pattern. In fact, in all farm household types, the model selects the same crop allocation as for the baseline; but it substitutes the current rice practices by the alternative ones which are more efficient in terms of seedling rates and sowing dates. The only cases where this substitution would not happen are for the farm household types “rice_mix_med” and “rice_per_big” because of their high labour costs. An example of such results is shown in Figure 36 for two farm household types. This means that, on the one hand, the increase in rice productivity provoked by the adjustment of sowing date and amount of seeds is not sufficient to boost rice activity and encourage farmers to increase its area in detriment to others crops and, on the other hand, the increase in farm household income reported above is explained more by the increases in rice productivity per unit area in all ecosystems (i.e. soil type) rather than by the rise in rice area. A part from the agro-climatic constraints (i.e. crop rotation and soil type), one of the reasons of lower competitiveness of new rice activities compared to other crops is its higher labour requirement as revealed in Figure 35.

Figure 36: Impacts of policy scenario 1 (PS1) on rice activities’ area

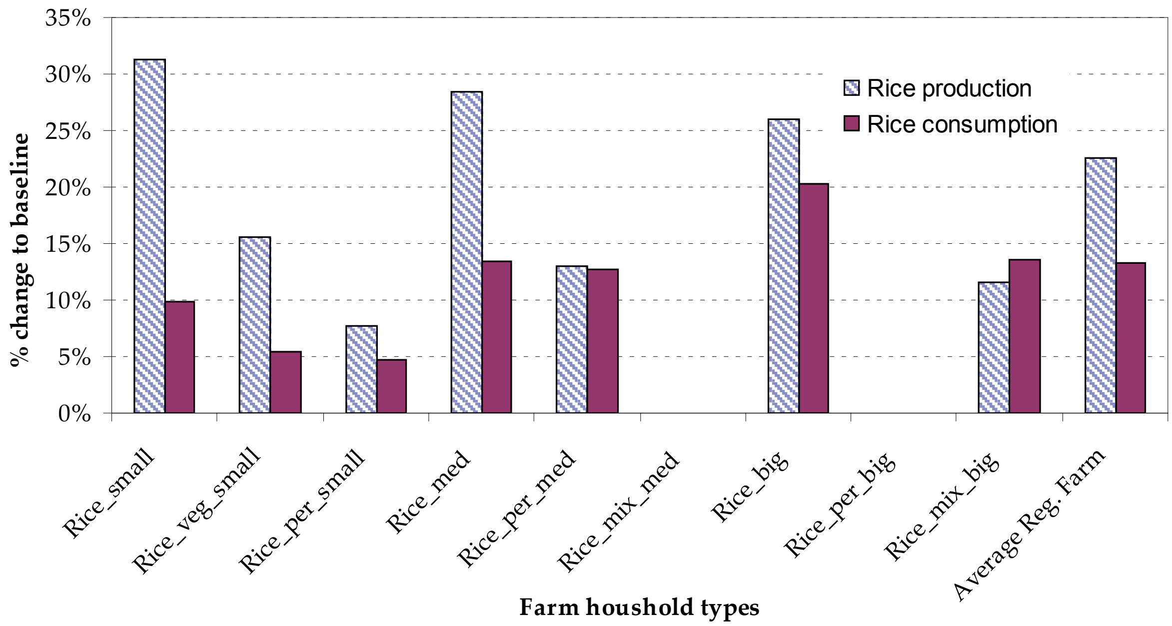


(a) Farm household type: Rice_small (b) Farm household type: Rice_big

The impacts of this policy scenario on the farm household's production and consumption of rice are reported in Figure 37. As expected, the full substitution of current rice practices by the alternative ones would lead an increase of rice production in most farm household types with different levels. The least increase would occur, naturally, in farm household types with low rice land share. The biggest increase would take place in farm household types with high initial share of Upland rice because rice yield in the Upland ecosystem is more sensitive to the variation of sowing date, in comparison to Boliland and IVS. This implies that, the increase in farm household income is positively correlated to the land share of upland rice. In fact, currently the rice yield in upland is lower compared to IVS and Boliland, consequently, an adjusting in the seedling rate and the sowing date could have a significant positive effect on yield. Nevertheless, because of the initial low productivity and the fallow rotation constraint, the expansion of rice in this ecosystem remains limited. The average percentage increase of rice production at regional level would exceed the 20% (i.e. average regional farm) explained by the relatively high increase of rice production in specialised rice farms.

Regarding consumption, the simulated policy scenario PS1 would lead to an increase in the consumption of rice in most of the farm household types ranging from 5% to 20$ (except for two farm household types where the impact is minim), with an average regional level exceeding the 13%. This increase is explained by the rise in both rice production and household income. Nevertheless, since rice is a necessity good its demand increases less than proportionally to the rise in income. Moreover, given the large difference between production and consumption levels, most of the additional rice quantities (surplus) generated by this policy scenario would be sold in the market which would decrease food prices for urban households.

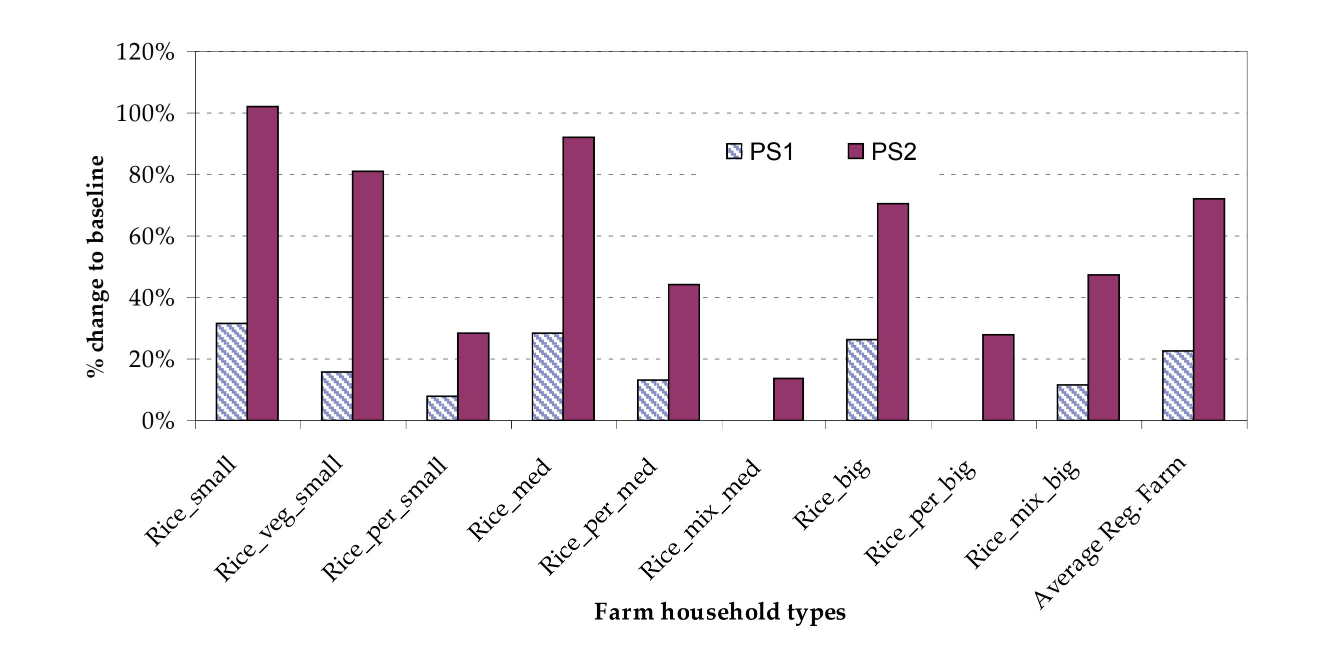
Figure 37: Change in production and consumption of rice under policy scenario 1 (PS1)



