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

Agricultural Management module of FSSIM, Production Enterprice Generator, Production Technique Generator, Simple Management Translator and Technical Coefficient Generator

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General information

Task(s) and Activity code(s):	T3.3
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Executive summary

The main objective of this deliverable is to describe the structure of the Agricultural Management (AM) module of the Farm Systems SIMulator (FSSIM) with respect to current and especially alternative activities. The deliverable addresses the different steps in the generation of activities and the quantification of their inputs and outputs. Current activities are based on expert knowledge of the current farming systems (PD3.3.9), while alternative activities are based on agronomic possibilities and limitations of the farming systems considered. The components of FSSIM-AM are the Production Enterprise Generator (PEG), Production Technique Generator (PTG), Simple Management Translator (SMT), Agricultural Production and Externalities Simulator (APES) and the Technical Coefficient Generator (TCG). The different components together quantify agricultural activities in terms of technical coefficients (inputs and outputs) that are offered to the FSSIM. Whereas, the procedures for constructing production enterprises and production techniques are quite different for current and alternative activities, the addition of costs and labour requirements and the processing of APES outputs are largely the same for current and alternative activities.

The SMT is a component which processes aggregate or ‘simple’ agro-management into detailed agromanagement, ready for simulation through APES. This simple aggregate agro-management is collected in the Simple Survey (PD3.3.9) as regional crop survey data, and/or from the PEG and PTG components. In the SMT, the aggregate physical input use and management timing is converted into a number of crop management events characterized by amounts, timing rules, machinery usage and working depths. Expert crop-specific management rules have been developed for sowing, harvesting, tillage, nutrient and water management. When for a region detailed crop management data is available, this conversion of management data through expert rules in the SMT is not needed.

The PEG is a tool to generate a feasible set of production enterprises (crop rotations) of the farm based on crop suitability filters, such as soil and climate characteristics, for annual arable rotation suitability filters. The PEG contains a number of ‘crop suitability and rotation filters’ that limit in an early stage the number of crop rotations for which production techniques need to be defined and that limit the number of simulations to be carried out by APES. The ‘crop suitability and rotation filters’ are a set of rules and parameters that filter out options that are not possible or desirable from an agronomic point of view.

The PTG is a tool to describe production techniques of agricultural activities for the feasible set of production enterprises. A production technique is a complete set of agronomic inputs, which can be characterized by type, level, timing and application technique. Production Techniques consist of five management practices: general management, water management, nutrient management, weed, pest and disease management, and conservation management. Each of these management practices consists of several aspects, for example, the method and

level of application (full replacement of water, e.g. 100% or allowing some water shortage), the timing of the application (both time window and timing rule used, e.g. irrigate every 14 days starting from the 1st of July) and input type (for example, manure or fertilizers). The PTG produces a set of agricultural activities (i.e. rotation plus production technique for crops in the rotation), which can consequently be assessed by APES for yields and environmental effects.

The Technical Coefficient Generator (TCG) links the agronomic input and output coefficients generated by the simple survey, SMT and APES or the PEG, PTG and APES to socio-economic inputs and outputs by simple calculations. The TCG quantifies other crop inputs in each agricultural activity and attaches costs to the various inputs. The result of the TCG is a fully quantified set of agricultural activities (Technical Coefficient Matrix) in terms of physical and economic units that is offered to FSSIM-MP. The TCG processes survey data into compatible inputs for FSSIM and links them to regional farm types, while calculating an average over several years for the observed cropping pattern, product price and yield variability for these farm types using data from the FADN-based farm typology

The PEG, PTG, SMT and TCG have been implemented in the Java™ programming language, facilitating the integration with SeamFrame and the development of components that are reusable, extensible and exchangeable. The objectives during development were to completely separate algorithms from data and user interface to facilitate easy linkage to other databases and user interfaces and to make the algorithms easily extensible and comprehendible. These objectives were achieved by (i) linking the algorithms to databases through the SEAMLESS ontology, (ii) developing a user interface at the very end, (iii) using strategies for software design that allow flexible (re-)use of algorithms and components.

The components of PEG, PTG, SMT, APES and TCG of FSSIM-AM together describe current activities, generate alternative activities and quantify the activities through all the required technical coefficients. Alternative livestock and perennial activities still need to be implemented and the conceptual approach to generate arable alternative activities can easily be used and extended. One bottleneck in the conceptual approach for alternative arable activities is combinatorial explosions that might occur, e.g. the potentially very large number of activities that can be generated by FSSIM-AM.

1 Introduction

1.1 Purpose of the Agricultural Management Module

The purpose of the Agricultural Management (AM) Module is to describe current activities, to generate alternative activities and to quantify the activities through all the required technical coefficients. These activities can be evaluated by the Agricultural Production and Externalities Simulator (APES) in terms of yields and environmental effects. The fully quantified agricultural activities i.e. the complete sets of technical coefficients are input of the Mathematical Programming module of the Farm Systems SIMulator (FSSIM-MP) for assessing their contribution to goals considered at farm level. Alternative activities are not applied in practice, but theoretically feasible alternatives for the future, often comprising technological innovations or newly developed cropping or husbandry practices (PD3.3.11/PD3.3.8). Current activities can be found in practice and can be derived from observed data (PD3.3.9).

