



**System for Environmental and Agricultural Modelling;
Linking European Science and Society**

A generic template for FSSIM

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General information

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Executive summary

The purpose of this deliverable is the development of a generic template for FSSIM (Farm System Simulator) with a limited number of variants, which is able to model major farm types that exist in the European Union and which can be easily transferred between geographic locations. The FSSIM is a Bio-Economic Farm Model that links a mathematical programming model formulation of farmers' resource management decisions, to a DATA module including agronomic and economic information coming respectively from the biophysical model APES and statistical data bases (costs, labour, machine requirement). The DATA module aims to generate a set of agricultural activities and to quantify the input output coefficients (both yields and environmental effects) of the farming system. In the DATA module, firstly a set suitable production enterprises is generated, secondly these production enterprises are linked to production techniques that describe all the agronomic inputs to the farming system and lastly, for these combinations between production enterprises and production techniques input-output coefficients are derived from APES and statistical databases. The set of agricultural activities and quantified input-output coefficients is then included in the FSSIM model. The FSSIM model tries to solve the mathematical programming model by maximising a utility function subject to a limited number of explicit constraints. As it is impossible to model all main categories of a farming system with the same generic frame, we have to develop several generic frames. Here only the static approach is described. The structure and global specification of FSSIM is: 1) the set of generated agricultural activities defined as a coherent set of production enterprises with a specified production technique; 2) the objective function describing the farmers' behaviour and goal, based on the maximization of expected income minus some measure of its variability, according to different states of nature; 3) the set of explicit constraints related to physical (land, water, labour, equipment) and economic resources (finances, cash flow) as well as those related to policy and environmental restrictions (price and market support, quota and set-aside obligations, cross-compliance policies, agri-environmental policies, etc).

Introduction

The Farm System Simulator (FSSIM) is a bio-economic farm model developed to quantify the integrated agricultural, environmental and socio-economic aspects of the agricultural farming systems. Applied at farm (micro) level, FSSIM tries to represent the actual farmers' behaviour according to knowledge of technical and socio-economic constraints, the relation between production factors, the amount of output obtained and the costs of each production activity and future market prices. The principal characteristic of this type of models is the application of engineering production functions, derived from biophysical models and other sources (experiments, expert knowledge, surveys, etc.), to assess the economic and ecological impact of agricultural policies, while taking into account the interaction between the biophysical processes and economic decisions. This articulation ecological-economic is essential, in order to analyse in an integrated manner the whole farming system.

The FSSIM is based on the link of a mathematical programming model formulations of farmers' resource management decisions, to a DATA module including agronomic and economic information coming respectively from the biophysical model APES and statistical data bases (costs, labour, machine requirement).

The DATA module aims to generate the set of agricultural activities and to quantify the input output coefficients of farming system, which is indispensable to solve FSSIM model. The FSSIM model tries, after including generated information from DATA module, to solve problems of maximising utility function under a limited number of explicit constraints representing the production opportunity set, resource constraints, and price parameters farmers' face.

The interaction between FSSIM model and DATA module and their respective components are shown in the diagram below (Figure 1):

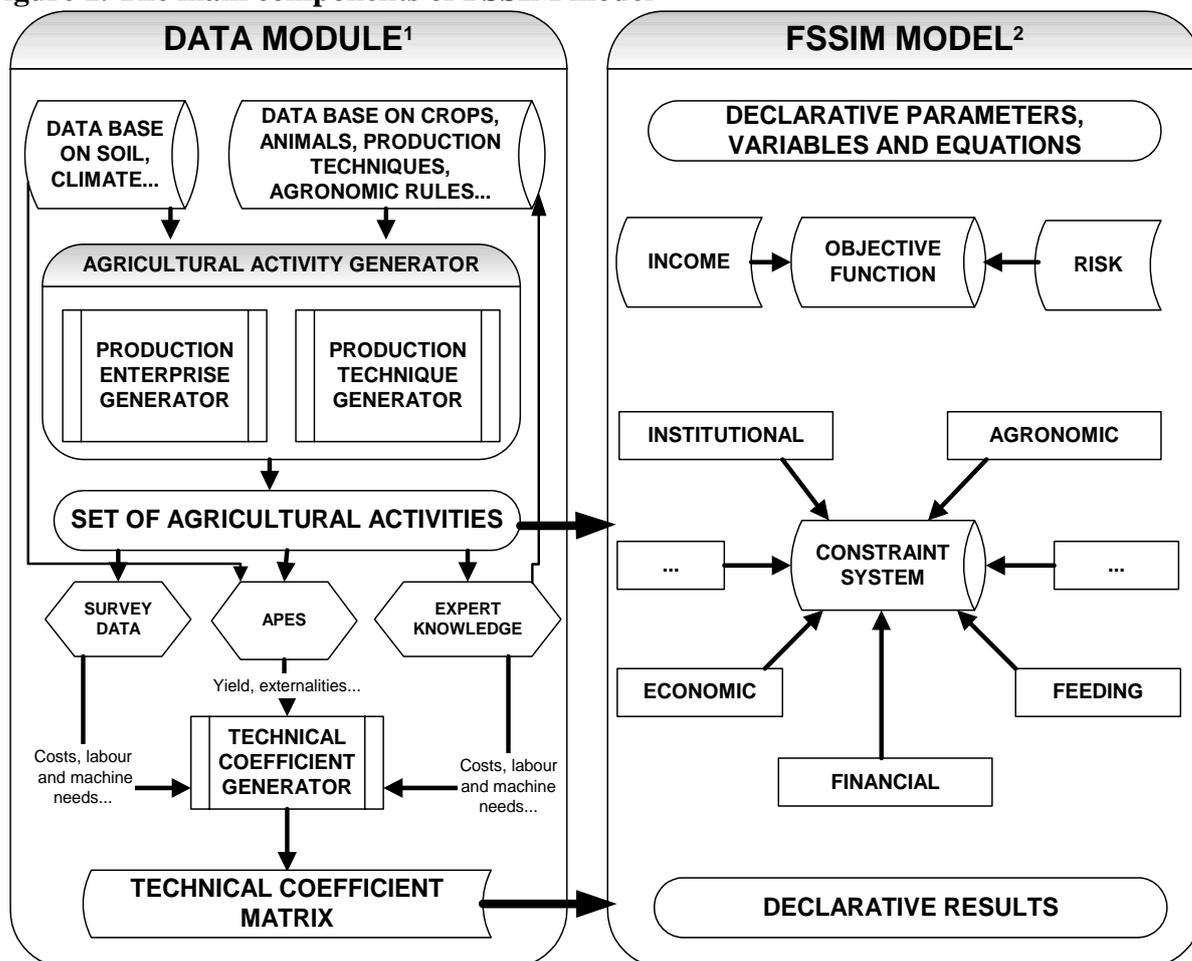
Data module:

- (i) The set of production enterprises including a coherent set of crops and animals without a specific (production) technique,
- (ii) The set of production techniques incorporating a complete set of agronomic inputs characterized by type, level, timing and application technique,
- (iii) The matrix of technical coefficients including, for each agricultural activity, the relation between production factors (inputs) used and outputs obtained (products, externalities ...).

FSSIM model:

- (i) The list of endogenous variables,
- (ii) The objective function describing the farmers' behaviour and goals in particular concerning risk,
- (iii) The set of explicit physical, financial, technical, economic, agronomic ... constraints and feeding restrictions.

Figure 1. The main components of FSSIM model



¹ Leader: WU team

² Leader: CIHEAM-IAMM team

In this section, we aim to develop a generic FSSIM model able to represent the various types of farms that exist in the European Union and which can be easily transferred between geographic locations. However, as it is impossible to model all main categories of farming system with the same generic frame, various approaches will be employed depending to the situation: static, dynamic, stochastic and possibly other approaches. For the first version, we start with a limited number of variants and with a static¹ approach i.e. one period decision programming model, with possibility of subdividing the period in time sub-periods. This means that the model optimizes an objective function for one period over which decisions are taken considering the specificity of each individual sub-period and the trade-offs between the sub-periods.

For easier modelling, the decision period within static version of FSSIM model will be one year, subdivided in several time periods that may differ according to regions, purposes, etc.

¹ The separation between static and dynamic approaches is based on the number of decision periods. The static approach will concern only one decision period whereas the dynamic approach will be associated to multi-period decisions.

1 General structure of FSSIM model: first version

As we said above, the first version of FSSIM will be based on a static approach. However, for incorporating some temporal effects, agricultural activities will be defined under “crop rotations” and “zoo-technical units” instead of individual crops and animals and the constraints will be included in a specific structure as developed by Pacini (2003). Rotations of annual crops can be considered as a type of perennial system with a mixture of agricultural uses of which the outputs may consist of multiple harvested products (Hengsdijk and van Ittersum, 2002). Interactions among successive crops with respect to soil nutrients, plague organisms... will be explicitly accounted for.

The general structure of the first version of FSSIM model can be formulated as:

$$\text{Max: Utility} = \mathbf{C}'\mathbf{X} - \phi\sigma$$

$$\text{Subject to: } \mathbf{A}\mathbf{X} \leq \mathbf{B};$$

$$\mathbf{X} \geq \mathbf{0}$$

Where **Utility** is the objective function to maximise, **C** is the (n x 1) vector of expected income from agricultural activities, **X** is the (n x 1) vector of agricultural activities' level (in an optimal farm plan), ϕ is the risk aversion coefficient according to the Mean-Variance method, σ is the standard deviation of income according to states of nature defined under three different sources of instability: yield -due to climatic condition, price and subsidies instabilities, **A** is the (m x n) matrix of technical coefficients, and **B** is the (m x 1) vector of available resource levels. Utility, X and σ are endogenous variables.