4.5.2. Policy scenario 2 (PS2)

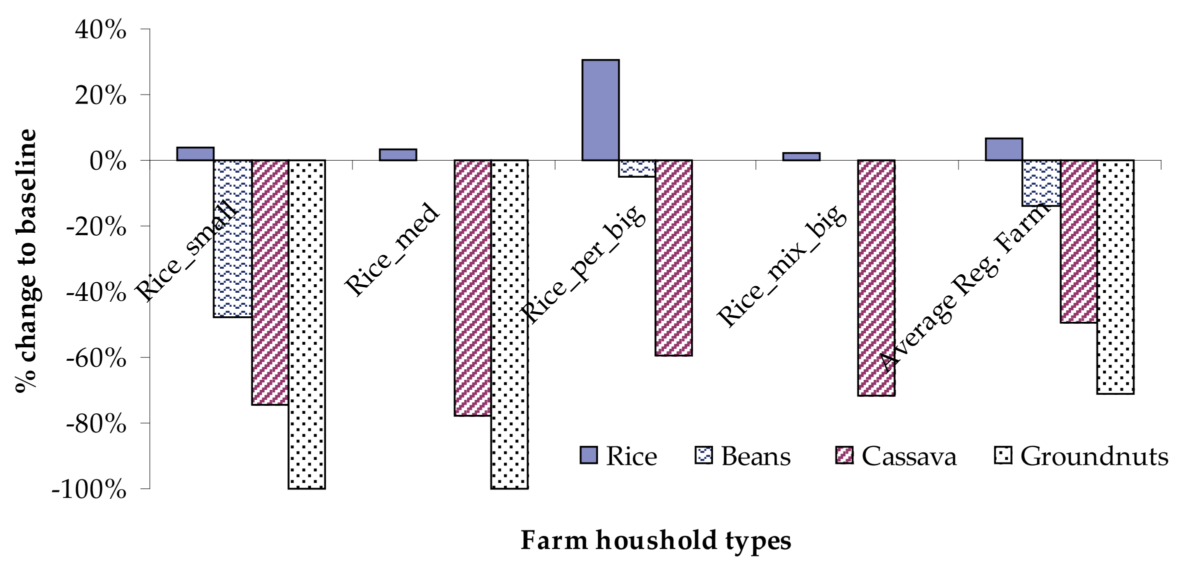
The combined effects of the appropriate sowing date and amount of seeds as well as of the application of subsidized fertilizer (i.e. PS2) on all the computed indicators (i.e. farm household income, crop pattern, production and consumption of rice...) would be more pronounced than in the PS1 scenario. As expected, farm household income will increase in all farm household types in comparison to the baseline and PS1 (Figure 38). The highest percentage increase would arise in farm types producing mainly rice such as Rice_small and Rice_med, reaching the 96% and 102%, respectively. In absolute term, the main increase is observed in big rice farm type, namely Rice_big (for further detail see Table 5.3 in Appendix 4). The average farm household income at regional level (i.e. average regional farm) would also be positively affected and its percentage increase, in comparison to baseline, would expand from 23%, in the PS1, up to 72% under the SP2 scenario. However, contrarily to the SP1 scenario, the increase in farm income in SP2 would concern all farm household types and, for the majority of them, it is driven by the rise in both rice productivity and rice area.

Figure 38: Farm household income change under simulated policy scenarios (PS1 & PS2)



As shown in Figure 39, the implementation of the policy scenario PS2 would induce a slight change in crop pattern for certain farm household types and a full substitution of current rice practices by the alternative ones (with fertiliser) for the majority of them. The change in crop pattern is manifested by a slight increase in rice area to the detriment of groundnuts, cassava and, to a lesser extent, beans. However, this increase remains very small, except for the Rice_per_big farm type where the raise would reach the 30%. The expansion of rice land is inhibited mainly by the agro-climatic conditions (i.e. soil types and crop rotation constraint), the highly labour costs of improved rice activities and the consumption requirement. In fact, vegetable crops are very useful for self-consumption in most of the farm households.

Figure 39: Crop pattern change under policy scenario 2 (PS2)

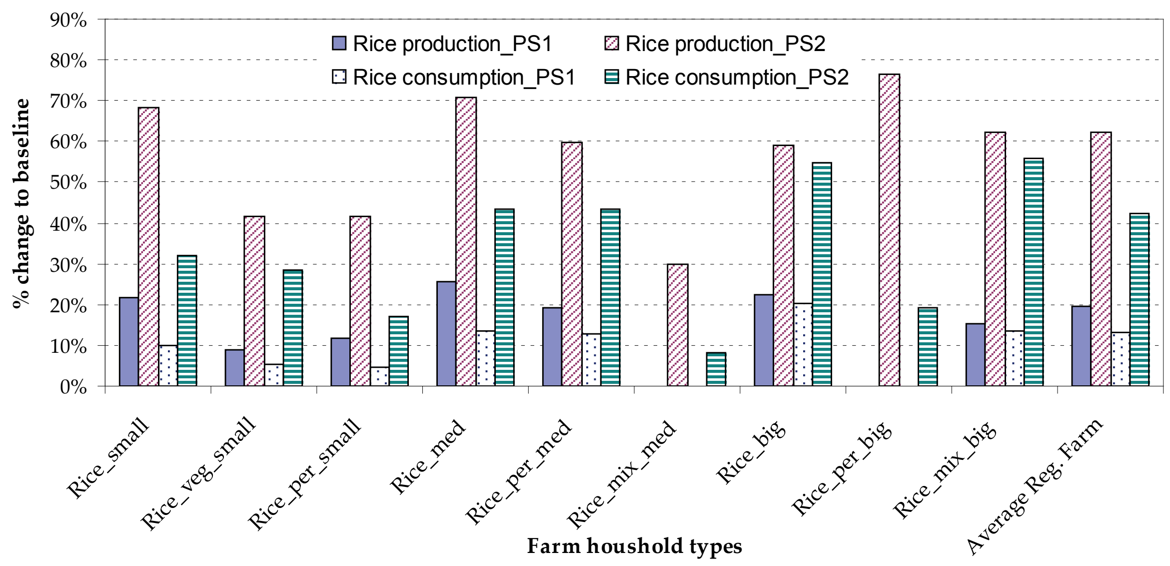


In addition, all the selected rice activities are fertilised; except for rice activities in IVS ecosystem where the soil is very fertile and the fertilization will not improve significantly the rice yield. This means that the improved rice activities with appropriate sowing date, amount of seeds and fertiliser are more efficient compared to the current ones. However, this efficiency is strongly dependent on subsidy for fertiliser because, according to our simulation, without subsidies no fertilised rice activities would be selected. This means that the amounts of N fertilizer required for, mainly, upland rice appear too high and costly and could not be applied by farm households without policy support (i.e. subsidies).

As expected, the expansion of rice production would be more significant under the SP2 scenario and it would exceed the 40% for most of the farm household types, reaching the 80% for some of them (Figure 40). This expansion is explained by the rise in productivity in Upland and by the increase in rice area in IVS. This is to say that one of the main ways of enhancing farm viability in Sierra Leone could be by improving rice productivity in Upland; especially because the vast majority of arable lands are located in this ecosystem.

As for the previous scenario, consumption of rice would expand under the SP2 scenario following the rise in both rice production and household income. Its percentage increase would be different across farm household types ranging between 8% and 58%, with an average regional level at around 42%. As we said before, given the large difference between production and consumption levels generated by this scenario and because of the low storage capacity of most farm households, the sold quantity would increase and this can have a positive impact on food prices for urban households. However, this kind of impacts can not be captured by our model.

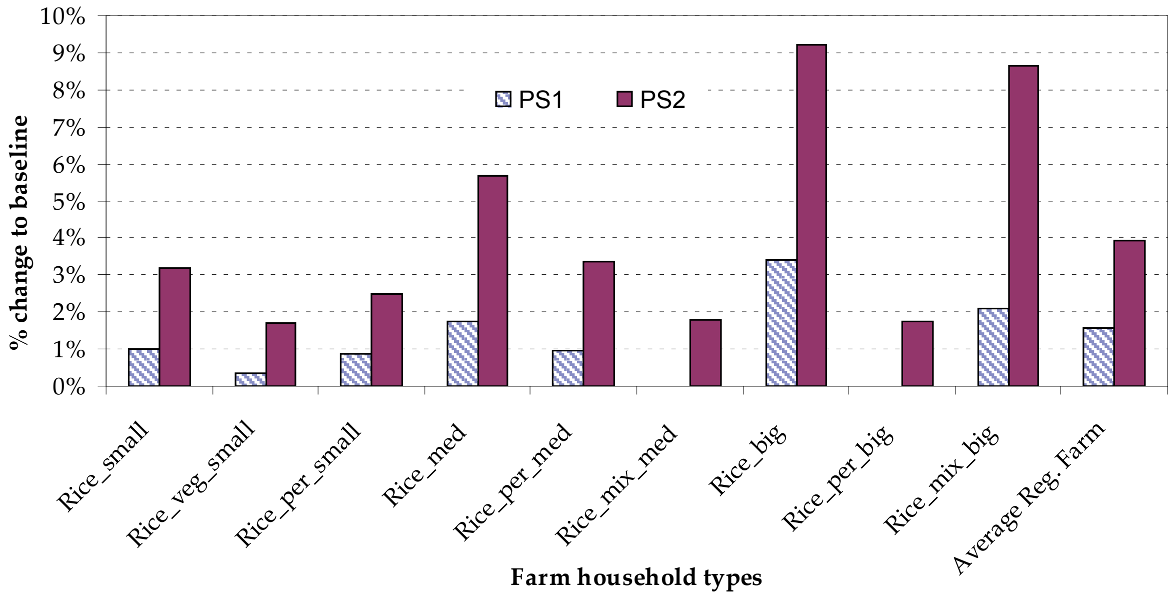
Figure 40. Change in production and consumption of rice under simulated policy scenarios (PS1 & PS2)



Regarding the poverty assessment, both scenarios would have very little impact on poverty reduction in the studied region. As shown in Figure 41, the improvement of poverty gap under both scenarios would be small in most of the farm household types, less than 10%. This means that even if all farms would improve their income and reduce their poverty gaps, most of them would continue to stay under the extreme poverty line of 1 USD-equivalent per day.

increase farm productivity and boost household income but they are not sufficient to fight poverty since most of the farm household types would continue to live below the extreme poverty line of 1 USD-equivalent per day. This application provide also quantitative evidence of the major role of agronomic and economic constraints, frequently raised in the literature to explain the poor rice productivity in Sierra Leone (Saito et al., 2012; Jalloh et al., 2012).

Figure 41: Percent improvement of poverty gap under simulated policy scenarios (PS1 & PS2)



4.6. Conclusion

In this section, the FSSIM-Dev model was used to assess the combined effects of input (fertiliser) subsidy policy and improved rice cropping managements on the livelihood of representative farm households in the Bombali region of Sierra Leone.