The AM Module consists of four components: (i) Production Enterprise Generator (PEG) for generating alternative production enterprises, i.e. rotations; (ii) Production Technique Generator (PTG) for generating and quantifying alternative management practices of the production enterprises; (iii) Simple Management Translator (SMT) for rule-based translation of current aggregate agro-management information into detailed agro-management data as input for cropping systems simulation through APES; and (iv) Technical Coefficient Generator (TCG) for quantifying, collecting and formatting technical coefficients.

The objectives of this deliverable are:

1. to describe the structure of the AM Module with respect to alternative activities: address the different steps in the quantification of inputs and outputs of alternative activities,
2. to describe the PEG, PTG, SMT and TCG, which are part of the AM Module. The APES component is only described briefly as a comprehensive description is available in D3.2.19
3. to discuss some important issues concerning the generation of technical coefficients (TCs) of agricultural activities,
4. to describe the linkage between the generators and FSSIM-MP and APES: explain the information flow between components within Task 3.3.
5. to establish a common terminology for the description of agricultural activities (see Glossary)

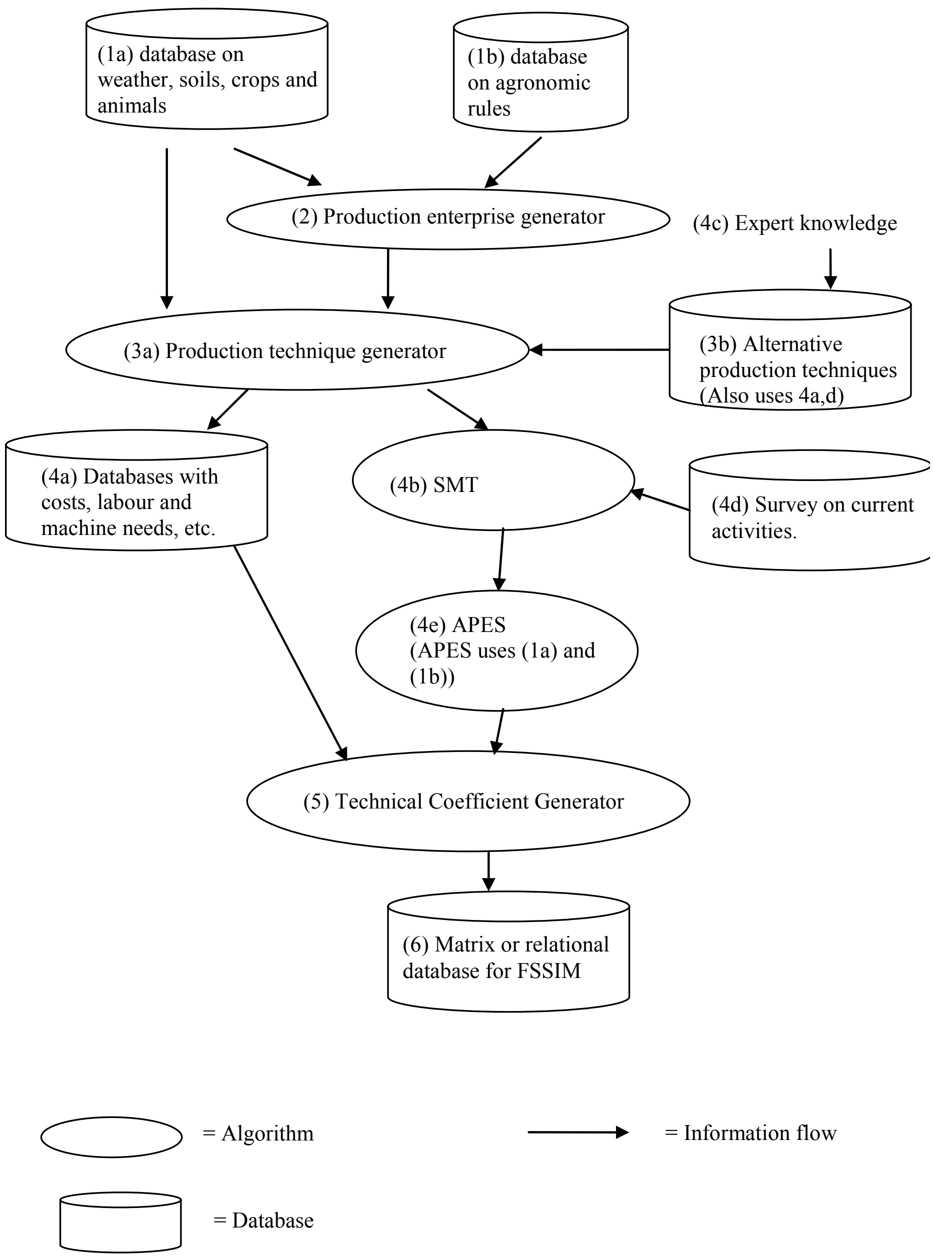
This deliverable focuses on annual cropping systems, but similar steps are needed for the quantification of animal (PD3.3.4) and perennial cropping activities (PD3.3.5).