For fixing ideas, Table 1 portrays a simple structure of the FSSIM model for a crop-livestock farm. Agricultural activities (including several alternative technologies) are shown in the top of the Table. Each activity has its own specific vector of input and output coefficients. All vectors together form the matrix **A**. The rows of the matrix indicate the type and form of the constraints used: constraints of fixed assets (land requirements, milk quota, equipment requirements), labour requirements, feed requirements (fibre, energy value, protein and dry matter requirements), crop production constraints (manure and slurry requirements, rotation constraints), legal constraints (set-aside, cross-compliance, maximum livestock density, ...) and environmental constraints (maximum on nitrogen leaching, nitrogen runoff, soil erosion, water use, potential risks of pesticide use and minima on herbaceous plant biodiversity, hedges and drainage system). In reality, the final version of FSSIM model will be more complicated and will have more specific constraints and equations.

Table 1. Simplified structure of FSSIM model

Objective function	Agricultural activities			Standard deviation (σ)	Maximise
	Crop activities for on-farm use	Crop activities for sale	Livestock activities	- Φ	
	- Costs	+ Gross margin	+ Gross margin		
Constraints					
1. Arable land	+ 1	+ 1			≤ Arable available hectare
2. Gras land	+ 1				≤ Graz available hectare
3. Labour requirement	+ a _{3i1}	+ a _{3i2}	+ a _{3i3}		≤ Available labour
4. Equipment requirement	+ a _{4i1}	+ a _{4i2}	+ a _{4i3}		≤ Available equipment
5. Feed requirement	- a _{5i1}		+ a _{5i3}		≤ 0
6. Set-aside	+/-	+/-			≤ 0
7. Quotas		+ a _{7i2}	+ a _{7i3}		≤ Available quotas
8. Nutrient	+ a _{8i1}	+ a _{8i2}	- a _{8i3}		= Surplus
...					

* a_{3i1} is the technical coefficient that relates activity i_1 to constraint 3

2 DATA module

2.1 Generating agricultural activities: coupling production enterprises and production techniques

The principal information required by FSSIM model concerns the specification of production enterprises and the selection of technique and management types to generate all possible agricultural activities.

To enable simulation of both current and alternative agricultural activities for the major European farm types, we need automated and generic procedures for generating all possible production enterprises and a complete feasible set of agronomic practices and technological alternatives. To do this, a computer program (i.e. generator) will be developed (see Dogliotti *et al*, 2004). In this program, firstly we generate the set of *production enterprises*, secondly we generate all possible *production techniques* and at the end we combine each production enterprise with different production techniques to generate all feasible *agricultural activities*. The full factorial number of possible combination is limited by a number of rules and filters which are given by a set of input parameters controlled by the user. These rules depend on current activities as well as physical and agronomic criteria (linking crops to previous crop, soil types, climate constraint, etc).

2.1.1 Production Enterprise Generator

2.1.1.1 Background

Production enterprises are designed as a coherent set of crops (cereal, vegetable, oilseed, fodder crops...) and animals without a specified (production) technique that forms production systems of the farming system. The set of production enterprises is obtained from the application of the *production enterprise generator* which is a tool to generate all feasible production enterprises of the farm based on biophysical filters, like soil-type, climate and for annual arable crops rotational constraints (or for animal husbandry systems herd composition constraints).

The production potential of crops and the type and amount of required inputs to attain a given yield in a particular environment depend on production technique of each crop, but also on the long-term effects on physical, chemical and biological soil fertility by the crop rotation (Dogliotti *et al.*, 2003). These effects are primarily determined by the combination of crop species, the frequency of each crop, the sequence of crops and the activities during intercrop periods. Therefore, this component in WP3 aims at the development of a tool to design crop rotations in a transparent way. In principle, all crops that may be grown in a given environment can be combined into different cropping sequences. However, not all of these combinations are agronomically feasible. The tool to be developed should contain a number of biophysical filters which limit the number of crop rotations for which production techniques need to be defined. 'The biophysical filters' are a set of rules and parameters that filter out any options that are not possible from an agronomical point of view.

The following numerical example explains why we need such filters:

- suppose we identify 30 interesting crops for Europe within Seamless,
- suppose we would design activities for all the possible crop rotations and incorporate those in the LP model
- suppose we would take a maximum length of the rotation of 6 years

In total we could construct $30^6 = 729.000.000$ possible crop rotations. If we add to this a limited number of management alternatives (2 water input levels \times 3 water application techniques \times 3 nutrient input levels \times 2 nutrient application techniques), we get in total 26.244.000.000 (26 billion) possible crop activities. For each of these 26 billion crop activities outputs (yields and environmental effects) would have to be estimated across Europe which might be possible, but is not very relevant. Through the 'biophysical filters' we want to eliminate any crops and crop rotations that are not possible in the first place and to design a set of activities that are feasible (even at low output, high pollution levels, even if not societal desirable). Here, a fine balance needs to be guarded. For example, about 25 farmers in the Netherlands have vineyards producing wine for a niche specialty market. In general, this wine is of low quality, but consumers are willing to pay a premium since it is an odd novelty. One could argue that vineyards do not offer a real alternative in the Netherlands, because of the low productivity and quality of grapes, of the high costs of production and of the limited market opportunities. In this and similar situations often less biophysical-oriented filters will enter the discussion. We need to develop a procedure to assess this balance and to make sure we do not go to the extreme of including everything in the LP model and creating a model that is too big and impossible to handle and to make sure that we do not leave out too much in an early stage with the risk of missing out on potentially promising activities. We propose to make the 'biophysical filters' explicit during implementation, so that we can add or leave out additional rules or parameters as we deem necessary.

2.1.1.2 Production Enterprise Generator for crops: An example

The main steps to generate crop enterprises are (Figure 2):

Step 1: Characterization of the physical environment (soil + climate) throughout the EU and identification of all possible crops.

- Characterization of physical environments throughout the EU: definition criteria need to be identified to characterize the physical environment. For example, soil types (soil fertility, stoniness, permeability, soil texture, etc.) and climate (radiation, minimum and maximum temperature, rainfall, wind).
- Identification of crops and crop groups: which crops do we take into account? Typology based on related crops (that result in an increase of soil-borne diseases when grown in succession)? Typology based on existing classifications?

Filter 1: Soil constraints, linking the soil of the region considered to all possible crops. In this example a number of crops are not possible on the soils of the region considered: chicory, cabbages, onions, sugar beets and grass.

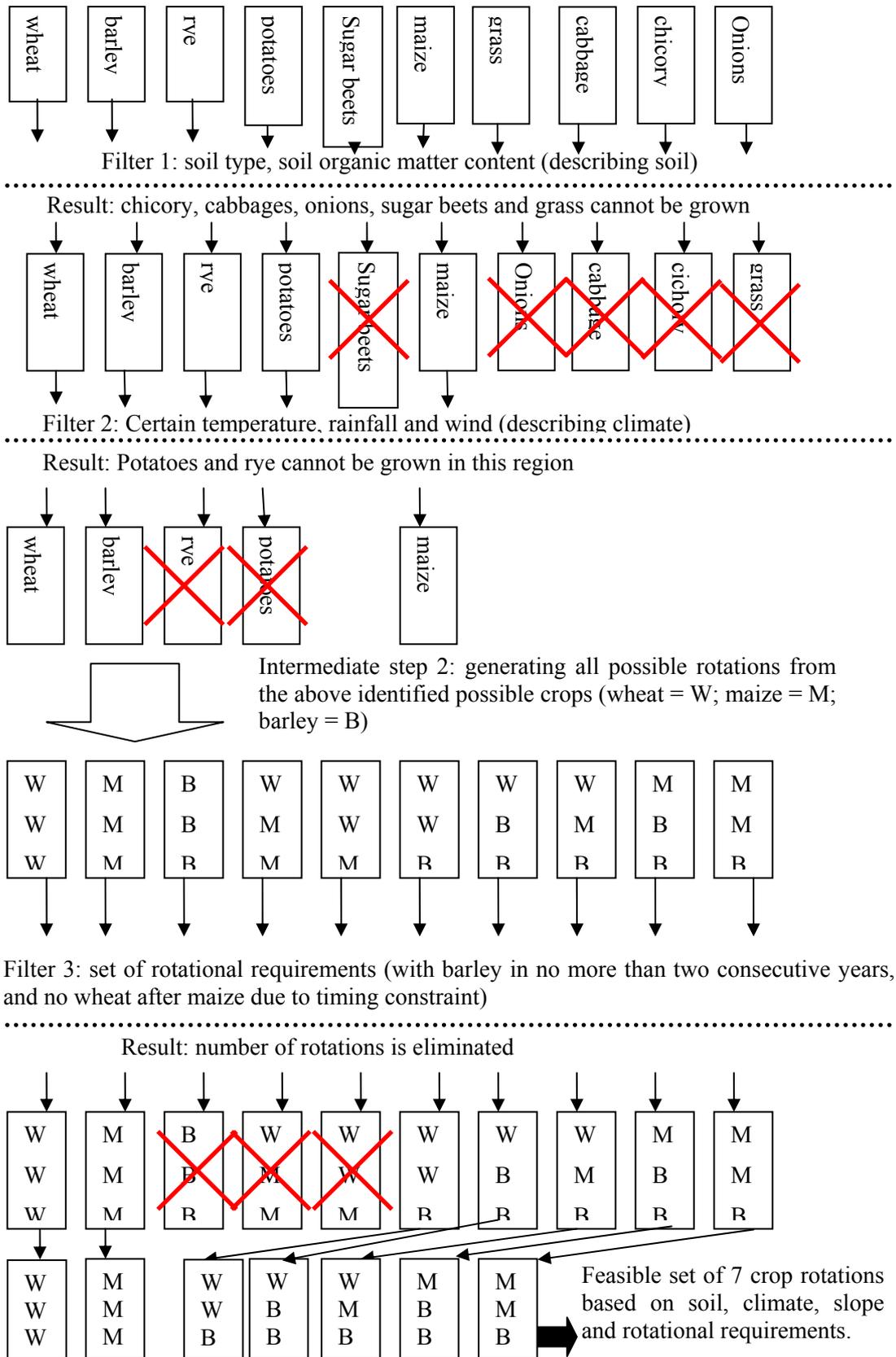
Filter 2: Climate constraints, linking the crops possible on the soils to the climate prevailing in the region. Here, two more crops are excluded potatoes and rye, for example, because they are sensitive to early and late season frost.