The main finding of this application is that: (i) the improvement of rice cropping management/practices is a key factor to boost significantly farm household income in Bombali region; (ii) the amounts of N fertilizer required for, mainly, upland rice appear too high and costly and could not be applied by farm households without policy support (i.e. subsidies); and (iii) the rice policy and the improved managements would

From the methodological viewpoint, this application highlights the relevance of this kind of models for making a finer policy analysis and for taking into account key features of low income economies. In fact, FSSIM-Dev model can be used for testing either very simple scenarios or more complex scenarios combining agronomic and economic drivers. In addition, this kind of approach facilitates the collaboration and the exchange of knowledge between scientists, stakeholders and policymakers such is the case in this study. However, like any model, it suffers from some limitations. The first is the arbitrary choice of the linear expenditure system. More flexible functional forms such as the Translog function may be preferable. The second limitation is the lack of critical assessment of the model's behaviour/performance in the simulation phase due to unavailability of data (e.g. a second dataset or price elasticity).

5. Conclusion and recommendations

In this report, a farm household model, called FSSIM-Dev, has been presented as a generic tool to be used in the context of developing countries to gain knowledge on farm households' livelihood strategies and to assess their responses to policy and technological changes. In order to illustrate the applicability of this model, it was applied to a representative sample of farm households belonging to the Northern region of Sierra Leone (Bombali). The aim was to assess the combined effects of rice support policy, namely fertilizer subsidy policy, and improved rice cropping management (practices). The main findings of this application in terms of policy impact are: (i) the improvement of rice cropping management is a key factor to significantly boost farm household income in the Bombali region; (ii) the amounts of N fertilizer required for, mainly, upland rice appear too high and costly and could not be applied by farm households without policy support (i.e. subsidies); and (iii) both the rice policy and the improved management would increase farm productivity and boost household income but they are not sufficient to fight poverty since most of the farm household types would continue to live below the extreme poverty line of 1 USD-equivalent per day.

Moreover, it is clear that the effort to increase rice production in Sierra Leone's north region should be focused primarily on upland rice which has a very low productivity. Of course, other technological innovations, such as improving transplanting rice in IVS ecosystems, could be also tested. Alternatively, it may be advisable to concentrate rice production in Lowlands (IVS and Boliland) and use Upland for tree crop production and other annual crops that cannot tolerate water logging conditions. There is presently enough Lowland area to produce sufficient rice for local consumption and even export. This alternative will significantly reduce the Upland area needed to grow rice and thereby increase the area that can grow into forest. These findings have to be considered, however, with some caution due to model assumptions and limitations.

The Sierra Leone application opens up many opportunities to extend the analysis for testing new cropping systems or/and new technology in other regions or/and under different socio-economic conditions. For example, by interaction with local experts from the Ministry of Agriculture two new scenarios of interest have emerged and could be tested in further model application: (i) the introduction of machinery for soil tillage and weeding; and (ii) the use of new seed varieties resistant to major diseases.

From methodological perspective, this application highlights the relevance of FSSIM-Dev for making a finer policy analysis and for taking into account the main characteristics of developing countries. To the best of our knowledge, the model presented here is one of the few farm household programming models which attempts to reproduce farm household production and consumption decisions in a separable regime and to endogenize household prices. This model also provides the possibility of taking into account farm heterogeneity and of simulating endogenously the switching between different forms of agricultural management for a given policy scenario. Furthermore, a number of key methodological choices, driven by the objective of the study and data availability (e.g. simulating average farms instead of individual real ones, switching off the risk module, etc.), was made for the Sierra Leone case study and can be easily adjusted for future model applications if needed.

From this statement of the conclusions, the main question will be to establish whether the FSSIM-Dev model can be easily extended to other African regions and what precautions ought to be considered for such a purpose?

Although FSSIM-Dev was designed to be sufficiently generic and easily adaptable, answering this question is not easy and depends largely on the target of the study. Globally, three situations, with different degrees of modelling chain complexity, can be discerned:

- Use of FSSIM-Dev as an analytical tool to analyse the effects of policy options on the behaviour of representative farming systems such as the case in this study. In this case great efforts are required before the farm modelling: i) to collect detailed information from literature, farm households and experts to characterize the current agricultural diversities, to define the farm household types and to evaluate the model performance and, ii) to apply a cropping system model (or an alternative approach such as expert knowledge) for simulating, at field level, the effects of biophysical (soil salinity, rainfall, fertility, toxicity) and crop practices (mix crop, irrigation, rainfed, soil tillage) on crop yields (and maybe environmental externalities). For this purpose, the re-usability of FSSIM-Dev for other African regions is possible but is costly in terms of data collection (i.e. model parameterisation) and model adjustment and calibration.

- Use of FSSIM-Dev as a tool to help policy makers to take strategic decisions. In that situation, the number of farm households could be reduced and data collection will be less costly than in the first option. However, the model results will be also less accurate because only a global specification will be explicitly modelled. For this purpose, FSSIM-Dev can be easily implemented without additional development. However, model results have to be considered with more caution and can be used only in a relative way for comparing scenarios.

- Use of FSSIM-Dev as a model-assisted participatory approach to help local actors make joint decisions. FSSIM-Dev could easily be used for this purpose because actors are generally interested in (i) the modelling of small numbers of real farms; and (ii) in the relative change of behaviour in comparison to a reference situation. In this case there is no need to spend much time and effort on model calibration and validation or indeed on up-scaling results at aggregated levels. In addition, data access and data collection will be easier and less costly.

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7. Appendices

Appendix 1. Indexes, parameters, variables and equations in FSSIM-Dev

Indexes	Description
h	Farm households
i & i'	Agricultural (crop and livestock) activities
jf	Goods and factors
j,j'	Goods
f	Factors (land, labour, water and capital)
tf	Tradable factors (land, labour and capital)

Parameters	Description
w_h	Representation (weight) of farm households within the village/region
ϕ_h	Risk aversion coefficient
$A_{h,i,f}$	Input coefficients (i.e. input use of factor *f* into activity *i*)
$B_{h,f}$	Initial resources endowment
$y_{h,i,j}$	Economic output coefficient (i.e. yield of activity *i*)
$a_{h,i}$	Accounting costs
$d_{h,i}$ & $Q_{i,i'}$	Implicit cost function's parameters estimated with PMP-ME approach
$\lambda'_{h,tf}$	Implicit marginal costs of tradable factors revealed through PMP approach
$\beta_{h,j}$ & $\gamma_{h,j}$	Household expenditure function's parameters
$sb_{h,i}$	Subsidies
p^m_{jf}	Market prices of goods and tradable factors
t^b_{jf}, t^s_{jf}	Multiplicative transaction costs of goods (buyer, seller)
fc_h	Fixed costs
$exinc_h$	Exogenous off-farm incomes for households
Hc_h	Household composition (adult equivalent)
K	Number of state of nature
P	Poverty line

Variables	Description
V	Weighted sum of representative farm households' utility
U_h	Farm household utility
R_h	Farm household (expected) income
Y_h	Farm household full income
$Rn_{h,k}$	Farm household income over state of nature (i.e. random full income)
σ_h	Standard deviation of farm household income
π_h	Agricultural (expected) income
$x_{h,i}$	Agricultural activity levels (i.e. land use and animal number)
$q_{h,j}$	Produced quantities of goods
$s_{h,jf}$	Sold quantities of goods / rented-out tradable factors
$b_{h,jf}$	Bought quantities of goods / rented-in tradable factors
$c_{h,j}$	Consumed quantities of goods
$c^s_{h,j}$	Self-consumed quantities of goods
$p_{h,jf}$	Prices of goods and tradable factors faced by households
M_{jf} & E_{jf}	Imported and exported quantities of goods and tradable factors

N°	Equations	Description
(1)	$Max\ \mathrm{V} = \sum_h w_h U_h$	Model objective function
(2)	$U_h = [R_h - \phi_h \sigma_h]$	Farm household utility function
(3)	$R_h = \pi_h + \sum_{tf} s_{h,tf} p_{h,tf} - \sum_j b_{h,j} p_{h,j} + exinc_h$	Farm household income
(4)	$Y_h = R_h + \sum_{f=land} B_{h,f} b_{h,f}$	Farm household full income
(5)	$\pi_h = \sum_j (s_{h,j} + c^s_{h,j}) p_{h,j} + \sum_i sb_{h,i} x_{h,i} - \sum_i a_{h,i} x_{h,i}$ $- \sum_i (d_{h,i} + 0.5 Q_{i,i'} x_{h,i}) x_{h,i} - \sum_{tf} (b_{h,tf} + \lambda'_{tf}) p_{h,tf} - fc_h$	Agricultural income
(6)	$\sigma_h = \left(\frac{\sum_k (Rn_{h,k} - R_h)^2}{K} \right)^{1/2}$	Standard deviation of farm household income due to price and yield variations
(7)	$\sum_i A_{h,i,f} x_{h,i} \le B_{h,f} + s_{h,f} - b_{h,f}$	Resource constraints at farm household level (land, labour, water, capital …)