1.2 Overview of the Agricultural Management Module

The main calculation components or modules of the AM Module are the Production Enterprise Generator (PEG), Production Technique Generator (PTG), Simple Management Translator (SMT), Agricultural Production and Externalities Simulator (APES), and the Technical Coefficient Generator (TCG) (Figure 1.1). Database structures are used to collect and (temporary) store input and output information for the different components. The different components together enable quantifying agricultural activities in terms of technical coefficients (inputs and outputs) to be offered to FSSIM-MP for assessing their contribution to goal achievement at farm level. The different components are connected through a framework that is part of SEAMLESS-IF. This framework is developed according to the guidelines provided by WP5.

Current activities, e.g. current production enterprises and current production techniques are identified on the basis of observed data and expert knowledge. Variable and fixed costs and labour requirements are derived from general agricultural statistics, which can also be used for alternative activities. PEG and PTG together generate alternative arable activities, and SMT and TCG are both used for current and alternative activities (Figure 1.1). Relevant data is extracted from databases by the components.

Figure 1.1: The components and structure of the Agricultural Management Module



1.3 Reading guide

Chapter 1 introduces FSSIM-AM and its link to other components of SEAMLESS. As Production Orientation is an important concept within FSSIM-AM, Chapter 2 addresses its meaning and its use in FSSIM-AM. Consequently, the conceptual approach of the components SMT, PEG, PTG, APES and TCG will be discussed in Chapters 3, 4, 5, 6 and 7, while Chapter 8 discusses the software implementation of these components with the aid of ontologies and databases. Finally, Chapter 9 provides some general conclusions and bottlenecks.

2 Production Orientation

A production orientation is a set of value driven aims and restrictions of the agricultural activity that affect the input and output levels (Van Ittersum and Rabbinge, 1997). Production orientations could, for instance, be labelled as 'integrated', 'organic', 'conventional' or 'low labour input.' Production orientations can be considered coherent sets of aims and limitations to the farming system, which are based on the preferences of the stakeholder and on the purpose of the study. For example, the meaning of 'conventional' is defined by the limitations set to the farming systems, i.e. crop rotations are used and do not exceed 5 years, and may even consist of monocultures, while there are no limitations on the use of nutrient sources (organic or inorganic) and crop protection agents. In our approach, the production orientation defines the maximum or minimum value of certain variables like minimum and maximum rotation length, the set of possible crop protection methods, the set of possible nutrient sources (organic and inorganic) and the set of possible tillage methods.

In the framework of the Agricultural Management Module, there is the possibility and flexibility to define many different production orientations, allowing to address the wide diversity of possible policy questions within SEAMLESS. Production orientations are thus user- and context-specific, e.g. dependent on the (policy) question the user wants to address. Many different production orientations are conceivable (conventional vs. integrated vs. organic; risk taking vs. risk neutral vs. risk averse; intensive vs. extensive). A few examples of important aspects which determine the choice of production orientations:

- Scale of the analysis: whole EU or case study of a specific region
- Comparing extreme production orientations or comparing a set of 'average' positions (for example with regard to nutrient emissions)
- Based on agronomic or economic parameters or a combination of both

In the current implementation, production orientation is used as in input by PEG, PTG and SMT. For the PEG, it contains information on the minimum and maximum rotation length and the maximum number of different crops. The production orientation specifies the alternative management aspects for the PTG for nutrient and water management, and will specify weed, pest, disease management and conservation management. The data for the crop management rules for the SMT is also linked to the production orientation, so that these data can be adapted to the policy questions by defining different production orientations.