Step 2 (Intermediate): Generating possible rotations on the basis of possible crops generated through soil and climate constraints. This is not part of ROTAT and concerns the first screening of crops that can not be grown because of environmental constraints, for example, no cotton in Sweden because of the length of the growing season or no potatoes on too stony soils.

Filter 3: Rotation requirements (timing, frequency and sequence), which in this example exclude rotations with barley in more than two consecutive years, and with wheat after maize (due to winter wheat being sown in early autumn, when it can not be ensured that maize is already gone).

Step3: Result: Feasible rotations given soil, climate, slope and rotational limitations; in this example 7 feasible rotations are identified. We will use ROTAT as a case to learn how selective filters work. We will compile a set of filters which will be offered for general feedback, so that any unwanted filters can be taken out and any desired filters can be added.

Figure 2. An example of a production enterprise generator



Through the first two filters a predefined list of crops should be generated that are possible given the climate and soil of the region in which the crop is grown. This predefined list can then be run through the last filter of rotational requirements. A comprehensive example of the last filter 3 (describing the rotational requirements) is ROTAT (Dogliotti et al., 2003). This model combines crops (maximum 30) from a predefined list to generate all possible rotations (maximum 250.000). User-defined filters and rules limit the number of rotations. The used rules/filters:

1. Timing constraints

1.1 Sowing and harvesting dates.

1.2 Minimum intercrop period (for soil preparation).

2. Sequence and frequency constraints

2.1 Restrictions on crop successions (successions that result in negative effects on physical, chemical and biological soil fertility).

2.2 Maximum frequency of each crop in the rotation, maximum frequency of groups of related crops and minimum period before repeating cultivation of a crop. (high frequency of a crop or a group of crops sensitive to the same soil borne diseases results in strong increase in the prevalence of soil-borne pathogens and in the need for crop protection). Example: See Table 3 in Dogliotti et al., 2004.

3 Farm specific feasibility and applicability

3.1 Maximum length of crop rotation (refers to number of farm plots/fields required to implement a rotation)

3.2 Maximum number of different crops per rotation (refers to available crops, farmer skills, and degree of specialization)

3.3 Maximum number of main crops and maximum number of secondary crops and maximum number of secondary crops per rotation (refers to capability, resources and interests of farmer)

2.1.2 Production Technique Generator

2.1.2.1 Background

One of the most difficult problems in economic modelling is to make an appropriate specification of what we may call the technical universe. It is very difficult to define a complete set of *production technique* possibilities. Usually the information is incomplete because it gives only the combination of factors of production currently used or that has been used in the past. In most case the range of variation of these techniques is small because the choice of technologies depends on the prevailing relative prices (Flichman et al, 1994). In this project, we aim to overcome this problem using Production Technique Generator which allows generating a wide range of techniques, both current and potential, avoiding the lack of information about potential techniques that may become feasible after modifications in the prices and support system associated with policy changes.

The Production Technique Generator is a tool to describe qualitatively the (alternative) production techniques of the feasible set of production enterprises. These production techniques describe the complete set of agronomic inputs characterized by level, timing and application technique (Van Ittersum and Rabbinge, 1997). There is a danger of too much detail and over-specification. Thus, it is important to determine the major inputs affecting outputs. Among these inputs we can identify the following management practices:

- Water management
- Nutrient management
- Weed pest and disease management
- Soil conservation management
- Landscape and biodiversity management
- ...

Each of these management practices consists of several aspects, for example for water management: the method of application and the level of application (full replacement of water, i.e. 100%) or allowing some water shortage (50% of unlimited water supply). The input level, timing and the application technique are three different definition criteria of water management as for each various alternatives can be designed affecting the outputs of agricultural activities.

When all management practices thus have been defined and values attached to them, they have to be internally consistent. This means that a high level of nutrient management cannot go together with a low level of weed management, as the positive effect of high nutrient management would be off-set by poor weed management. Production orientations (integrated, highly innovative, conventional...) can be taken as a guideline to assess if the agronomic inputs are internally consistent.

2.1.2.2 Production Technique Generator: the main steps

The main steps to generate production techniques are:

Step 1: Identification of relevant management practices: Before specifying agronomic inputs, the main management practices have to be identified. A set is given in Figure 3, but it could well be that management practices are still lacking.

Step 2: Identification of key management aspects: What are the crucial aspects of agronomic inputs determining economic output and environmental effects of activities? For example, in pesticide application, this is the frequency of application, dose, timing and the type of pesticide used.

Step 3: Quantifying the crucial management aspects: what are the relevant input levels, application techniques and timing for farmers?

Step 4: Defining rules to filter out any inconsistent and infeasible combination of agronomic inputs: This can be done by defining production orientations, for example 'only high input levels' or 'only low input levels.'

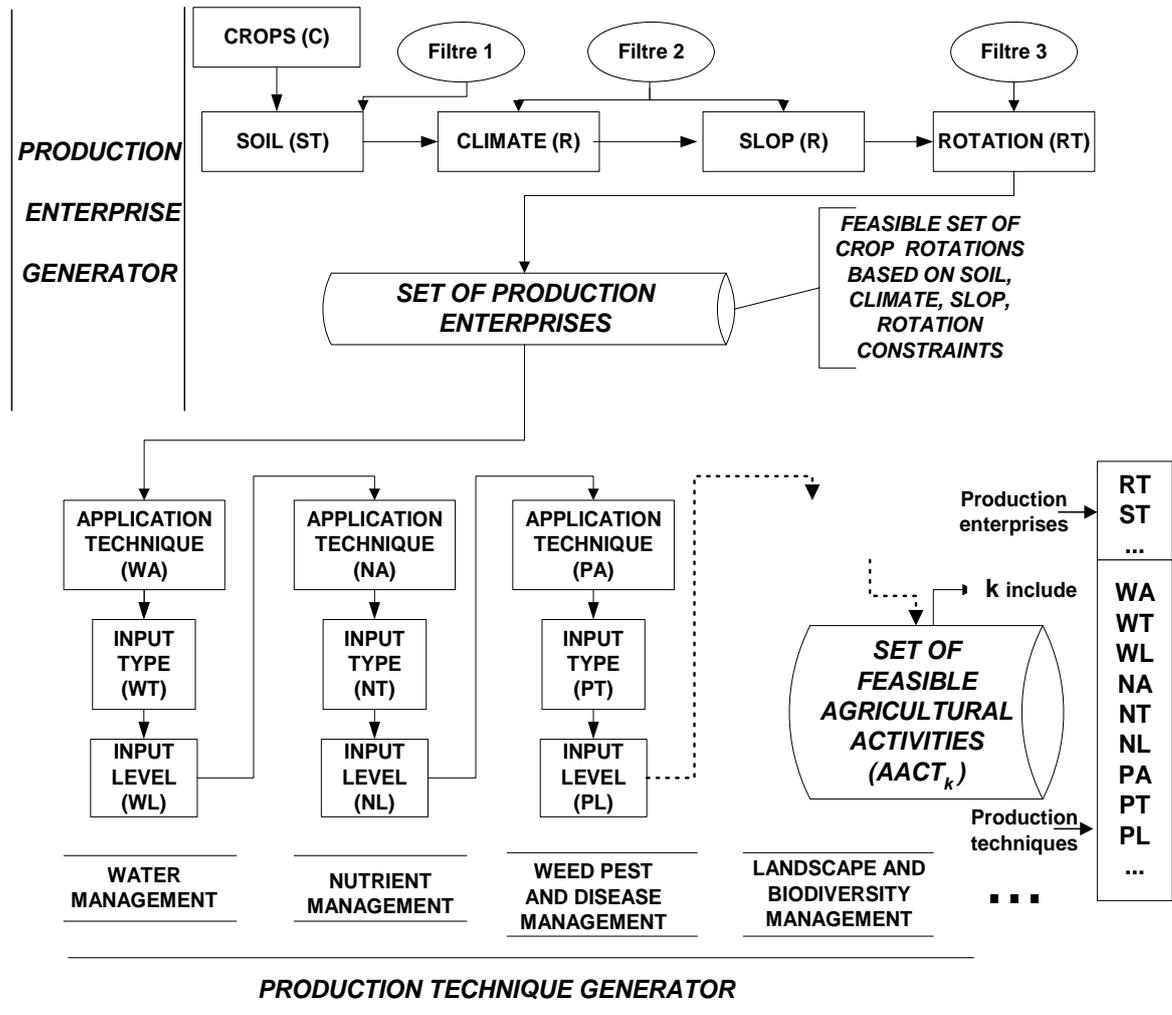
2.1.3 Agricultural Activity Generator: Linking production enterprise generator and production technique generator

As we said, the link between the feasible *crop rotations*, identified with the production enterprise generator, and feasible *production techniques*, obtained by production technique generator, engender what we call the set of feasible *agricultural activities*.

Agricultural activities are designed as a coherent set of production enterprises with a specified production technique resulting in e.g. the delivery of a marketable product, the restoration of soil fertility, or the production of feedstuffs for on-farm use (Ten Berge et al., 2000; Van Ittersum and Rabbinge, 1997).