N°	Equations	Description
(8)	$q_{h,j} + b_{h,j} = s_{h,j} + c_{h,j}$	Quantity balance for goods at farm household level
(9)	$q_{h,j} = \sum_i y_{h,i,j} x_{h,i} = s_{h,j} + c^s_{h,j}$	Produced goods at farm household level
(10)	$p_{h,j} \leq p^m_j t^b_{h,j}$ $p^m_j t^s_{h,j} \leq p_{h,j}$	Price bands for goods
(11)	$s_{h,j}(p_{h,j} - p^m_j t^s_{h,j}) = 0$ $b_{h,j}(p_{h,j} - p^m_j t^b_{h,j}) = 0$	Complementary slackness conditions
(12)	$s_{h,j} b_{h,j} = 0$	Households buy or sell goods, not both
(13)	$\sum_j s_{h,j} p_{h,j} + \sum_{tf} s_{h,tf} p_{h,tf} + \sum_i sb_{h,i} x_{h,i}$ $+exinc_h \geq \sum_j b_{h,j} p_{h,j} + \sum_{tf} (b_{h,tf} + \lambda'_{h,tf}) p_{h,tf}$ $+\sum_j a_{h,i} x_{h,i}$	Cash constraint
(14)	$c_{h,j} p_{h,j} = \beta_{h,j} \left(Y_h - \sum_{j'=j} \gamma_{h,j'} p_{h,j'} \right) + \gamma_{h,j} p_{h,j}$	Farm household expenditure function
(15)	$\sum_h w_h s_{h,j} + M_j = \sum_h w_h b_{h,j} + E_j$	Quantity balance of goods at aggregated level (region/village)
(16)	$\sum_h w_h s_{h,tf} + M_{tf} = \sum_h w_h b_{h,tf} + E_{tf}$	Quantity balance of tradable factors at aggregated level (region/village)
(17)	$PG = \sup\left[0, \frac{(P - R_h / Hc_h)}{P} * 100\right]$	Poverty Gap

List of outputs generated by FSSIM-Dev at farm and aggregated (village/regional) levels

Type	Output	Unit
Economic	Poverty Gap	%
	Farm household income	National currency
	Farm income	National currency
	Farm household income per household unit	National currency/HUnit
	Farm income per work unit	National currency/WUnit
	Farm income per ha	National currency /ha
	Gross production	National currency
	Total subsidises	National currency
	Total costs	National currency
	Land shadow price	National currency
	Produced quantities of goods	Tons
	Bought quantities of goods	Tons
	Consumed quantities of goods	Tons
	Self-consumed quantities of goods	Tons
Input use	Total nitrogen use	Kg N/ha
	Water use	mm/ha
	Nitrogen use	Kg N/ha
	Pesticide use	g/ha
	Labour use	Hours/ha
	Labour rented-in and rented-out	Hours/ha
	Energy use of irrigation	toe/ha
	Energy use of tillage	toe/ha
	Energy use of mineral nitrogen	toe/ha
	Energy use of animal food	toe/ha
	Energy use of animal housing	toe/ha
	Total energy use for crops	toe/ha
	Total energy use for livestock	toe/ha
	Total energy use	toe/ha
	Nitrogen use per forage area	Kg N/ha
	Use of organic nitrogen	Kg N/ha
	Use of mineral nitrogen fertilizer	Kg N/ha

Type	Output	Unit
Environment (i.e. positive and negative externalities)	Soil erosion	T/ha
	Water drainage	mm/ha
	Nitrate volatilization	Kg NH3-N/ha
	Soil Fertility rate	Ha
	Soil Fertility gain	Ha
	Soil organic matter	
	Pesticide volatilization	g/ha
	Pesticide runoff	g/ha
	Pesticide leaching	g/ha
	Runoff	mm/ha
	Average energy efficiency for crops	toe/tDM
	Average energy efficiency for livestock	toe/tDM
	Erosion peak	T/ha
	Runoff Peak	mm/ha
	Average farm nitrogen surplus	Kg N/ha
	Farm gate N surplus	Kg N
	Farm gate N efficiency	
	Crop diversity	Ha
Structural	Land use	Ha
	Crop area (per crop)	Ha
	Crop activity level *i*	Ha
	Animal number (per animal type)	Head
	Animal activity level *i*	Head
	Stocking rate (livestock density)	LU/ha
	Stocking rate (livestock density) on the total forage area	LU/ha
	Stocking rate (livestock density) on the total grass-land area	LU/ha

Food Security Indicators

1. Introduction

Food uncertainties are at the top of the agendas of African regional organisations and the international community in general. According to the FAO (1996), food security is defined as "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

Food security is a major challenge for developing countries, especially in Africa. Chronic food insecurity and hunger are widespread in sub-Saharan Africa (Boon, 2007). According to USAID, in August 2011, famine expanded in Somalia while the food security emergency deteriorated in the rest of the eastern Horn of Africa. About "3.7 million people in Somalia, 3.7 million people in Kenya, 4.8 million people in Ethiopia, and 0.16 million people in Djibouti are in need of assistance" (USAID, 2011, p.1).

All African agricultural and food security policies stress the demographic challenges faced. Between 1950 and 2010, West Africa's population increased fivefold and will double again between 2011 and 2050. Urban growth rates are still more spectacular: twentyfold increase between 1950 and 2010 and an expected fourfold increase in urban population between 2011 and 2050 (OECD, 2011). This growing global population and shifting food demands put strain on natural resources, allied to the impact of climate change and price volatility.

This paper will briefly trace food security global trends in Africa and introduce the concept of food security and its four dimensions: availability, accessibility, utilisation/quality and stability. Main measurement indicators assessing each of these aspects will be presented. The measurement of relative levels of food security is not a straightforward matter.

2. Food crises and food security in Africa

Since the late 1970's, the FAO Global Information and Early Warning System (GIEWS) has been monitoring all countries of the world to detect factors leading to impending crises and give an early warning to affected countries and the international community. The retrospective analysis of this information shows that the number of countries struck by an acute food security crisis (rather than the number of people affected) has increased since the early 1980's, natural causes (slow or sudden onset disasters) being relatively more prevalent during the first decade, natural and man-made crises (linked to conflict and insecurity, but also to economic shocks) evolving more closely from then on. Generally speaking, Africa has been the region with the highest number of countries in crisis, and frequency of occurrence, by country (FAO, 2011). The number of countries in food security crisis at any given time reached a record high recently owing to the combined effects of the 2007-2008 food price crisis, and the 2009 global financial crisis.

The 2007-2008 World food price crisis

The 2007-2008 World food price crisis saw very sharp increases in maize and wheat prices, of 54 and 125 respectively, over a period of a few months. This crisis had been building up for some years, changes in incomes and consumption patterns in populous countries of Asia gradually driving down the global cereal stock-to-utilization ratio, and rising energy prices. It was precipitated by severe production shortfalls in some of the world's major producing countries, and policy-driven increased reliance on biofuels in others. Subsequently, between October 2007 and April 2008, world market prices for rice tripled, going from $335/ton to over $1000/ton, an unprecedented increase that was probably the most serious shock to world food security in the previous 25 years, since rice is the most important source of calories for the world poor (Dawe and Slayton, 2010).

Sub-Saharan Africa takes up nearly one-third of the world's rice exports, and West Africa, which includes countries with some of the continent's highest rates of per capita rice consumption (Guinea-Bissau: 86 kg/cap/year, Senegal: 74 kg, Côte d'Ivoire: 64 kg), is also the largest sub-continental importer, accounting for about half of sub-Saharan Africa rice imports. In response to the increase in imported cereal prices in 2007-2008, importing countries reduced or suspended import duties on cereals. Some, like Mali and Burkina Faso put a ban on exports of domestic and imported cereals but with very limited effectiveness. Other countries have also announced or have taken steps in order to reduce their dependency on imports. In addition, a number of bilateral agreements have been negotiated to secure rice supplies over several years (Senegal with India for six years, Nigeria with Thailand, etc.) (Gajigo and Denning, 2010).

West African crises

West Africa has been confronted with both natural disasters and human-induced crises (either economic shocks or conflict related) with a significant impact on poverty and food insecurity. Both natural disasters and significant human-induced (or anthropogenic) crises are well-known to "set countries back along the development path", for instance, and most countries of the region have been affected by both. However, distinguishing between natural and man-made factors is not always a simple task, and there have been many cases, such as in complex emergencies, where the root factors of food insecurity have worked in combination with one another. Human induced crises, for example, can intertwine socio-economic stress and conflicts in intricate ways: social inequalities can lead to conflicts, while conflicts destroy assets and can leave a country impoverished for many years. Lebanon and Iraq are ready examples, but one can also think of Liberia, Sierra Leone or Côte d'Ivoire as well. Protracted crisis situations, on the other hand, are characterized by recurrent natural disasters and/or conflict, the longevity of food crises, a breakdown in livelihood systems and an insufficient capacity to react to or break out of, crises[17].

Most West-African countries have made progress in reducing under-nourishment and their vulnerability to food insecurity: undernourishment rates fell over the last 30 years in eight countries, were stable in four, and increased in 6. Region-wide, undernourishment rates in West Africa remain much lower than in East, Central and Southern Africa[18]. Since the late 1970's West African countries have also figured less often than other countries of the continent on the FAO/GIEWS list of "countries in crisis requiring external assistance" as we show in the section on crises. Still, undernourishment rates remain clearly higher than in most other parts of the world, and a very recent global assessment of food insecurity risk[19] puts almost all West-Africa countries in the "high risk" category; Ghana being assessed as a "medium risk" and Liberia an "extreme" one.