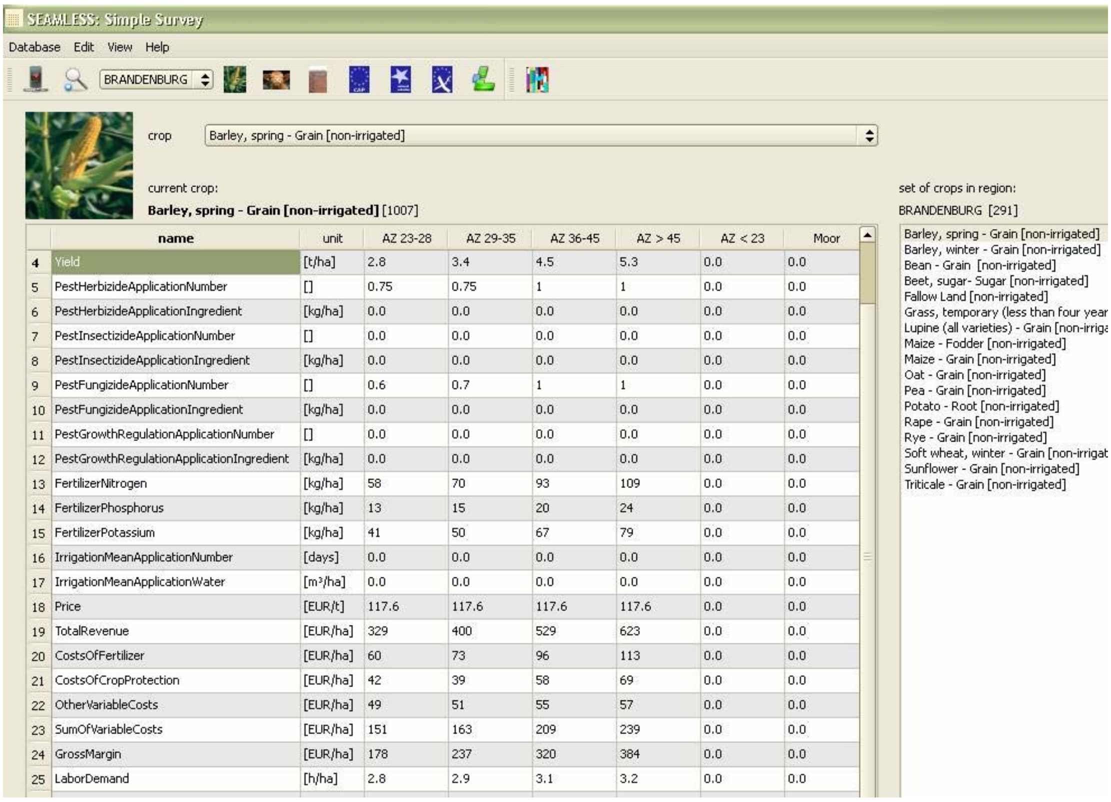
3 Simple Management Translator

3.1 Conceptual approach

Agricultural activities simulated by the cropping systems model APES are either current activities, originating from the SEAMLESS database, or user-defined alternative activities. To simulate crop yields and environmental effects by APES (Chapter 6), these activities need to be specified in terms of the agro-management applied. Therefore, each management event in a crop year has to be specified in a Rule-Operation structure, in which the Rule determines the timing of the Operation (*when*), and the Operation the type of the agro-management (*what*). For many regions, this type of data is scarce or difficult to access. Two options are available to address this data problem: 1) use a model using coarse or aggregate data 2) use an intermediate step enabling a detailed model to use coarse or aggregate data. Here, the second approach was chosen.

The agro-management data available for simulation of crops was obtained by a simple survey carried out in 19 EU regions (PD3.3.9). Data consists of the total amount of irrigation water, number of irrigation events, total nitrogen fertiliser input, and the average sowing week number (Figure 3.1). Using expert knowledge a rule-based system was developed, translating these simple survey data to Rule-Operation based agromanagement, suitable for simulation by the APES cropping systems model.

Figure 3.1: Screen shot of the crop sheet of the Simple Survey (PD3.3.9)



	name	unit	AZ 23-28	AZ 29-35	AZ 36-45	AZ > 45	AZ < 23	Moor
4	Yield	[t/ha]	2.8	3.4	4.5	5.3	0.0	0.0
5	PestHerbizideApplicationNumber	[]	0.75	0.75	1	1	0.0	0.0
6	PestHerbizideApplicationIngredient	[kg/ha]	0.0	0.0	0.0	0.0	0.0	0.0
7	PestInsectizideApplicationNumber	[]	0.0	0.0	0.0	0.0	0.0	0.0
8	PestInsectizideApplicationIngredient	[kg/ha]	0.0	0.0	0.0	0.0	0.0	0.0
9	PestFungizideApplicationNumber	[]	0.6	0.7	1	1	0.0	0.0
10	PestFungizideApplicationIngredient	[kg/ha]	0.0	0.0	0.0	0.0	0.0	0.0
11	PestGrowthRegulationApplicationNumber	[]	0.0	0.0	0.0	0.0	0.0	0.0
12	PestGrowthRegulationApplicationIngredient	[kg/ha]	0.0	0.0	0.0	0.0	0.0	0.0
13	FertilizerNitrogen	[kg/ha]	58	70	93	109	0.0	0.0
14	FertilizerPhosphorus	[kg/ha]	13	15	20	24	0.0	0.0
15	FertilizerPotassium	[kg/ha]	41	50	67	79	0.0	0.0
16	IrrigationMeanApplicationNumber	[days]	0.0	0.0	0.0	0.0	0.0	0.0
17	IrrigationMeanApplicationWater	[m³/ha]	0.0	0.0	0.0	0.0	0.0	0.0
18	Price	[EUR/t]	117.6	117.6	117.6	117.6	0.0	0.0
19	TotalRevenue	[EUR/ha]	329	400	529	623	0.0	0.0
20	CostsOfFertilizer	[EUR/ha]	60	73	96	113	0.0	0.0
21	CostsOfCropProtection	[EUR/ha]	42	39	58	69	0.0	0.0
22	OtherVariableCosts	[EUR/ha]	49	51	55	57	0.0	0.0
23	SumOfVariableCosts	[EUR/ha]	151	163	209	239	0.0	0.0
24	GrossMargin	[EUR/ha]	178	237	320	384	0.0	0.0
25	LaborDemand	[h/ha]	2.8	2.9	3.1	3.2	0.0	0.0

3.2 Simple management rules

3.2.1 Introduction

The agro-management rules presented here translate yearly, aggregate Simple Survey agro-management information into detailed, daily agro-management events. For the Rule-Operation structure required by APES, the *Rule* for timing of events is based on biophysical conditions like the rainfall, soil water conditions, day of the year, crop development stage, etc. The *Operation* describes the type (e.g. irrigation, nutrient, pesticide) and actions (e.g. machinery, working depths) of the agro-management to be executed. For more details on APES and its agro-management component, see deliverable D3.2.19.