This activity set is specified by the symbol $AACT_k$, which is defined under a set of criteria k including production enterprise and technique ($k \in \{RT, ST, WA, WT, WL, NA, NT, NL, PA, PT, PL \dots\}$). For easy reference, the signification of some criteria coupled to crop rotation activities are presented and summarised in Figure 3.

Figure 3: Processes for generating agricultural activities

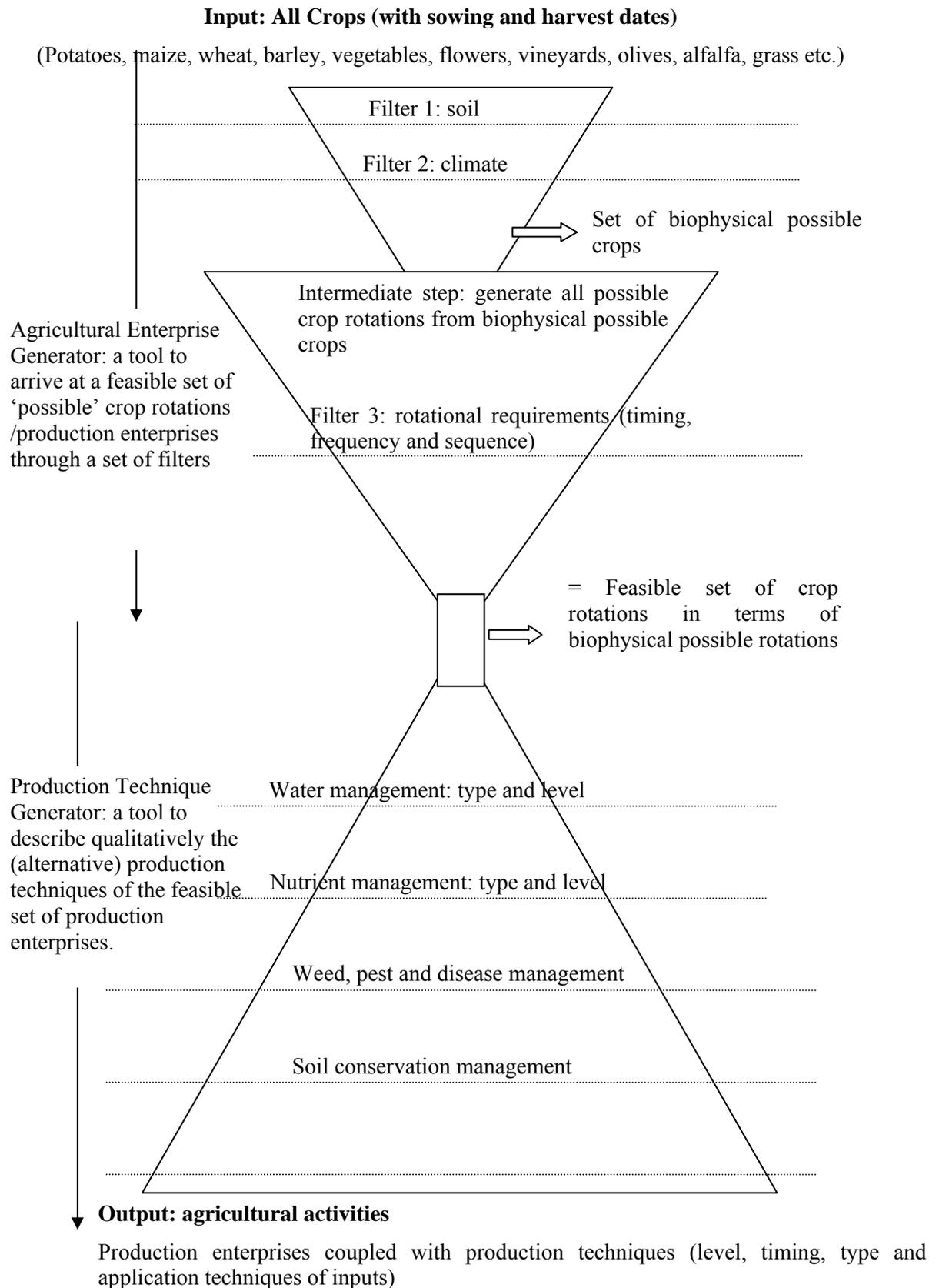


As one can see, each generated agricultural activity will have a specified production technique described in terms of level, timing, type and application techniques of inputs. However, there is the possibility to add multiple set of production techniques and various timing and input levels for each one of them. We can also combine each production technique such as water level with various nutrient levels, weed pest levels, mechanisation levels... The flexibility offered by this structure allows to generate a large set of agricultural activities. The rules and filters given by users allow the elimination of inconsistent and infeasible combinations.

The selection of a broad range of agricultural activities is very important, as the exclusion of some agricultural activity limits the potential solution in the optimisation phase. Nevertheless, each production enterprise (rotation) with a specified production technique provides the information required to parameterize the biophysical model APES, which will be used to calculate productivity of agricultural activities and environmental externalities.

The generated agricultural activities will be separated on current and alternative activities. The identification of current agricultural activities is based on the relative closeness to current activities found in observed data (from statistical sources: FADN, FSS, detailed national or regional surveys, Eurostat, etc). For alternative activities, we discriminate between the ‘on the shelf’ techniques and those ‘in the pipeline’. The former do exist and are applied already in practice on some farms or in some regions, whereas the latter are only known in theory or from experiments.

Figure 4. Interaction between production enterprise generator and production technique generator

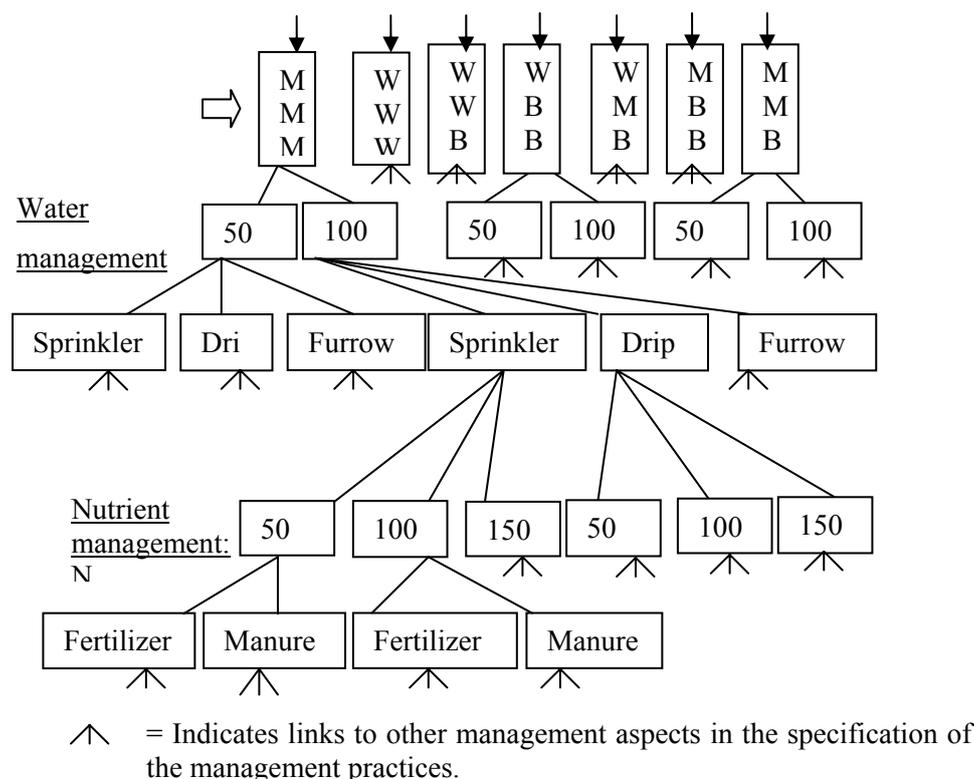


2.1.3.1 An example of Agricultural Activity Generator for crop

Figure 5 shows how production techniques on the basis of two management practices (water and nutrients) can be designed using the 7 rotations (production enterprises) from section 1.1.1.1 as an example. The number of possibilities increases rapidly with increasing alternative production techniques. Here, the total number of possibilities for the seven rotations (combined with two management practices) is 252 (= 7 rotations × 2 water input levels × 3 water application techniques × 3 nutrient input levels × 2 nutrient input sources). Still three other type of management practices need to be added and usually there are many more feasible rotations than 7, so this indicates that in practice the number of possibilities is far larger than 252 as in this example. The typology expands rapidly by increasing the description of management practices. It is important to be explicit about the relevancy of management aspects to be incorporated.

Here, for reasons of simplicity the production technique is only described in terms of input levels (water and nutrients), application technique (water), and input type (nutrients). However, to parameterize APES additional information will be required such as timing of input application, application technique for nutrients, etc. We need to identify which other factors are of importance for characterizing management practices, and whether such factors are attributes of input level, application technique, or should be considered as separate management aspect.

Figure 5. Simplified description of the link between 7 production enterprises (rotation) and two management practices (water and nutrients) as part of the production technique of an activity.