3. How to measure food security

The concept of food security

The food security concept has significantly evolved over time in parallel with the development of the official political thought (Clay, 2002). Food security has become a major concern for international institutions since the global food crises of 1972-1974, following major episodes of drought and food shortages in the Sahel (Heidhues et al., 2004). The term of food security appeared at the 1974 World Food Summit and was mainly defined in regards to food supply, "Availability at all times of adequate world supplies of basic food-stuffs (...), to sustain a steady expansion of food consumption (...) and to offset fluctuations in production and prices" (UN, 1975). This primary approach was substantially a matter of food availability which is determined by food production level, stocks and trade.

Towards a multi-dimensional understanding of food security

From the mid-1980s, concerns with food security have evolved, especially after Sen's works on human development (1981). Attention to food security has shifted from national food supply assessment to its allocation at the household and individual levels, and focused on the mechanisms carried out by the populations to gain access to food. In 1983, the FAO analyses focused on food accessibility conditions which are recognized as a key determinant of food security. Thus, it comes to aiming at ensuring that, at any time, any individual has a physical and economical access to the food supplies which he/she needs. In 1989, the World Food Program defined food security as "when every person has, at all times, physical and economic access to meet their basic food needs. A national food security strategy cannot be contemplated without guaranteeing food security at the level of the home".

In the same vein, Frankenberg (1992) acknowledged that "The viability of the household as a productive and reproductive unit (not) threatened by food shortage". In this regard, the analyses concerning the intra-household distribution of consumption highlighted the vulnerability of some populations (women, children and elderly people). Thus, the fight for food security has shifted from the household level to the individual level (Padilla, 1997). At the individual level, the approach to food security in quantitative terms has shifted to a concept of micro-nutrient intake quality in order to achieve a balanced and nutritious diet. Since the mid-1990's, attention has been drawn on the correlation between health, hygiene, food quality, sanitation practices and on the safety and nutritional quality of food. Staatz (1990) states that food security consists of "The ability (...) to assure, on a long term basis, that the food system provides the total population access to a timely, reliable and nutritionally adequate supply of food".

The Rome Declaration on World Food Security:

The Rome Declaration on World Food Security (1996) gives the following definition, which is now widely acknowledged: "Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". The main determinants of food security thus fall into three broad categories: availability, accessibility and utilization; some measure of stability and predictability in each of these three categories also being regarded as critical. The stability and predictability of governance systems are critical factors, but natural or anthropogenic (human-induced) crises can also affect food security in various ways. These include loss of

17 See the FAO/State of Food Insecurity in the World 2010.

18 See the FAO/State of Food Insecurity in the World 2008.

19 Maplecroft, in collaboration with WFP, 2011.

life and assets, conflict-related insecurity, or transmission of external economic shocks through the income and expenditure sides of household budgets, and thus food consumption and nutrition.

Availability

The concept of availability refers to the physical existence of food whether it comes from self-production or markets. Food availability is assessed compiling food balance sheets. It consists of the difference between, on the one hand, production, trade balance (imports – exports) and stock variations, and, on the other hand, any other uses which is not aimed at human consumption (seed, animal feed, waste, etc.). It therefore applies to food supply at a regional and national level (Riely et al., 1995). However, in the absence of food consumption survey data, this availability is often considered similar to energy intakes. Even though the FAO itself warns that its food balance sheets indicate human consumption only "from a supply perspective", they are commonly used to define country profiles and consumption trends. This data are especially used to assess the nutrition policies flagship indicators such as the DES – Dietary Energy Supply.

Main indicators:

1 The DES (Dietary Energy Supply) estimates food available for human consumption expressed in kilocalories per person per day (kcal/person/day). At a national level, it is calculated as the food remaining for human use after deduction of all non-food consumption (exports, animal feed, industrial use, seed and waste).
2 Food group contribution to the total energy availability. The food groups taken into account are: grains, roots and tubers, oils, fats and animal products. Other plant origin products (starches, groundnuts, oleaginous seeds, sweeteners, vegetables and condiments) are not included.
3 Nutrient contribution to the total energy availability. It analyses the diet composition according to the contribution of energy providing nutrients (such as carbo-hydrates, proteins and fats) to the total energy availability aimed at human consumption.
4 The FAO Chronic Hunger index is based on the prevalence of under-nourishment, corresponding to the percentage of a country's population with a level of dietary energy consumption (DEC) lower than the dietary energy requirements (DER). This approach relies on probabilistic models of the joint distributions of DEC and DER, in turn depending on country level food balance sheets and various types of household-level studies (e.g. food consumption, diet diversity or nutrition surveys, living standards measurement surveys, etc.). The prevalence of under-nourishment is an indicator of chronic hunger capturing the evolution of fundamental elements driving long term nutritional status. It does not reflect such short-term phenomena as seasonal food shortages or the impact of temporary food price increases, nor does it take into account mechanisms used by households to cope with temporary food crises (Gennari, 2011). Similarly, the IFPRI Global Hunger Index also uses the prevalence of undernourishment and combines it with the prevalence of underweight in children under five years and the under-five mortality rate, all three factors being given equal weights. In terms of trends and relative rankings, it provides similar results to the FAO index.

The DES is the most important indicator mentioned in the nutrient profiles by country established by the FAO in particular. Smith (1998) has proven that this indicator is a good reflection of food availability on a national scale but it does not adequately measure the household access to food which is the key to food security. He thus argued for household surveys which are useful tools to complement the DES analyses in so far as their results are sometimes notably different. However, since Dowler and Seo (1985), some researches have demonstrated the unreliability of supply estimates as proxy indicators of consumption and question their current usage for food policy design and management.

Accessibility

Accessibility is ensured when every household, and every individual within these households, have sufficient resources to get appropriate food for a nutritious diet (Riely et al., 1995). It depends on household resource level and on prices. Note however that households can have an adequate access without being self-sufficient in food production. The most important thing is the household ability to generate sufficient income which, in conjunction with self-production, can be used to meet their food needs.

Main indicators:

- As a first approximation of accessibility, various measures of income can be used such as the average daily income per person. On the other hand, the Food and Nutrition Technical Assistance (FANTA) project and Food Aid Management[20] (FAM) focused on the household income. More accurate poverty indicators have been introduced, for example the headcount poverty index set up by the World Bank. National poverty rate or headcount index is the percentage of the population living below the national poverty line.
- HFIAS (Household Food Insecurity Access Scale), a composite indicator developed by the FANTA project (with FAO collaboration), provides information on food insecurity at the household level within thirty days after survey. The nine questions assess the household accessibility to food, including anxiety about procuring food, and quantity and quality of diets (variety/diversity is assessed). There is another simplified indicator, the Household Hunger Scale (HSS), which is derived from HFIAS.

The HFIAS indicator has been tested by Becquet et al. (2010) in Ouagadougou (Burkina Faso) to approximate the adequacy of urban households' diets. In conclusion, HFIAS performed

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well in approximating adequacy of urban households' diets[21]. They are informative indicators about urban food insecurity, promising for evaluation and monitoring but not for household targeting given their insufficient predictive power.

Utilisation and quality

The Hunger index, mentioned above, is somewhat limited. In particular, it is based on the assumption that energy deficiencies – as opposed to nutrient deficiencies - are the key indicator of hunger. On the contrary, quality refers to food in itself and in particular to its nutritional intakes. When enough food is available and accessible, households have to make decision concerning the purchase, preservation, preparation, consumption and intra-household distribution. Even though the overall access to food may be measured as sufficient, some individuals might suffer from nutritional deficiency when intra-household distribution is uneven. The same applies if the composition of foods consumed is not balanced.

Main indictors:

1. Malnutrition defines an abnormal physiological condition caused by an unbalanced, excessive or inadequate consumption of macro-nutrients (carbo-hydrates, proteins, fats) and micro-nutrients. This condition includes all the deviations from an adequate nutrition, such as undernourishment (or protein, carbo-hydrate, fat, and/or vitamin and mineral deficiencies), overeating (or excessive consumption of some food components such as saturated fats, added sugars, combined with low physical activity), and specific deficiencies (or excess) of essential nutrients, i.e. vitamins and minerals.
2. MAR (Mean Adequacy Ratio) measures a standard measure of average adequacy to recommended nutritional intakes (Madden et al., 1976). It is the mean ration of intakes to recommended intakes for selected nutrients.
3. The Dietary Diversity, HDDS (Household) and IDDS (Individual), scores (FANTA). They link the adequate nutrient intakes (coverage of basic food needs in terms of macro and micro-nutrients) with a varied and balanced diet, two of the most important elements of food quality.
4. Composite indicators: The DQI-I (Diet Quality Index International), defined by Kim et al. (2003) focuses on four major aspects of a high-quality diet, i.e. variety, adequacy, moderation and overall balance. The HEI (Healthy Eating Index), developed by Kennedy (1995), is based on a 10-component system of five food groups, four nutrients, and a measure of variety in food intake. Each of the 10 components has a score ranging from 0 to 10, so the total possible index score is 100.

The MAR is a well recognized and proven indicator. It was tested by Torheim et al. (2004) in a study in a Malian urban area not only as an indicator but also as a validation tool for two other indicators focusing on the variety (Food Variety Score) and diversity of food (Dietary Diversity Score).