Three types of operations are implemented in the SMT: 1) Tillage, sowing and harvest 2) Irrigation and 3) Fertilisation. In the next sub-sections these operations and their associated rules are described in detail. For each operation default implements (machinery, etc.) and implement parameters, like working depth, are retrieved from the database.

3.2.2 Primary tillage, seedbed preparation, sowing and harvesting

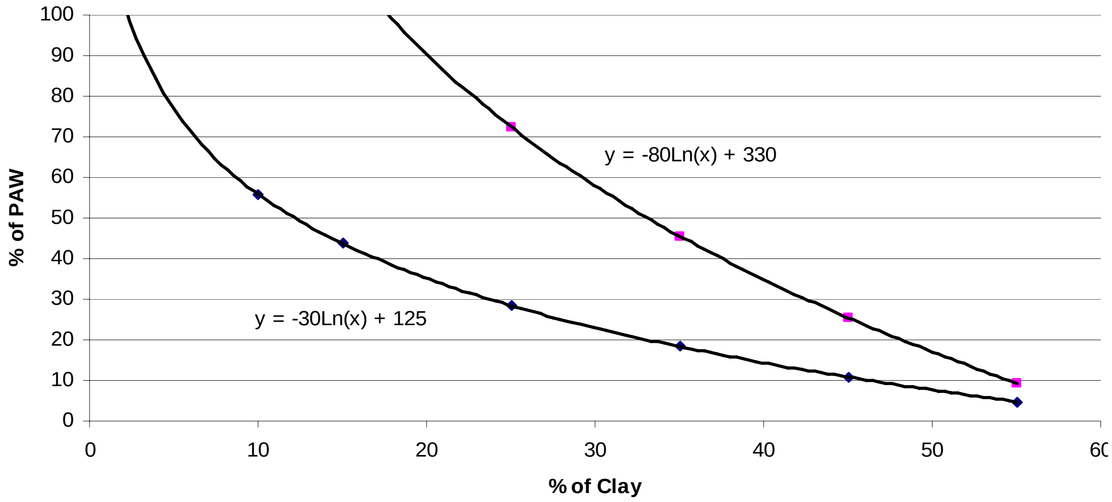
The average current sowing date is available from the Simple Survey as a week number. A time window of 10 days (length can be varied according to user needs) before and after this week number has been defined, providing a window of 27 days for sowing. In this time window seedbed preparation and sowing are started simultaneously as soon as the plant available water percentage (PAW) in the top soil layer (0 - 0.2 m) is within a soil type specific range (equations 1 and 2), i.e. above the lower threshold PAW_{low} and below the upper threshold PAW_{high}. Minimum (for PAW_{low}) and maximum (for PAW_{high}) of the range are set at 10% and 90%, respectively. When the actual PAW is below the PAW_{low} the soil is assumed to be too dry, when the actual PAW is above PAW_{high} the soil is assumed to be too wet. PAW is continuously simulated by APES at a daily time-step.

$$PAW_{low} = -30\ln(ClayContent) + 125 \quad (1)$$

$$PAW_{high} = -80\ln(ClayContent) + 330 \quad (2)$$

In these equations *ClayContent* is the percentage of clay of the soil which is available in the SEAMLESS soil database. PAW is calculated as a percentage (Figure 3.2). If the conditions are not met, i.e. PAW is continuously too high or too low within the rule window, seedbed preparation and sowing take place at the end of the window.

Figure 3.2: Curves of upper and lower PAW thresholds for sowing



Primary tillage, i.e. the ploughing of the field, can be initiated in two distinct ways. First, for winter and spring crops on clay soils (clay content >25%, as a default, but can be changed by the user) tillage is initiated 10 days after the harvest of preceding crop in the rotation. Second, for spring crops on non-clay soils, the primary tillage is initiated two weeks before the start of the sowing window of the crop, i.e. 24 days before the sowing week number as available in the Simple Survey.

Harvesting is initiated in a time window of 30 days, starting at crop physiological maturity, i.e. when the crop's development stage (DS) reaches 2. For crops that are harvested before physiological maturity, i.e. seed potato and fodder maize, this window starts at DS=1.8. When there are two consecutive days without rain within the harvest window, the crop is harvested. If this requirement is not met during the harvest window the crop is automatically harvested at the end of the window.