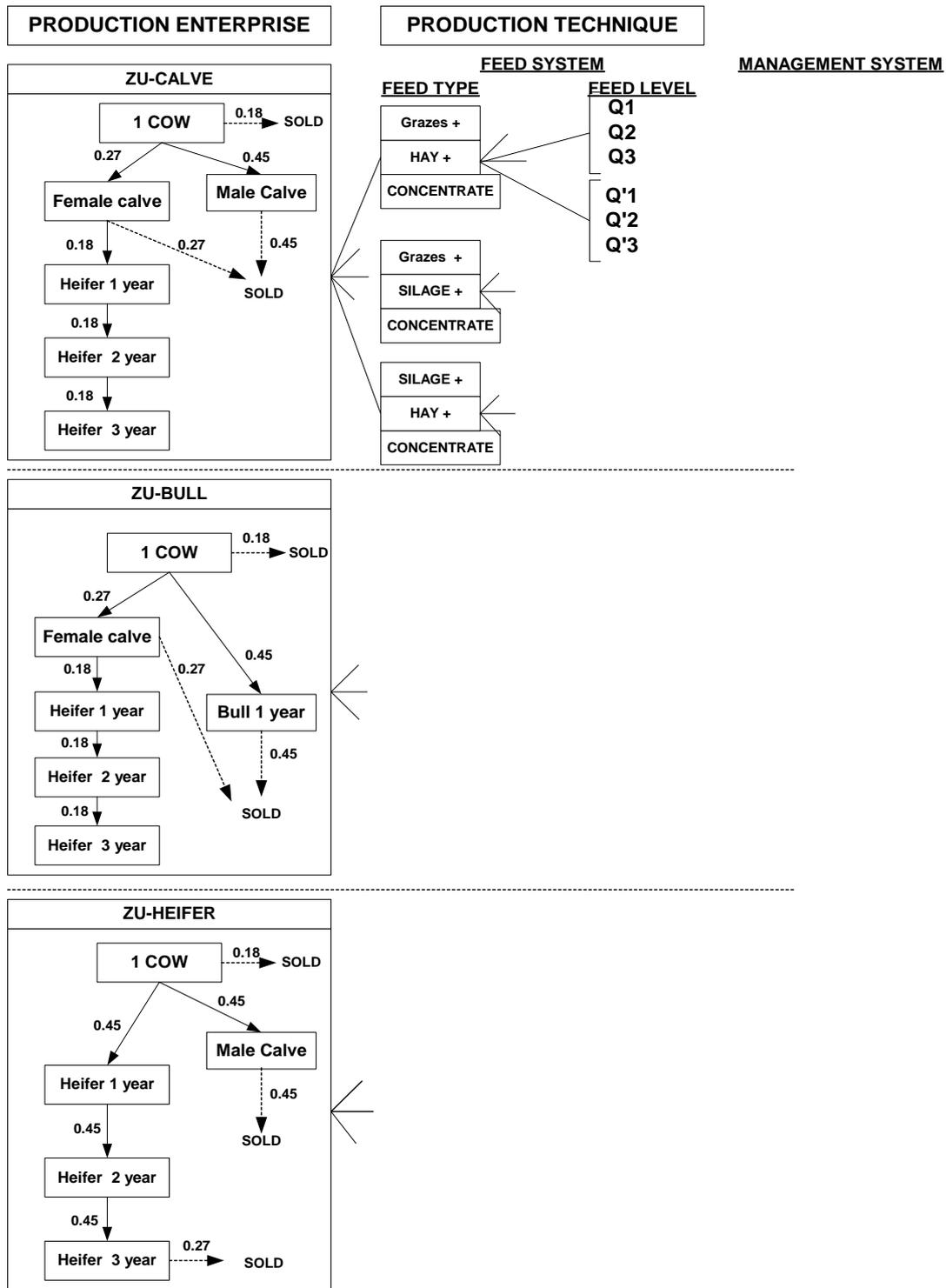


2.1.3.2 An example of Agricultural Activity Generator for animals

The same processes will be applied to generate livestock activities defined under a combination of enterprise activities identified by “zoo-technical unit” (ZU) and production technique based on management and feed systems described in terms of level, time and type.

The zoo-technical unit is defined as a female and its continuation: per example 1 ZU calve = 1 cow + 0.45 male calve + 0.27 female calve + 0.18 heifer of 1 year + 0.18 heifer of 2 year + 0.18 heifer of 3 year. The principal weakness of identifying the agricultural activities under crop rotation and zoo-technical unit instead of individual crops and animals is the non-legibility of the used data and the solution found.

Figure 6. Example of generated livestock activities



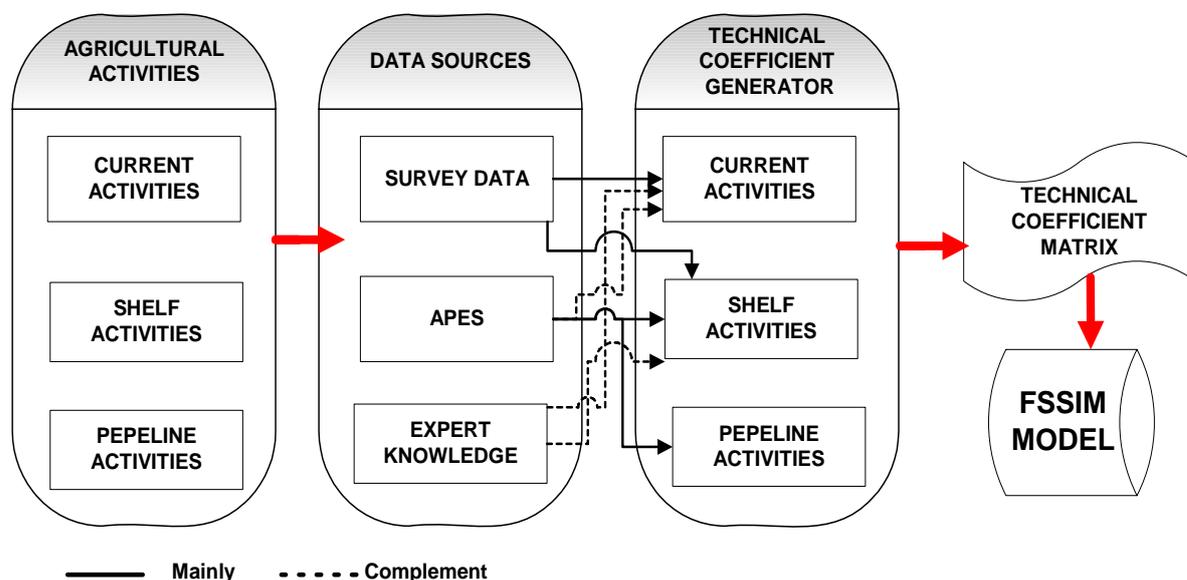
2.2 Quantification of technical coefficients

The starting point for quantification process is the estimation of output coefficient (productivity and externalities: yield, nitrate losses, pollution, pesticide losses...) associated to each production enterprises (rotation) with a specified production technique. For doing this, we separated our analysis between current and alternative (shelf and pipeline) activities.

For current and shelf activities, survey data collected from statistical sources (FADN, FSS, detailed national or regional surveys, Eurostat, etc) are used complemented with APES and expert knowledge for outputs which cannot be obtained by surveys (e.g. nitrate leaching). For the pipeline activities we apply mainly APES and experiments. APES will assess environmental externalities and productivity of agricultural activities, while survey data and expert knowledge will determine quantities and costs of input and resources required (labour, machine needs) as well as product prices, subsidies and taxes associated to each agricultural activity. In cases where there is no past information (new policies, new crops, new technologies...) we will need to apply some inventive approach. APES provide also information for states of nature in term of yield variability due to climatic condition.

All the information obtained from APES simulation and other sources (survey, expert) are then introduced in the Technical Coefficient Generator (TCG). The TCG adapt this information, under a technical coefficient matrix format, in order to make it readable by FSSIM model.

Figure 7. Framework for constructing the input output coefficients for activities



Using one of the rotations of the previous example as an illustration, the generated inputs and outputs (matrix; the generation of this matrix could be based on relational databases) may look like Table 2.

Table 2. Example1 of input output coefficients of some agricultural activities in soil 1

Agricultural activity (AACT _k)	OUTPUTS COEFFICIENTS																				
	Rotation	WL	WA	NL	NA	Y1	Y2	Y3	L1	L2	L3	W1	W2	W3	N1	N2	N3	L1	L2	L3	
MMB	50	sprinkler	50	Fertilizer																	
MMB	100	sprinkler	50	Fertilizer																	
MMB	50	Drip	50	Fertilizer																	
MMB	100	Drip	50	Fertilizer																	
MMB	50	Furrow	50	Fertilizer																	
MMB	100	Furrow	50	Fertilizer																	
MMB	50	sprinkler	100	Fertilizer																	
MMB	100	sprinkler	100	Fertilizer																	
MMB	50	Drip	100	Fertilizer																	
MMB	100	Drip	100	Fertilizer																	
MMB	50	Furrow	100	Fertilizer																	
MMB	100	Furrow	100	Fertilizer																	
MMB	50	sprinkler	150	Fertilizer																	
MMB	100	sprinkler	150	Fertilizer																	
MMB	50	Drip	150	Fertilizer																	
MMB	100	Drip	150	Fertilizer																	
MMB	50	Furrow	150	Fertilizer																	
MMB	100	Furrow	150	Fertilizer																	
MMB	50	sprinkler	50	Manure																	
MMB	100	sprinkler	50	Manure																	
MMB	50	Drip	50	Manure																	
MMB	100	Drip	50	Manure																	
MMB	50	Furrow	50	Manure																	
MMB	100	Furrow	50	Manure																	
MMB	50	sprinkler	100	Manure																	
MMB	100	sprinkler	100	Manure																	
MMB	50	Drip	100	Manure																	
MMB	100	Drip	100	Manure																	
MMB	50	Furrow	100	Manure																	
MMB	100	Furrow	100	Manure																	
MMB	50	sprinkler	150	Manure																	
MMB	100	sprinkler	150	Manure																	

MMB	50	Drip	150	Manure
MMB	100	Drip	150	Manure
MMB	50	Furrow	150	Manure
MMB	100	Furrow	150	Manure

WL = Water input level (50 or 100% unlimited water supply)

WA = Water application technique (drip or irrigation)

NL = Nutrient input (50 or 100% unlimited nutrient supply)

NA= Nutrient type (fertilizer or manure)

Y1, Y2 and Y3 = yield in first, second, third year, respectively

L1, L2 and L3 = Nitrogen leaching in first, second, third year, respectively

W1, W2, W3 = water input in first, second, third year, respectively

N1, N2, N3 = nutrient input in first, second, third year, respectively

L1, L2, L3 = labor requirements in first, second, third year, respectively

3 FSSIM model

The challenge for FSSIM model will be (1) to reproduce, as positive as possible, the farmer's observed behaviour, (2) to help to understand the cognitive structures and the decision rules which govern family farmer decision making (positive assumption) and (3) to enable assessment of the impact of agricultural and environmental policies, behavioural changes and new production technologies on production, revenue, environmental resources, etc (normative assumption).