Stability

Stability deals with the question of food vulnerability and resilience. These concepts combine exposure to risk and assessment of its impacts (vulnerability), and the individual or community capacity to handle it more or less efficiently and recover (resilience) depending on their productive, human or social capital (Bebbington, 1999). More precisely, the concept of resilience allows an accurate reflection of the strategies carried out by the households when confronted with exogenous shocks. The micro-economic analysis has used the resilience analysis framework to study the household vulnerability, especially concerning food. Vulnerability is defined as the threat of being affected by poverty. Concerning food, vulnerability could be defined as "the probability for an individual or a group to find their food security jeopardized by an unexpected climatic or economic event" (Droy and Rasolofo, 2004, p.2). Vulnerability to food insecurity is caused by the presence of factors that place people at risk of becoming food insecure or malnourished including those factors that affect their ability to cope. It can also be defined as the ratio between Risk and Coping Capacity, risk itself often being expressed as the expected value of a harmful event (i.e. the probability of it happening multiplied by the loss imputable to the event). A population group with low exposure to risk and high coping capacity is deemed to have low vulnerability. Conversely, a group with high exposure to risk and low coping capacity is considered highly vulnerable. Several estimators have been proposed that determine the households' resilience and vulnerability to crises factors.

Main indicators:

- The resilience tool was first piloted in Palestine in 2007 by the FAO in cooperation with the World Food Programme (WFP) and the Palestinian Bureau of Statistics.
- The Global Information and Early Warning System (GIEWS) of FAO recently developed a composite index measuring the relative vulnerability of a country to natural and anthropogenic shocks (Troubat, 2011). It reflects both (a) social coping capacity, as strongly influenced by the relative level of education, health and (b) macro-economic coping capacity, reflected through a country's economic performance and capacity to mobilize resources. It was designed to detect short term changes in a country's sensitivity to the risk of food insecurity on the basis of long term structural indicators and of information that can be frequently updated, such as consumer prices. The index ranges in values from 0 to 1, with higher values corresponding to the most vulnerable countries. The FAO/GIEWS Vulnerability Index thus captures three components of vulnerability: The degree of exposure to potential shocks, the relative severity of shocks and coping ability (social and macro-economic).
- A food prices' fluctuation index has sometimes been introduced by the FAO. As prices came out as one of the

21 The individual dietary diversity score (IDDS) was also assessed and found positively correlated with the mean adequacy ratio, used in both case as the benchmark for diet adequacy. See sub-section 3-4.

most important accessibility criteria, their propensity to fluctuate according to regions has been seen as an element participating in the concept of stability.

A “resilience tool” has been developed by the FAO (Alinovi et al., 2009) and has previously been studied concerning the Palestinian case in 2007. This composite indicator was successfully tested in five Palestinian sub-regions and resulted in significant differences. This resilience tool uses available data from many national surveys of living standards. It can thus be used in several countries and allows an analysis of the households’ resilience to shocks.

Conclusion

The main determinants of food security interact with, and can offset, each other to a considerable extent. Relatively ample and steady domestic food availability can help offset limited access to international markets, while relatively high incomes, even when obtained through remittances, can compensate for low domestic production. By the same token, ample supplies and high incomes only translate into high levels of food security under conditions of proper nutrition and food utilization by the body. This implies good child care and feeding practices, hygiene, good drinking water and sanitation, etc. In the end, significant and sustainable gains in the food security status of a population come from appropriate increases – widely distributed within the population – in the variables underpinning all three determinant categories (availability, access, utilization). Some balance must be maintained between these three broad determinants[22].

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22 The definition of other relevant concepts, such as malnutrition, stunting, wasting, etc. are presented in the Appendix 1section at the outset of this report.

Technical and economic coefficients of rice cropping systems

1- Upland rice cropping system (CS1) with low yield (0.21t/ha) and low labour (174 day/ha).

	Hired labour (Man days)			Family Labour (Man days)				CS1	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	22	0	22	5	1	2	7	29	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	18	3	21	4	3	3	10	31	6000
4. Harrowing	1	7	7	1	1	1	3	10	10000
5. Planting of minor crops	0	0	0	1	3	1	5	5	3000
6. First bird scaring	0	0	0	1	1	2	3	3	3500
7. Puddling	0	0	0	0	0	0	0	0	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	3	18	20	3	5	3	12	32	6000
10. Fencing	0	0	0	1	0	0	1	2	4500
11. Second bird scaring	0	0	0	3	3	7	13	13	3500
12. Harvesting	12	5	18	4	5	3	13	30	6000
13. Threshing/Winnowing	4	2	6	3	3	3	8	15	6000
14. Drying	0	0	0	1	2	1	4	4	3000
Total cost	**62**	**34**	**96**	**27**	**26**	**26**	**79**	**175**	**603632**
Rice price (Leones/ha)									**1701903**
Rice yield (t/ha)									**0,21**
Production of minor crop (cassava) (Leones/ha)									**73016**
Production of rice (Leones/ha)									**363275**
Farm income with family labour (Leones/ha)									**399783**
Farm income without family labour (Leones/ha)									**-203849**

2- Upland rice cropping system (CS2) with low yield (0.23t/ha) and high labour (319 day/ha).

	Hired labour (Man days)			Family Labour (Man days)				CS2	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	44	0	44	1	0	0	2	46	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	37	4	42	2	1	1	4	45	6000
4. Harrowing	0	19	19	1	0	1	2	21	10000
5. Planting of minor crops	0	0	0	7	4	3	13	13	3000
6. First bird scaring	0	0	0	3	2	1	5	5	3500
7. Puddling	0	0	0	0	0	0	0	0	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	8	44	52	1	1	1	2	55	6000
10. Fencing	1	0	1	3	0	0	4	5	4500
11. Second bird scaring	0	0	0	11	5	5	21	21	3500
12. Harvesting	32	4	35	1	1	1	3	38	6000
13. Threshing/Winnowing	27	11	37	1	1	1	4	41	6000
14. Drying	0	0	0	3	15	10	28	28	3000
Total cost	**149**	**82**	**231**	**33**	**30**	**24**	**88**	**319**	**1460895**
Rice price (Leones/ha)									**1701903**
Rice yield (t/ha)									**0,23**
Production of minor crop (cassava) (Leones/ha)									**73016**
Production of rice (Leones/ha)									**391054**
Farm income with family labour (Leones/ha)									**-1334089**
Farm income without family labour (Leones/ha)									**-996825**

3- Upland rice cropping system (CS3) with high yield (0.39t/ha) and low labour (163 day/ha).

	Hired labour (Man days)			Family Labour (Man days)				CS3	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	23	0	23	2	1	1	4	28	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	19	3	22	2	2	2	6	28	6000
4. Harrowing	0	9	9	0	1	0	2	10	10000
5. Planting of minor crops	0	0	0	1	2	2	5	5	3000
6. First bird scaring	0	0	0	1	1	2	3	3	3500
7. Puddling	0	0	0	0	0	0	0	0	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	2	18	20	2	4	1	6	26	6000
10. Fencing	1	0	1	1	0	1	2	3	4500
11. Second bird scaring	0	0	0	2	4	4	10	10	3500
12. Harvesting	14	6	20	3	3	3	9	29	6000
13. Threshing/Winnowing	7	4	11	2	2	1	5	16	6000
14. Drying	0	0	0	1	3	2	5	5	3000
Total cost	**66**	**39**	**105**	**17**	**23**	**18**	**58**	**163**	**665126**
Rice price (Leones/ha)									**1701903**
Rice yield (t/ha)									**0,39**
Production of minor crop (cassava) (Leones/ha)									**38174**
Production of rice (Leones/ha)									**666792**
Farm income with family labour (Leones/ha)									**-247505**
Farm income without family labour (Leones/ha)									**38174**

4- Upland rice cropping system (CS4) with high yield (0.44t/ha) and high labour (268 day/ha).

	Hired labour (Man days)			Family Labour (Man days)				CS4	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	25	0	25	6	2	4	12	37	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	22	6	28	6	9	5	21	49	6000
4. Harrowing	0	8	8	0	3	1	4	12	10000
5. Planting of minor crops	0	0	0	1	5	4	10	10	3000
6. First bird scaring	0	0	0	0	2	5	7	7	3500
7. Puddling	0	0	0	0	0	0	0	0	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	7	17	24	7	8	6	22	45	6000
10. Fencing	0	0	0	3	0	0	3	3	4500
11. Second bird scaring	0	0	0	3	10	20	33	33	3500
12. Harvesting	7	6	13	13	12	4	28	42	6000
13. Threshing/Winnowing	6	2	8	4	5	4	13	21	6000
14. Drying	0	0	0	0	6	2	9	9	3000
Total cost	**67**	**39**	**106**	**43**	**63**	**56**	**162**	**268**	**668262**
Rice price (Leones/ha)									**1701903**
Rice yield (t/ha)									**0,44**
Production of minor crop (cassava) (Leones/ha)									**38174**
Production of rice (Leones/ha)									**757162**
Farm income with family labour (Leones/ha)									**-662632**
Farm income without family labour (Leones/ha)									**161916**

5- IVS rice cropping system (CS5) with low yield (0.28t/ha) and low labour (158 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS5	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	1	0	1	0	0	0	0	1	6000
2. Brushing and Mounding	21	0	21	3	1	2	6	27	5500
3. Plowing and seeding	10	0	11	0	0	0	1	11	6000
4. Harrowing	0	1	1	0	0	0	0	1	10000
5. Planting of minor crops	0	0	0	0	0	0	0	0	3000
6. First bird scaring	0	0	0	0	0	1	1	1	3500
7. Puddling	10	0	10	4	2	3	10	20	5700
8. Transplanting	11	1	12	3	2	2	7	19	5700
9. Weeding	0	2	2	0	0	0	1	2	6000
10. Fencing	0	0	0	0	0	0	0	0	4500
11. Second bird scaring	0	0	0	4	4	6	15	15	3500
12. Harvesting	16	5	20	3	3	3	9	29	6000
13. Threshing/Winnowing	10	5	15	3	2	3	8	23	6000
14. Drying	0	0	0	1	4	2	8	8	3000
Total cost	**78**	**14**	**92**	**22**	**20**	**23**	**66**	**158**	**538607**
Rice price (Leones/ha)									**1608735**
Rice yield (t/ha)									**0,28**
Production of rice (Leones/ha)									**448723**
Farm income with family labour (Leones/ha)									**-412622**
Farm income without family labour (Leones/ha)									**-89884**