In case crop residues are harvested a crop-specific fraction is specified in the SEAMLESS database for the amount of crop residues that remain in the field as stubble. Currently, this fraction is set at 5% for all crops of which the crop residues can be harvested. In case crop residues are not harvested a crop-specific fraction is available in the SEAMLESS database specifying the amount of crop residues that remain in the field. Currently, this fraction is set at 100% for all crops. For all harvests a default post-harvest yield loss of 5% is defined, i.e. 5% of the yield at physiological maturity is lost due to the harvest operation, transport, or storage.

3.2.3 Irrigation management

Irrigation management thresholds and time windows can be fully defined by the management rules as described in this section, or can (partially) be pre-defined through alternative management specifications, i.e. have fixed, user-defined values.

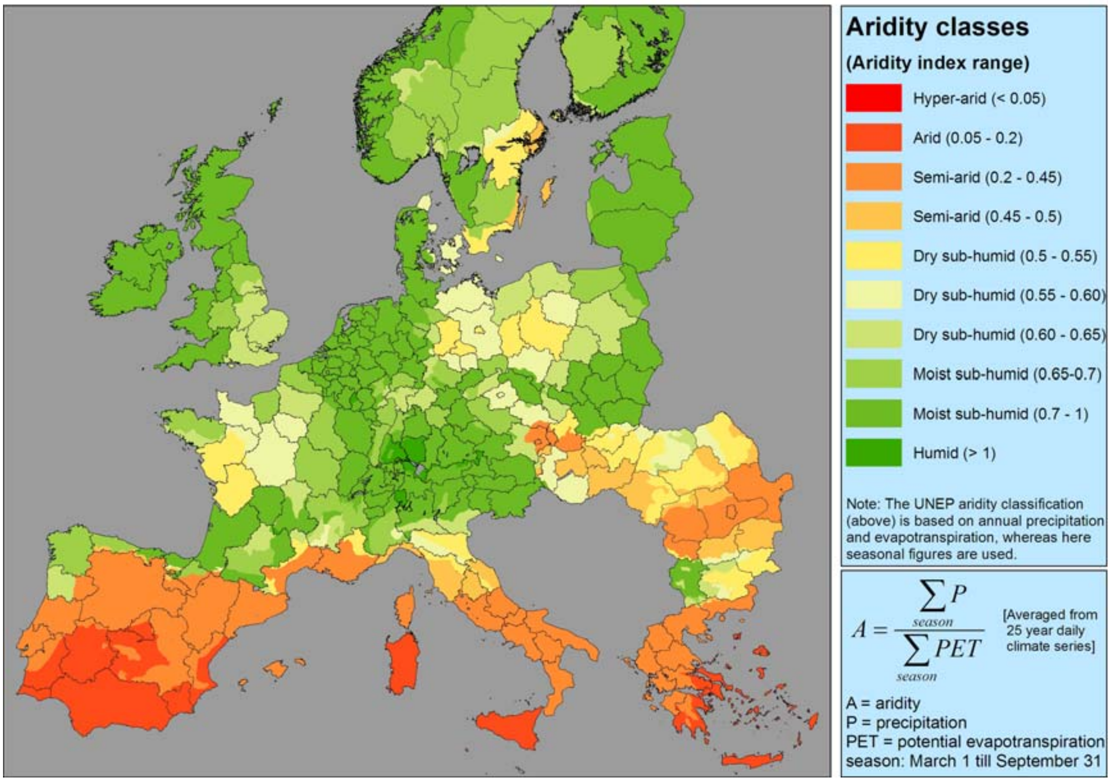
Irrigation is initiated based on a PAW threshold in the rooting zone (with a minimum of 0.4 m). The PAW threshold is 80% for water-sensitive crops (potato, sugar beet, maize, soya) and 60% for less water-sensitive crops (other crops). For alternative irrigation management the PAW threshold values can be changed by the user. The amount of water applied per irrigation event equals the total amount of water divided by the maximum number of irrigation events, which both are provided in the simple survey, or can be specified in alternative management.

For current irrigation management time windows, in which irrigation is possible, are defined based on crop phenological stages. As these irrigation windows will be longer in more arid regions, irrigation windows have been defined based on regional aridity. For that, per agri-environmental zone an aridity index has been calculated (Equation 3) and stored in the database (Figure 3.3):

$$A = \frac{\sum_{years} \frac{\sum_{season} P}{\sum_{season} PET}}{years} \qquad (3)$$

With P being the seasonal precipitation (in mm) and PET being the seasonal potential evapotranspiration (in mm). The season refers to the period March 1 to September 31.

Figure 3.3: Map of aridity index across Europe (black borders indicate NUTS2 regions)



The use of regional aridity values for defining irrigation windows enables adapting the length of the irrigation window to regional conditions. For maize, for example, in northern Europe the irrigation window spans only summer, while in southern Europe it can span most of the crop growth period. Currently, only more humid (aridity index ≥ 0.5) and more arid (aridity index < 0.5) regions are distinguished (Table 3.1).

Instead of using phenological stages, alternative management irrigation windows can be specified in absolute terms, i.e. with fixed start and end day. Amount of water can be current water use from the Simple Survey, or a user defined value.