As we said above, for the first version of FSSIM we will start with a static model with a limited number of variants even if the model include component such as investment which seem to be more realistic with dynamic approach. The FSSIM calibration will be based a priori on the risk aversion improved if necessary by the Positive Mathematical Programming approach.

3.1.1 Objective function

Most studies that have modelled farmer decision-making have assumed that farmers are rational profit-maximiser and their production decisions are influenced mainly by the relative prices of inputs and products (Falconer and Hodge, 2000). They have nevertheless ignored the reality that decisions of farmers are generally influenced by the issue of risk, of responding to uncertain events and maybe minimizing the probability of adverse states.

FSSIM will be a Risk Programming Model which takes into account the risk and uncertainty. Many alternative formulations/approaches could be used to modelling risk from relatively complex specifications using expected utility theory to a simplified one, just taking into account expected profit and standard deviation of it, according to states of nature. The most commonly used methods for including risk in mathematical programming farm models are Mean-Variance, MOTAD (Hazell et al, 1986, Mc Carl, 1989), Target MOTAD (Tauer, 1983) and Focus Loss (Boussard, 1971).

For the moment we start with a basic specification relating to the Mean-Variance method in which expected utility is defined under two arguments: expected income and risk (of course, we will most probably test more interesting ones also). The objective function will thus suppose that the farmers make their decisions in order to maximise the expected income minus some measure of its variability, according to different states of nature defined under three different sources of instability: yield -due to climatic condition, price and subsidies.

The risk aversion coefficient (ϕ) is exogenously specified. Its value is chosen with reference to the cropping patterns and income levels observed in the base years. Producer prices are also taken as exogenously set.

$$\text{Max: } U = Z - \phi\sigma$$

With:

ϕ : the risk aversion coefficient,

σ : the standard deviation of income according to states of nature defined under three different sources of instability: yield -due to climatic condition, price and subsidies,

Z : expected income

$$Z = \sum_j P_j S_j + \sum_i Dp_i X_i Cop_i \alpha Bv + \sum_i Sp X_{\text{"eligible"}} (1 - Cop_i) \alpha - \sum_i Cv_i X_i$$

(Gross revenue: price*quantities + remaining coupled payment + decoupled payment) -
 (Variable cost)

$$- \sum WL - Fc - \sum Ct \Delta T - \sum INVC_i / D_i$$

- (Labour cost) - (Fixed cost) - (Land cost / income) - (Investment cost)

i: agricultural activities (i.e. AACT_k: crop rotation and zoo-technical unit)

j: crop and animal products (grain, silage, hay, milk, meat,...)

I: investment type

Variables list

X_i : level of selected activity i (in ha per crop and head per animal)

$X_{\text{"eligible"}}$: level of current eligible activities

Q_j : total production

$$Q_j = \sum_i \overline{Y_{i,j}} X_i = S_j + U_j$$

S_j : sold production

U_j : on-farm used production

ΔT : (land in - land out)

Exogenous parameters' list

P_j : producer price

$\overline{Y_{i,j}}$: average yield over various states of nature for each product j

Dp_i : direct payment per ha/head

Sp : single payment per ha/head

$$Sp = [(average \Sigma \text{Farmer's Individual Aid 2000-2002}) / (average \Sigma \text{Individual's Eligible Hectares 2000-2002})]$$

Cop_i : coupling degree for each payment

α : percentage of payment modulation

Bv : binary variable (related to attribution criteria of animal premium)

Cv_i : variable cost of activity i

Ct : land cost per ha (land is valued at its market price without transaction cost)

W : labour cost per hour

L : temporary labour hour rent

Fc : fixed costs

D : depreciation period for each investment type (I)

$INVC_i$: investment cost per type (investment cost will be replaced by *annuity* in the dynamic model).

There are two methods from which Member States can choose to apply the payment schema: (1) SFP – based on an average of previous payments from 2000-2002 per farmer, referred to as the “historic payment,” and (2) taking a region’s historic average of direct payments and then doling it out per farmer based on their hectares, referred to as the “flat-rate” (Schroer, 2004).

In the preliminary version of FSSIM we will use the first one. Single Farm Payment is based on individual historic payments from 2000-2002:

$$\text{SFP Aid (each farmer)} = [(\text{average } \Sigma \text{ Farmer's Individual Aid 2000-2002}) / (\text{average } \Sigma \text{ Individual's Eligible Hectares 2000-2002})] * \text{Farmer's Current Eligible Hectares}$$

3.1.2 Principal constraints and equations

The idea is to develop as much as possible the real constraints operating in different farms that exist in the EU, not to build artificial ones. Anyway, it is necessary to check the results of FSSIM before starting the simulation, as we do not think appropriate to use the model if some constraints are forgotten or violated. Parametric simulations can be done in order to analyse the sensibility of some constraints, particularly when we are not sure of the exact level of them.

As we will use the Farm Type Methodology, these constraints will be active for some representative farm and inactive for others according to observed situation in the base years.

3.1.2.1 Production factor constraints

3.1.2.1.1 Arable land constraints

This constraint set limits the level of the crop production activities to on-farm availability, for both irrigated and rain-fed crops.

As shown in the last section, several soil types will be defined in FSSIM model. For each type of soil the technical coefficients of each crop rotation are specified. Some may be the same but others will differ (irrigation and fertilisation levels, yields, etc.). These features imply that we should introduce a number of constraints concerning the allocation of these soils.

For each type of soil (ST) and during each period (Pe), the cultivated arable land (T_{used}) should not exceed initial arable land endowment (T_i) plus land in (T_{in}) minus land out (T_{ou}). In the first version of FSSIM we will not introduce land market which allows land transfers between farms, so the value of land in and land out are equal to zero.

$$\sum_i X_{i,ST,pe} = T_{used}_{ST,pe} \leq T_i_{ST,pe} + T_{in}_{ST,pe} - T_{ou}_{ST,pe}$$

3.1.2.1.2 Perennial activities constraints

The static programming model described above is not well suited to handle activities with a different planning horizon than arable crops (i.e. Grande Cultures and their competitors). For these reasons we will not develop greatly these constraints.

Grassland constraints

The specification of these constraints is more complicated than those concerning the arable land, as the quality and the access to grassland are very different from one farm to another. For easy modelling, the initial land endowment of grass and grazing activities will be more specified according to some criteria such as the pasture access, the slope gradient and gravel density, the land access... For easy reference we specify "easy land" devoted to temporary meadows (renewable and fit to reap) and "difficult land" devoted to permanent meadows which can be only grazed. We assume that there is not market land for grassland.

$$\sum_i X_{i,ST,pe} \leq Le_{ST,pe} + Ld_{ST,pe}$$

This constraint will be more developed in the final version of the generic template, as we will introduce the possibility of renewing temporary meadows and perhaps transfer of these meadows to arable land.

Perennial crops constraints

All perennial crops (Citrus, Apples, Olives, Tobacco, Table grapes, Table olives, Table wine, Tobacco...) are linked to long-term investment decisions and should be analysed with a dynamic programming model or an econometric framework to forecast these crops. This constraint will be more explained in the next version of FSSIM template.

3.1.2.1.3 Labour constraints

These constraints have to be considered carefully because normally there is not a strict amount of labour available but, firstly, different types of labour, for doing different things, with different costs and, secondly, available working day according to weather.

For the first one which is the simplest, the "**gender issue**" can be tackled, when there is a clear division of labour crossing genders. In some cases it is necessary to take into account "supervision labour", when using temporary labour force. This means that for a certain number of temporary workers the farm needs a supervisor that can be a member of the family or somebody with a specific higher wage.

Formally this constraint can be specified as: in each period (Pe) and for each labour type (k), the sum of labour required for each activity (Lreq) should be less than the amount of available family labour (LF) in this period helped by temporary labour (SL) if needed. LF is an exogenous parameter. A labour market which allows the transfer of labour between farms will be introduced in certain regions if necessary.

$$\sum_i X_{i,pe} * Lr_{i,k,pe} = Lreq_{k,pe} \leq LF_{k,pe} + LS_{k,pe}$$

$Lr_{k,pe}$: labour type required per period for each activity i

However, it is difficult to define strict limits to labour availability. Everybody knows that the other real constraint is the **available working days related with different tasks in the farm according to weather**. This is a real constraint that limits in many cases what is possible to do in a certain region. If necessary, this constraint will be introduced out of agronomic expertise.

3.1.2.1.4 Equipment constraints

As well as labour constraint, in each period (Pe) and for each kind of equipment (K'), the sum of equipment required for each activity (Ereq) should not exceed the available equipment (Ea) in this period helped by bought equipment (Eb) if needed. This implies that new equipment can be bought if operations are carried out with own mechanisation. The possibility of investing in new equipment, which is an endogenous variable, will depend on the supply and demand of equipment.

$$\sum_i X_{i,pe} * Er_{k',pe} = Ereq_{k',pe} \leq Ea_{k',pe} + Eb_{k',pe}$$

$Er_{k',pe}$: equipment type required per period for each activity i

3.1.2.1.5 Water constraints

These constraints are very important for irrigated agricultural regions. Generally, two types of constraints are identified concerning the water use: irrigable land and water availability.