6- IVS rice cropping system (CS6) with low yield (0.33t/ha) and high labour (248 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS6	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	10	0	10	3	0	0	3	13	6000
2. Brushing and Mounding	25	0	25	3	1	2	7	32	5500
3. Plowing and seeding	19	0	19	2	1	1	3	22	6000
4. Harrowing	2	2	3	1	0	1	2	5	10000
5. Planting of minor crops	0	0	0	0	0	0	1	1	3000
6. First bird scaring	0	0	0	1	0	1	2	2	3500
7. Puddling	11	2	13	7	5	4	16	29	5700
8. Transplanting	15	6	21	5	5	3	12	33	5700
9. Weeding	0	3	3	0	0	0	1	3	6000
10. Fencing	0	0	0	1	0	0	1	1	4500
11. Second bird scaring	0	0	0	5	6	8	19	19	3500
12. Harvesting	20	7	27	7	7	4	17	44	6000
13. Threshing/Winnowing	10	6	16	3	5	4	12	29	6000
14. Drying	0	0	0	2	9	4	15	15	3000
Total cost	**111**	**26**	**137**	**40**	**40**	**31**	**111**	**248**	**814799**
Rice price (Leones/ha)									**1608735**
Rice yield (t/ha)									**0,33**
Production of rice (Leones/ha)									**532185**
Farm income with family labour (Leones/ha)									**-840981**
Farm income with family labour (Leones/ha)									**-282614**

7- IVS rice cropping system (CS7) with high yield (0.71t/ha) and low labour (178 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS7	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	1	0	1	0	0	0	0	2	6000
2. Brushing and Mounding	24	0	24	4	2	2	8	32	5500
3. Plowing and seeding	5	0	5	1	0	0	1	6	6000
4. Harrowing	0	0	0	0	0	0	0	0	10000
5. Planting of minor crops	0	0	0	0	0	0	0	0	3000
6. First bird scaring	0	0	0	0	0	1	1	1	3500
7. Puddling	16	0	16	2	1	1	5	20	5700
8. Transplanting	14	5	18	3	3	2	9	27	5700
9. Weeding	2	0	2	0	1	0	2	4	6000
10. Fencing	3	0	3	0	0	0	0	3	4500
11. Second bird scaring	0	0	0	4	7	7	19	19	3500
12. Harvesting	15	5	19	5	3	2	11	30	6000
13. Threshing/Winnowing	7	6	13	4	4	2	10	23	6000
14. Drying	0	0	0	1	7	3	11	11	3000
Total cost	**86**	**16**	**102**	**26**	**29**	**21**	**76**	**178**	**586271**
Rice price (Leones/ha)									**1608735**
Rice yield (t/ha)									**0,71**
Production of rice (Leones/ha)									**1144401**
Farm income with family labour (Leones/ha)									**-953486**
Farm income without family labour (Leones/ha)									**558130**

8- IVS rice cropping system (CS8) with high yield (0.52 t/ha) and high labour (334 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS8	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	25	0	25	5	0	2	7	31	6000
2. Brushing and Mounding	24	2	26	3	4	1	9	34	5500
3. Plowing and seeding	16	0	16	14	1	8	24	40	6000
4. Harrowing	0	3	3	0	0	0	0	3	10000
5. Planting of minor crops	0	0	0	0	0	0	1	1	3000
6. First bird scaring	0	0	0	1	0	1	2	2	3500
7. Puddling	10	3	14	11	8	9	28	42	5700
8. Transplanting	11	10	21	5	11	4	20	40	5700
9. Weeding	0	0	0	0	0	6	6	6	6000
10. Fencing	0	0	0	0	6	6	12	12	4500
11. Second bird scaring	0	0	0	5	2	11	19	19	3500
12. Harvesting	10	7	18	11	16	7	35	59	6000
13. Threshing/Winnowing	6	4	10	3	11	6	20	30	6000
14. Drying	0	0	0	0	9	4	14	14	3000
Total cost	**102**	**30**	**131**	**59**	**71**	**67**	**196**	**334**	**776796**
Rice price (Leones/ha)									**1608735**
Rice yield (t/ha)									**0,52**
Production of rice (Leones/ha)									**833958**
Farm income with family labour (Leones/ha)									**-985726**
Farm income without family labour (Leones/ha)									**57162**

9- Boliland rice cropping system (CS9) with low yield (0.19 t/ha) and low labour (85 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS9	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	0	0	0	0	0	0	0	0	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	6	1	7	1	1	0	2	9	6000
4. Harrowing	8	1	9	1	1	1	3	12	10000
5. Planting of minor crops	0	0	0	0	0	0	0	0	3000
6. First bird scaring	0	0	0	0	0	1	2	2	3500
7. Puddling	1	4	5	0	2	0	2	7	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	7	11	18	1	3	1	5	23	6000
10. Fencing	0	0	0	0	0	0	0	0	4500
11. Second bird scaring	0	0	0	1	1	1	2	2	3500
12. Harvesting	6	5	11	1	1	7	9	21	6000
13. Threshing/Winnowing	3	2	5	1	1	0	2	7	6000
14. Drying	0	0	0	1	1	1	2	2	3000
Total cost	**32**	**24**	**56**	**7**	**10**	**12**	**29**	**85**	**370033**
Rice price (Leones/ha)									**1351445**
Rice yield (t/ha)									**0,19**
Production of rice (Leones/ha)									**257443**
Farm income with family labour (Leones/ha)									**-285229**
Farm income without family labour (Leones/ha)									**-112590**

10- Boliland rice cropping system (CS10) with low yield (0.20 t/ha) and high labour (225 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS10	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	4	0	4	3	0	1	3	7	6000
2. Brushing and Mounding	15	0	15	4	0	3	7	22	5500
3. Plowing and seeding	17	2	19	7	1	2	11	29	6000
4. Harrowing	22	3	25	9	3	2	13	38	10000
5. Planting of minor crops	0	0	0	0	0	0	0	0	3000
6. First bird scaring	0	0	0	0	0	1	2	2	3500
7. Puddling	0	4	4	1	1	1	3	8	5700
8. Transplanting	3	0	3	1	1	0	1	4	5700
9. Weeding	11	14	24	8	8	3	20	44	6000
10. Fencing	0	0	0	0	0	0	0	0	4500
11. Second bird scaring	0	0	0	2	3	5	11	11	3500
12. Harvesting	11	8	19	6	9	6	21	40	6000
13. Threshing/Winnowing	2	1	3	3	5	3	11	14	6000
14. Drying	0	0	0	0	4	2	7	7	3000
Total cost	**84**	**32**	**116**	**44**	**36**	**30**	**110**	**225**	**783501**
Rice price (Leones/ha)									**1351445**
Rice yield (t/ha)									**0,20**
Production of rice (Leones/ha)									**273740,302**
Farm income with family labour (Leones/ha)									**-1164944**
Farm income without family labour (Leones/ha)									**-509760**

11- Boliland rice cropping system (CS11) with high yield (0.36 t/ha) and low labour (145 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS11	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	0	0	0	1	0	0	1	1	6000
2. Brushing and Mounding	0	0	0	0	0	0	0	0	5500
3. Plowing and seeding	13	5	18	2	1	1	4	22	6000
4. Harrowing	13	4	17	4	1	1	6	23	10000
5. Planting of minor crops	0	1	1	0	0	0	0	1	3000
6. First bird scaring	0	0	0	0	1	1	3	3	3500
7. Puddling	3	3	6	0	1	0	2	7	5700
8. Transplanting	0	0	0	0	0	0	0	0	5700
9. Weeding	7	12	19	5	9	3	16	36	6000
10. Fencing	0	0	0	0	0	0	0	0	4500
11. Second bird scaring	0	0	0	1	1	1	3	3	3500
12. Harvesting	15	11	26	6	7	3	15	42	6000
13. Threshing/Winnowing	1	1	3	1	1	0	3	5	6000
14. Drying	0	0	0	1	1	0	2	2	3000
Total cost	**53**	**38**	**91**	**21**	**23**	**11**	**54**	**145**	**609142**
Rice price (Leones/ha)									**1351445**
Rice yield (t/ha)									**0,36**
Production of rice (Leones/ha)									**482875**
Farm income with family labour (Leones/ha)									**-453629**
Farm income without family labour (Leones/ha)									**-126268**

12- Boliland rice cropping system (CS12) with high yield (0.47 t/ha) and high labour (217 day/ha)