Table 3.1: Crop irrigation windows (development stages: 0-2) in two types of aridity regions

Crops / Crop groups	Arid & semi arid	Dry sub-humid to humid
Maize, sorghum	0 – 2	0.8 – 2
Sunflower	0 – 1.8	0.8 – 1.8
Cereals	0 – 1.8	0.8 – 1.8
Rape	0.8 – 1.8	0.8 – 1.8
Sugar beet	0 – 2	0 – 2
Peas	0.2 – 1.2	0.2 – 1.2
Soybean	0.9 – 1.8	0.9 – 1.8
Potato	1 – 1.6	1 – 1.6
Seed potato	none	1 – 1.6
Cotton	0 – 2	1 – 2
Rice	0 – 2	0 – 2

3.2.4 Fertiliser management

Fertiliser management is only specified for inorganic fertiliser, applied by broadcasting as ammonium nitrate. Organic fertilisation is not taken into account.

The amount of fertiliser specified is split in a number of applications during the growing season. For each crop or group of similar crops a set of fertiliser splits has been developed based on existing fertiliser recommendations. The amount of fertiliser determines the number of splits, for example, if the fertiliser amount is limited the total amount is given in one split, if it is more than a crop-specific amount more than one split is needed (Table 3.2). The timing of the fertiliser splits depends on the crop phenological stage.

Table 3.2: Fertiliser splits for all simulated crops

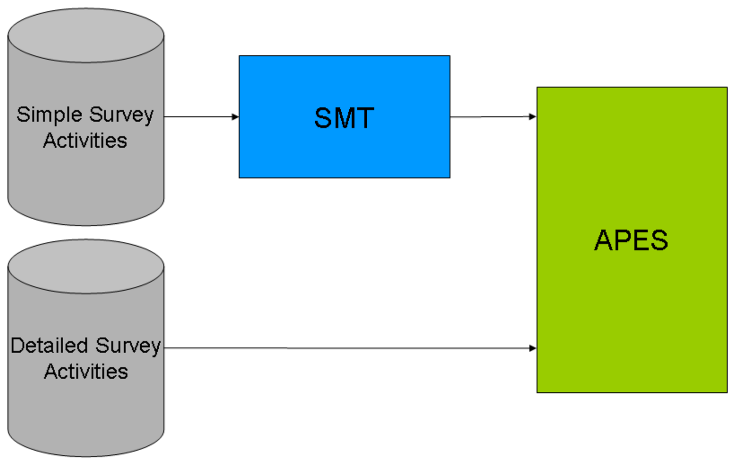
Crops / Crop groups	Nitrogen limits (kg/ha)	Development stage	Split fraction
Maize, sorghum, sunflower	<150	0	1
	>150	0 0.8	1/3 2/3
Cereals	<100	0.7	1
	100-150	0.2 0.7	4/10 6/10
	>150	0.2 0.7 0.9	3/10 4/10 3/10
Rape	<100	0.8	1
	100-170	0.3 0.8	3/10 7/10
	>170	0.3 0.8 1	3/10 4/10 3/10
Sugar beet	<120	0	1
	>120	0 0.5	2/3 1/3
Potato	<150	0	1
	>150	0 1	2/3 1/3
Leguminous crops	No nitrogen fertilisation		

3.3 Use of the SMT component

The SMT component is part of model chains using Simple Survey data to run APES. After the 'translation' of survey data by the SMT component a complete set of detailed management data is available to run APES.

A separate simulation path is available for regions where Detailed Survey data is available. In this case, the survey data can be directly fed into the wrapper of APES, and the SMT component is not used (Figure 3.4).

Figure 3.4: Relationship of SMT component, survey data and APES



4 Production Enterprise Generator

4.1 Conceptual approach

The production potential of crops and the type and amount of required inputs to attain a given yield in a particular environment depend on the production technique of each crop and 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.

PEG is a tool to generate a feasible set of production enterprises (crop rotations) of the farm based on crop suitability filters, such as soil and climate characteristics and for annual arable crops rotation suitability filters (or for animal husbandry systems herd composition constraints). The PEG aims to design production enterprises in a coherent transparent and reproducible 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 or desirable. The PEG contains a number of 'crop and rotation suitability filters' that limit in an early stage the number of crop rotations for which production techniques need to be defined and that limit the number of simulations to be carried out by APES. The 'crop and rotation suitability filters' are a set of rules and parameters that filter out any options that are not possible from an agronomical point of view. These 'crop and rotation suitability filters' can be adapted according to the policy question analyzed and to a specific context, and may include also more farm economic constraints. For example, the unavailability of machinery at a farm may inhibit the production of certain crops, and rotations with these crops can be filtered out in an early stage in the PEG. A machinery constraint within FSSIM-MP could also take the unavailability of machinery into account, although at a much later stage.