Irrigable land

For each type of soil (ST) and during each period (Pe), the sum of area devoted to different irrigated activities can not exceed the initial irrigable land (ISi) in each soil.

$$\sum_i X_{i,ST,pe} \leq ISi_{ST,pe}$$

Water availability

In each period (Pe), the sum of water requirement for each activity (Wused) should not exceed the water volume available (Wa).

$$\sum_i X_{i,pe} * Wr_{i,pe} = Wused \leq Wa_{pe}$$

Wr_{i,pe}: irrigation water requirement per period for each activity *i*
 Wa_{pe}: available total water per period (m³/period).

3.1.2.2 Animal constraints

These constraints are critical in particularly in a mixed farming system where part of the crop production is used as animal feed. Development of animal components will allow the simulation of the relations between available feed quantity and quality, feed intake by the relevant animal species (cattle, small ruminants (sheep/goats), pigs, poultry), animal production (meat, milk, eggs), and nutrient excretion (manure, slurry). Quality of feed components and feed requirements of different types of animal systems will be quantified. The two will be matched endogenously in the farm model via these constraints.

3.1.2.2.1 Animal feeding constraints

The main constraint for feeding is that the produced feed for on-farm use (U) plus the purchased feed (PURCH) plus commercial concentrates (CONC) must cover the herd requirements for energy, protein, etc. The feed set (j) is based on silage, fresh grass (grazed or cut), hay, pulses, straw and grain cereals that are produced in the farm as well as those bought from the market. Feed production depends on many factors such as available amounts of water and nutrients, growing conditions, length of the growing season, harvesting frequency, etc.

Two methods can be applied for modelling the feeding constraint:

* The first one consists to specify animal requirement and feed available in nutrient term, in particular in dry matter, energy and protein and than to indicate that the available quantity of nutrient must cover animal requirements. In this case the distributed quantity of each feed category (silage, fresh grass, hay, pulses, straw, grain...) will be endogenously determined. The advantage of this method is that the model is more flexible, as we have a large substitution between various categories of feed. The inconvenience is that the calibration of the model will be more complicate only if severe constraints are introduced.

$$\sum_j VPROD_{j,nut,pe} + \sum_{co} VCONC_{co,nut,pe} + \sum_j VPURCH_{j,nut,pe} \geq \sum_A AREQ_{A,nut,pe} * EFF_A$$

- *VPROD* is the quantity of nutrient content (nut), in particular in dry matter, energy and protein for each type of produced fodder for on-farm use ($U_{j,pe}$). The qualitative value of the production depends on decisions concerning the harvesting system and frequency, fodder species, stage of maturation during the period and land improvement at the beginning of the period. Total nutrient intake is calculated as follows:

$$VPROD_{j,nut,pe} = U_{j,pe} * VALIM_{j,nut,pe}$$

- *VALIM* is the quantity of nutrient content in fodder/crop products.

- *VCONC* is the quantity of purchased concentrate multiplied by the nutrient content in each concentrate.

- *VPURCH* is the quantity of purchased fodder multiplied by the nutrient content in each fodder.

- *REQUI* is the requirement (for maintenance and production) for each animal per period, obtained by multiplying required nutrient for each animal category (AREQ) by the number of animals (EFF) composing the zoo-technical unit. Nutritional requirements for maintenance are calculated from the average daily need per animal (defined by categories and sex). Nutritional requirements for production are specified by product unit.

* The second one, which is more realistic, consists to identify for each animal or zoo-technical unit several feed systems described in terms of level, time and type of feed. The selection of these feed systems is based on current systems applied in practice on some farms or regions as well as alternatives systems. The problem of this method is its potential rigidity. For avoiding this problem, it is necessary to define a large number of feeding systems from the beginning.

Our choice is to define the livestock activities (i) through the feeding system (level, time and type of feed) choice that implies the application of the second method.

$$U_{j,pe} + \sum_{co} CONC_{co,pe} + PURCH_{j,pe} \geq \sum_i REQUI_{i,j} + \sum_{i,co} REQUI_{i,co}$$

$U_{j,pe}$: produced feed for on-farm use per period

$CONC_{co,pe}$: purchased concentrates per period

$PURCH_{j,pe}$: purchased feed per period

$REQUI_{j,pe}$: feed requirement (for maintenance and production) for each livestock activity. Grazes are expressed in ton of dry matter.

$REQUI_{co,pe}$: concentrate requirement for each livestock activity (several varieties of concentrates can be bought: "B45", "B80", "melasse", "pulpe", "pulco", "Physio" ...).

We can add also other constraints such as: commercial concentrate intake cannot exceed 70 % of dry matter diet; total crude cellulose of the diet must exceed 18% of dry matter intake of the total die, etc.

3.1.2.2.2 Herd demography

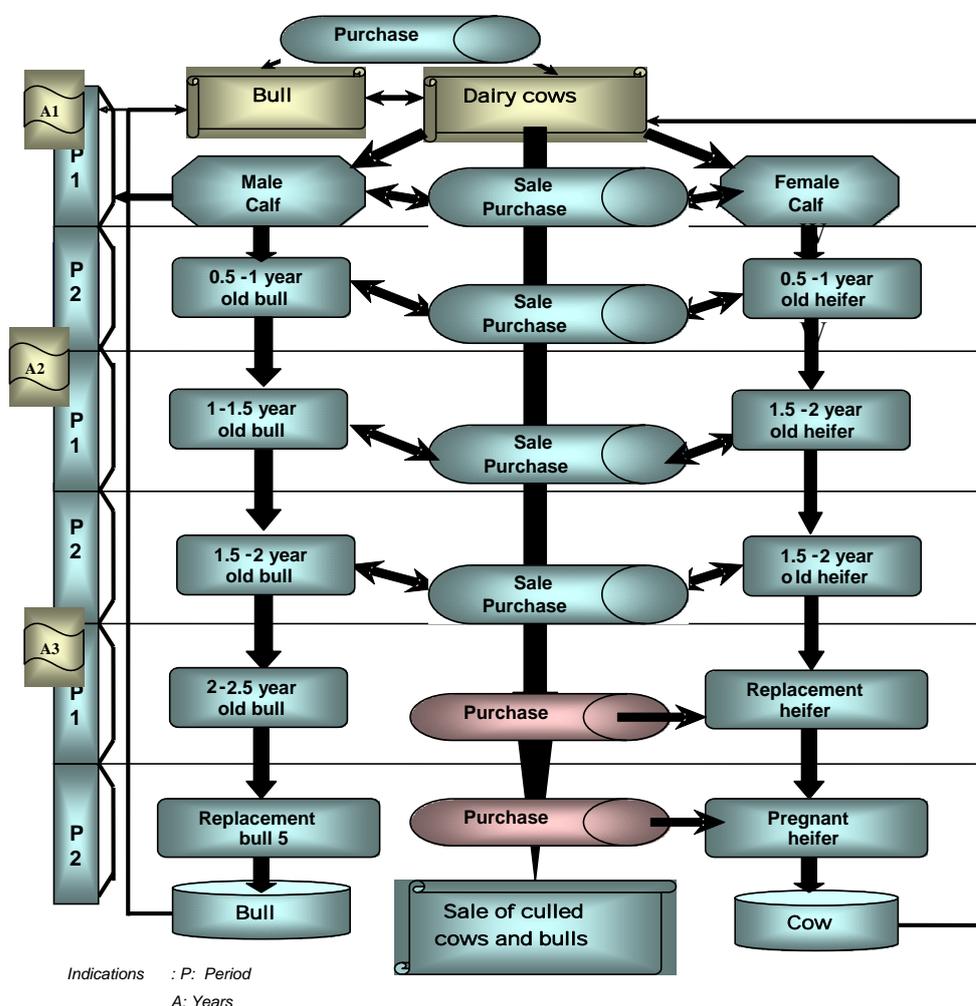
Herd demography represents the inter-generational dependences. It depends on fertility parameters but also on the farmers' decisions concerning animal stocking or destocking. Two approaches can be used for modelling herd demography: a dynamic or a static approach.

- The dynamic approach reflects the demographic growth and the production process in time. Each animal category is analysed separately but linked to the others animal categories by explicit relations. The culling and fertility rates which depend on

farmer's strategy in term of renewal and performance, are taken as exogenous parameter, whereas, traded animals (sold and purchased animals) are determined endogenously (Louhichi et al, 2004). An example of this approach is show in figure 8, which reflects, for a dairy herd, the demographic change at the herd level, between periods in the same year and between years respectively. It also reflects the diverse possibilities concerning purchases, sales and stocks of animals. The same diagram can be applied for modelling demography for suckling cows, sheep and goats. In this example we have chosen only two periods per year but we could easily extend the time analysis if needed.

- The static approach consist on taking the "family" of animals, with a certain inter-generational representation as fixed, but proposing to the model several patterns of "families". All the animal categories of the same "family" are regrouped together under a zoo-technical unit, which is defined as a female and its "family". As we said above, for the FSSIM model we have chosen this approach, consistent with the approach concerning crop rotations. Several zoo-technical units (ZU) (i.e. several patterns of families) will be considered according to farmer's strategy in term of renewal and performance observed in the EU. Culling and fertility rates as well as kept and traded animals (sold and purchased animal) will be chosen exogenously inside each livestock activity, according to various farming systems defined in the livestock activity.

Figure 8. Example of herd demographic modelling in the dynamic approach



3.1.2.3 Policy constraints

Specific policy constraints will have to be implemented. This is the case of (sugar and milk) quota and set-aside obligations as well as all cross-compliance policies and agri-environmental policies when specific subsidies are related to the enforcement of "good farming practices" (maintenance of land in good agricultural condition and respect of statutory environmental, food safety, animal health and welfare standards). Extensification premiums will be also modelled, as well as additional premiums granted by Member States.