	Hired labour (Man days)			Family Labour (Man days)				CS12	
	Male	Female	Total	Male	Female	Children	Total	**Total**	
1. Brushing/Felling/Clearing	1	0	1	1	0	1	2	3	6000
2. Brushing and Mounding	4	0	4	0	0	0	0	4	5500
3. Plowing and seeding	25	3	28	8	3	1	12	39	6000
4. Harrowing	17	5	21	6	4	2	12	33	10000
5. Planting of minor crops	3	0	3	0	0	0	1	3	3000
6. First bird scaring	0	0	0	0	0	1	1	1	3500
7. Puddling	4	2	6	2	2	1	4	10	5700
8. Transplanting	4	1	4	1	1	1	2	6	5700
9. Weeding	11	11	22	3	11	3	17	38	6000
10. Fencing	0	0	0	0	0	0	0	0	4500
11. Second bird scaring	0	0	0	2	3	7	12	12	3500
12. Harvesting	9	14	22	10	10	5	24	46	6000
13. Threshing/Winnowing	2	3	5	3	4	2	9	14	6000
14. Drying	0	0	0	0	3	3	6	6	3000
Total cost	**78**	**37**	**115**	**36**	**42**	**25**	**103**	**218**	**763173**
Rice price (Leones/ha)									**1351445**
Rice yield (t/ha)									**0,48**
Production of rice (Leones/ha)									**648104,509**
Farm income with family labour (Leones/ha)									**-720690**
Farm income without family labour (Leones/ha)									**-115069**

Main FSSIM-Dev results for different farm household types

Table A5.1. Baseline vs. Policy scenario 1 (PS1) results

	Rice_small		Rice_veg_small		Rice_per_small		Rice_med	
	Baseline	*PS1*	*Baseline*	*PS1*	*Baseline*	*Baseline*	*PS1*	*Baseline*
Farmer utility (Leones)	251 245	329 930	137 899	159 423	640 211	251 245	329 930	137 899
Farm income (Leones)	251 245	329 930	137 899	159 423	640 211	251 245	329 930	137 899
Income per HHUnit (Leones/HHU)	46 874	61 554	31 628	36 565	112 713	46 874	61 554	31 628
Poverty Gap (%)	97	96	98	98	93	97	96	98
Income per WUnit (Leones/WU)	85 749	112 604	62 187	71 893	172 331	85 749	112 604	62 187
Income per ha (Leones/ha)	81 573	107 120	80 174	92 688	284 538	81 573	107 120	80 174
Total outputs (Leones)	589 714	681 741	397 952	423 510	1 471 465	589 714	681 741	397 952
Accounting costs (Leones)	315 315	328 658	178 943	182 977	852 055	315 315	328 658	178 943
Other costs & income (Leones)	-23 154	-23 154	-81 110	-81 110	20 801	-23 154	-23 154	-81 110
Total land use (ha)	3	3	2	2	2	3	3	2
Total labour use (Days)	437	453	414	418	275	437	453	414
Land shadow price (Leones)	47 960	73 002	55 332	67 846	83 764	47 960	73 002	55 332

Source: FSSIM-Dev results

Table A5.2. Baseline vs. Policy scenario 1 (PS1) results (follow-up)

	Rice_mix_med		Rice_big		Rice_per_big		Rice_mix_big	
	Baseline	*PS1*	*Baseline*	*PS1*	*Baseline*	*PS1*	*Baseline*	*PS1*
Farmer utility (Leones)	846 135	846 135	1 203 989	1 517 675	755 408	755 408	1 556 351	1 736 110
Farm income (Leones)	846 135	846 135	1 203 989	1 517 675	755 408	755 408	1 556 351	1 736 110
Income per HHUnit (Leones/HHU)	177 759	177 759	179 700	226 519	91 013	91 013	240 178	267 918
Poverty Gap (%)	89	89	88	85	94	94	85	83
Income per WUnit (Leones/WU)	263 799	263 799	260 041	327 792	145 481	145 481	299 155	333 707
Income per ha (Leones/ha)	300 048	300 048	141 479	178 340	212 193	212 193	162 458	181 222
Total outputs (Leones)	2 259 546	2 259 546	2 626 422	2 970 826	2 192 219	2 192 219	4 138 501	4 347 738
Accounting costs (Leones)	1 271 142	1 271 142	1 452 318	1 483 038	1 400 703	1 400 703	2 522 313	2 551 792
Other costs & income (Leones)	-142 270	-142 270	29 885	29 887	-36 109	-36 109	-59 836	-59 836
Total land use (ha)	3	3	9	9	4	4	10	10
Total labour use (Days)	441	441	1 288	1 346	676	676	1 221	1 257
Land shadow price (Leones)	54 537	62 411	75 246	124 828	75 196	75 196	53 040	80 113

Source: FSSIM-Dev results

Table A5.3. Baseline vs. Policy scenario 2 (PS2) results

	Rice_small		Rice_veg_small		Rice_per_small		Rice_med		Rice_per_med	
	Baseline	PS2	Baseline	PS2	Baseline	PS2	Baseline	PS2	Baseline	PS2
Farmer utility (Leones)	251 245	507 953	137 899	249 572	640 211	821 742	547 171	1 049 877	825 261	1 190 768
Farm income (Leones)	251 245	507 953	137 899	249572	640 211	821 742	547 171	1 049 877	825 261	1 190 768
Income per HHUnit (Leones/HHU)	46 874	94 767	31 628	57241	112 713	144 673	90 591	17 3821	109 451	157 927
Poverty Gap (%)	97	94	98	96	93	91	94	89	93	90
Income per WUnit (Leones/WU)	85 749	173 363	62 187	112547	172 331	221 196	129 892	249 229	134 792	194 490
Income per ha (Leones/ha)	81 573	164 920	80 174	145100	284 538	365 219	99 305	19 0540	143 274	206 731
Total outputs (Leones)	589 714	868 852	397 952	513659	1 471 465	1 657 340	1 437 108	1 979 371	2 357 563	2 741 688
Accounting costs (Leones)	315 315	334 738	178 943	182977	852 055	856 399	791 258	822 491	1 478 082	1 496 700
Other costs & income (Leones)	-23 154	-26 162	-81 110	-81 110	20 801	20 801	-98 679	-107 003	-54 221	-54 221
Total land use (ha)	3	3	2	2	2	2	6	6	6	6
Total labour use (Days)	437	468	414	424	275	290	819	876	661	696
Land shadow price (Leones)	47 960	140 284	55 332	94724	83 764	14926	50 621	66 219	41 843	129 129

Source: FSSIM-Dev results

Table A5.4. Baseline vs. Policy scenario 2 (PS2) results (follow-up)

	Rice_mix_med		Rice_big		Rice_per_big		Rice_mix_big	
	Baseline	PS2	Baseline	PS2	Baseline	PS2	Baseline	PS2
Farmer utility (Leones)	846 135	963 028	1 203 989	2 053 099	755 408	967 324	1 556 351	2 294 563
Farm income (Leones)	846 135	963 028	1 203 989	2 053 099	755 408	967 324	1 556 351	2 294 563
Income per HHUnit (Leones/HHU)	177 759	202 317	179 700	306 433	91 013	11 6545	240 178	354 099
Poverty Gap (%)	89	87	88	80	94	93	85	77
Income per WUnit (Leones/WU)	263 799	300 243	260 041	44 3434	145 481	186 292	299 155	441 050
Income per ha (Leones/ha)	300 048	341 499	141 479	241 257	212 193	271 720	162 458	239 516
Total outputs (Leones)	2 259 546	2 376 440	2 626 422	3 506 244	2 192 219	2 551 944	4 138 501	4 923 939
Accounting costs (Leones)	1 271 142	1 271 142	1 452 318	1 483 038	1 400 703	1 452 723	2 522 313	2 559 760
Other costs & income (Leones)	-142 270	-142 270	29 885	29 893	-36 109	-131 897	-59 836	-69 617
Total land use (ha)	3	3	9	9	4	4	10	10
Total labour use (Days)	441	448	1 288	1 371	676	798	1 221	1 297
Land shadow price (Leones)	54 537	140 456	75 246	183 443	75 196	141 386	53 040	157 302

Source: FSSIM-Dev results

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Abstract
This report presents a farm household model for use in the context of developing countries to gain knowledge on food security and rural poverty alleviation under different economic conditions and agri-food policy options. This model, called FSSIM-Dev (Farming System Simulator for Developing Countries), is an extension of the FSSIM model developed within the SEAMLESS project for impact assessment of agricultural and environmental policies on farm performances across Europe. FSSIM-Dev is conceived to be applied for family or peasant agriculture where farm household production, consumption and labour allocation decisions are non-separable due to market imperfections. Contrary to most well-known household models which are econometric-based, FSSIM-Dev is a non-linear optimization model which simultaneously solves a set of microeconomic models reproducing the behaviour of representative farm households.
FSSIM-Dev is designed to capture five key features of developing countries' agriculture: non-separability of production and consumption decisions; interaction among farm households for market factors; heterogeneity of farm households with respect to their both consumption baskets and resource endowments; inter-linkage between transaction costs and market participation decisions; and the seasonality of farming activities and resource use.
Model use is illustrated in this report with an analysis of the combined effects of rice support policy and improved rice cropping management on the livelihood of representative farm households in Sierra Leone. Results show that, first, the improvement of rice cropping management is a key factor to significantly boost farm household income in the studied region. Second, the amount of N fertilizer required for, mainly, upland rice appears too high and costly and could not be applied by farm households without policy support. Third, both the rice policy and the improved crop management would increase farm productivity and boost household income but they are not sufficient to fight poverty since most of the farm household types would continue to live below the extreme poverty line of 1 USD-equivalent per day.

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