For the first version of FSSIM only the measures of Agenda 2000 are handled. However, FSSIM will provide a large framework in order to be able to easily adapt for new policy scenarios and new issues that will certainly appear.

3.1.2.3.1 Milk and sugar quotas

The implementation of the milk and sugar quota systems differs throughout the EU. In some member states, the quota may be traded or leased across regions. In other member states,

quota trade is regulated with a fixed price or is bounded to occur within certain regions. To simplify the analysis, we assume for the moment that there is not a quota market, i.e. quotas are not tradable.

Milk quota

Annual milk production (*PRODmilk*) should not exceed the milk quota.

$$\sum_{pe} X_{i,'dcows',pe} * Y_{i,'milk',pe} = PRODmilk \leq Milk_Quota$$

$Y_{i,'milk',pe}$: periodic milk yield for the dairy cows.

Sugar beet quota

* Annual A sugar beet production (*PRODasugb*) should not exceed A sugar beet quota.

$$\sum_{i,pe} X_{i,'Asugb',pe} * \bar{Y}_{i,'Asugb',pe} = PRODasugb \leq ASugb_Quota$$

$Y_{i,'Asugb',pe}$: periodic yield for A sugar beet.

* Annual B sugar beet production (*PRODBsugb*) should not exceed B sugar beet quota.

$$\sum_{i,pe} X_{i,'Bsugb',pe} * \bar{Y}_{i,'Bsugb',pe} = PRODBsugb \leq BSugb_Quota$$

$Y_{i,'Bsugb',pe}$: periodic yield for B sugar beet.

* Total sugar beet production equal to A+B+C sugar beet production.

$$PRODSugb = \sum_{i,pe} X_{i,'Asugb',pe} * \bar{Y}_{i,'Asugb',pe} + \sum_{i,pe} X_{i,'Bsugb',pe} * \bar{Y}_{i,'Bsugb',pe} + \sum_{i,pe} X_{i,'Csugb',pe} * \bar{Y}_{i,'Csugb',pe}$$

3.1.2.3.2 Set aside constraint

National regulations on set-aside land will be modelled and compulsory and voluntary set-aside constraints will included in the model.

The compulsory constraint simply means that in order to receive area payment, the producer is subject to the obligatory set-aside of minimum 10% of its COP area. Voluntarily up to 33% of the COP surface can be set aside.

$$10\% * \sum_{COP} X_{COP,pe} \leq \sum X_{"Set-aside",pe} \leq 33\% * \sum_{COP} X_{COP,pe}$$

Producers who apply for direct payment to an area smaller than the one needed to produce 92t of cereals are exempted from the obligatory set aside (Junker et al, 2003).

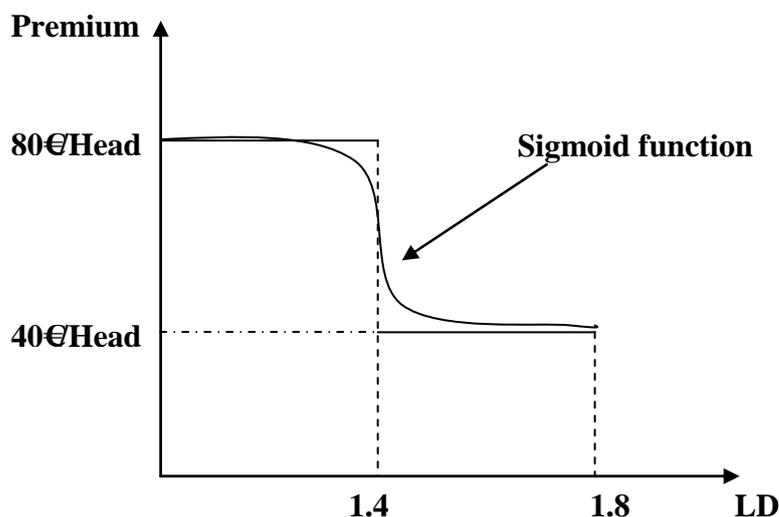
3.1.2.3.3 Livestock density constraints

The first constraint limits the total premiums for bovine to the producer's entitlement and verifies whether the livestock density² (LD) condition is respected, exempting from this criteria those producers with up to 15 livestock unit (LU).

- Headage payments: 150 EUR for steers (two payments), 210 EUR for bulls/year and 200 EUR/year for suckler cows.
- Slaughter premium of 80 EUR (bulls, steers, cows) and 50 EUR (calves)
- Eligibility criteria: up to 1.8 LU/ha (from 01.01.03, currently 1.9 LU), head limit of 90 (with derogation)

National envelope (budget)

The second constraint concerns the extensification premiums which are often conditioned by the respect of livestock density. In respect of the calendar year 2002 and the subsequent years, these premiums are fixed to 80 EUR per premium for a livestock density below 1.4 LU/ha and 40 EUR for more than 1.4 LU/ha, without surpassing a density of 1.8 LU/ha.



For modelling cross-compliance policies and represent thresholds it is needed to use binary (integer) variables³. Other manner less elegant is to apply a sigmoid (fudging) function developed by Arne Drud, the “brain” behind the CONOPT solver (Junker et al, 2003).

$$a) \sum_i LU_i / \sum_i X_i = LD \leq 1.4 * Bv \quad (1)$$

$$b) 1.4 \leq \sum_i LU_i / \sum_i X_i = LD \leq 1.8 * (1 - Bv) \quad (2)$$

LU: livestock unit

² The livestock density (livestock unit per hectare) is an aggregate measure of the number of animals per hectare of arable land. The livestock unit will be calculated by using conversion factors for different animals. The purpose of "Livestock units in agriculture" is to produce statistics describing the number of livestock units in farm holdings, including figures for type of farm holding, area of farm holding and geographical distribution of farm holdings.

³ A mixed-integer nonlinear programming (MINLP) solver will be used in order to allow an elegant solution for this type of problem. That's why we suggest that all partners should acquire solver licence (i.e. DICOPT) for MINLP models.

LD: livestock density

X: arable land

Bv: binary variable. Bv = 0 i.e. equation (2) is binding; Bv = 1 i.e. equation (1) is binding.

3.1.2.4 Investment constraints

It is not easy to represent these constraints in a static model. They are related with credit rules and policies. Generally, investment decisions in farm system depend on the farmer's projects and financial means. The types of investment (I) which are generally included into the farm are: farm equipment, farm building, plantation, land transaction, purchase of breeding stock, etc. These investments are covered with own capital (OK) or/and long-term credit (CREDLT). The sliding annuity is calculated each period and deducted from the cash flow and income (in the case of a dynamic model).

$$\sum_I INVC_I = OK + CREDLT$$

Handling investment with a different planning horizon in a static programming model is very complicated. The simplest method consists in apply the depreciation value to take into account the annual investment cost. In this case we do not deduct annuity from the income, but depreciation value (*see the objective function*).

3.1.2.5 Cash Flow constraints

If we will take into account investment possibilities, this constraint is important (credits have to be reimbursed) for assessing credit policies.

The equation of periodic cash flow is written as:

$$CASH_{pe} = RECEIPT_{pe} - EXPEND_{pe} + CASH_{pe-1} + CREDCT_{pe} - ANNUI_{pe} - REMDCT_{pe} \\ - Fc_{pe} - CONS_{pe} - OK_{pe} - SAVE_{pe}$$

The receipt (RECEIPT) comprises the sale of animal and vegetable products plus the financial support (as the subsidy or premiums from the Common Agricultural Policy CAP) plus salaries or incomes from other non agricultural activities. The expenditure (EXPEND) concerns all the operational charges such as fuel, fertiliser, purchased feed, labour, rent in, etc.

To these traditional components, we added the cash of the previous period (CASH_{pe-1}) and the contracted credit (CREDCT) and we deduce the annuity for long-term debts (ANNUI), the reimbursement of short-term debts (REMDCT), the fixed cost (Fc), the private consumption (CONS), the own capital available for investment (OK) and the saving (SAVE) used to increase the capital asset of the farm.

3.1.2.6 Risk equations

As we said on top of the paper, risk is introduced in the FSSIM close to the Mean-Variance method proposed by Freund (1957). This method computes for each combination of states of nature the negative deviation of actual income from expected value of it. Each state of nature (n) is defined under three different sources of instability: yield -due to climatic condition, price and subsidies.

Risk is considered according to the next two equations which used to calculate the standard deviation:

$$Z_n + Dev_n = Z$$

$$\left[\frac{\sum_n \sqrt{Dev_n}}{N} \right]^2 = \sigma$$

Dev: deviation dependent upon different states of nature

N: number of states of nature

Z: expected income

Z_n: income of different states of nature

σ: the standard deviation of income according to states of nature defined under three different sources of instability: yield -due to climatic condition, price and subsidies.

3.1.2.7 Environmental constraints

The type of environmental constraints that will be taken into account in FSSIM concerns especially nitrogen leaching, nitrogen runoff, soil erosion, water use, potential risks of pesticide use and minima on herbaceous plant biodiversity, hedges and drainage system. These constraints will be included under several options according previous and current EU agri-environmental payment and common market organisations (CMOs') regulations:

- Imposing the cross-compliance restrictions. The cross-compliance restrictions represent the environmental constraints as currently in the common market organisations regulations.
- Imposing a set of environmental sustainability thresholds (we include in the model as right-hand side constraints reflecting legal limitations as imposed by law or reported in the literature).

...

Modelling environmental constraints will be possible thanks to the biophysical model APES which will assess environmental externalities of each agricultural activity (nitrate pollution, erosion, chemical pollution, nice landscape, etc.).

Of course, these are not the only constraints to take into account, but they give a first global idea. Other equations deal with other specific constraints, technical, economic and environmental, applicable to some regions will be also added.

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