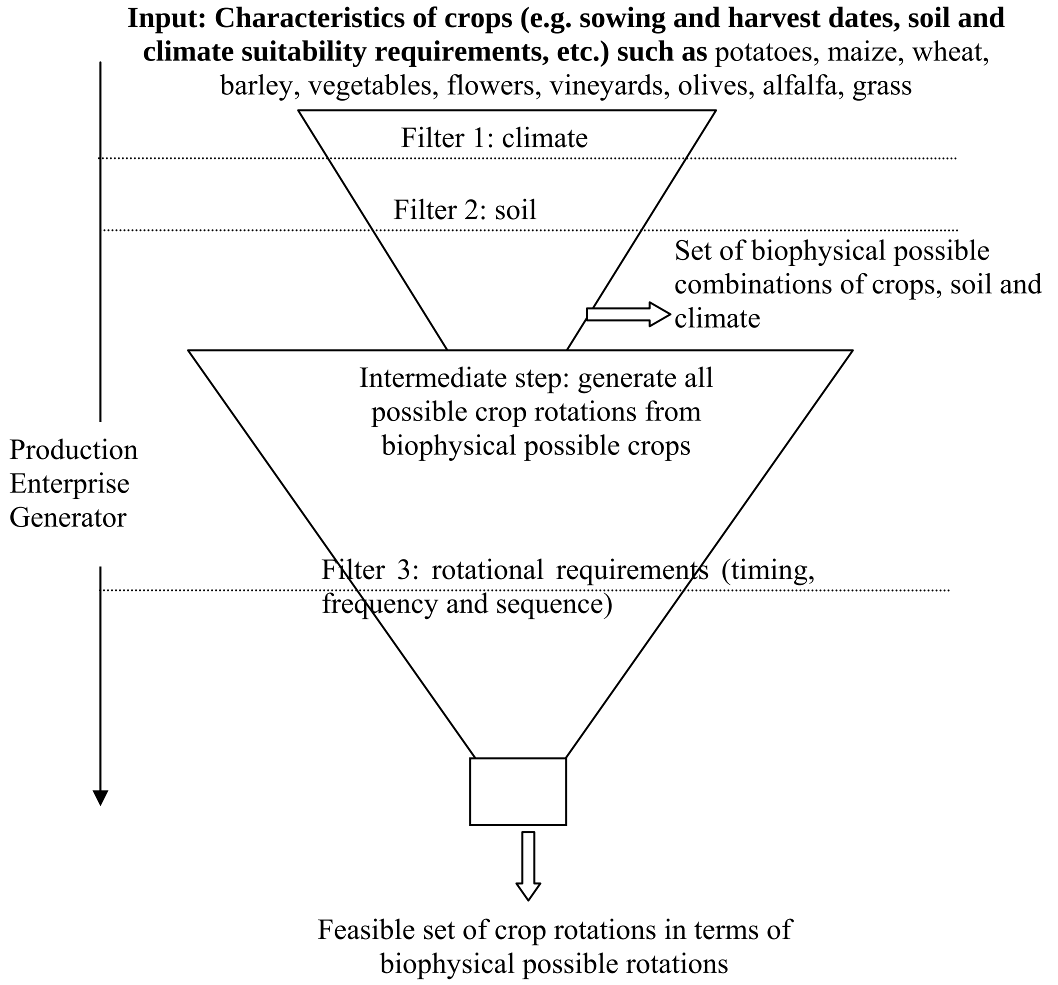
A delicate balance needs to be guarded in the application of crop suitability filters and rotation filters to a set of possible crops or rotations. For example, about 25 farmers in the Netherlands have vineyards producing wine grapes for a niche specialty market, for which consumers are willing to pay 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, but in our approach these kind of crops can be incorporated as these will be ultimately assessed in the FSSIM-MP or any other farm level model. Hereby we ensure that we do not omit potentially promising alternatives in an early stage, while keeping the data requirements manageable and not going to the extreme of including all possible crops and rotations resulting in a model that is too big and impossible to handle.

Production enterprises are constructed from a feasible set of crops in a two step procedure (Figure 4.1): The first step selects from a list of available crops, those crops, that are possible given well-defined soil-climate characteristics of a certain spatial unit (crop suitability filters). The second step generates on the basis of this list with suitable crop-soil-climate combinations production enterprises subject to a number of restrictions on crop successions (rotation filters). The result of this two stage procedure is a set of possible crop production enterprises for a given soil type and climate of a certain spatial unit.

In a later stage also socio-economic filters could be added to the PEG to reflect for example the investment possibilities farmers have or their preferences for certain activities. A farm with low credit availability cannot choose activities with high capital requirements in terms of investments or variable costs and these activities could be filtered out. This last aspect of farm resource endowments is one of the characteristics of the representation of farm types in a farm typology (on the basis of size, intensity and specialization), which might have implications for the set of activities considered to a specific farm type.

In this section first an example is given of the procedure used in the PEG followed by an explanation of the crop suitability filters (Section 4.2) and the rotation filters (Section 4.3).

Figure 4.1: Overview of the PEG and the internal information flow



An example of the procedure within the PEG is[1] (Figure 4.2):

Step 1. Characterization of the biophysical environment (soil + climate) for one specific region from the biophysical typology and identification of all possible crops.

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 (results filter 1) 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.

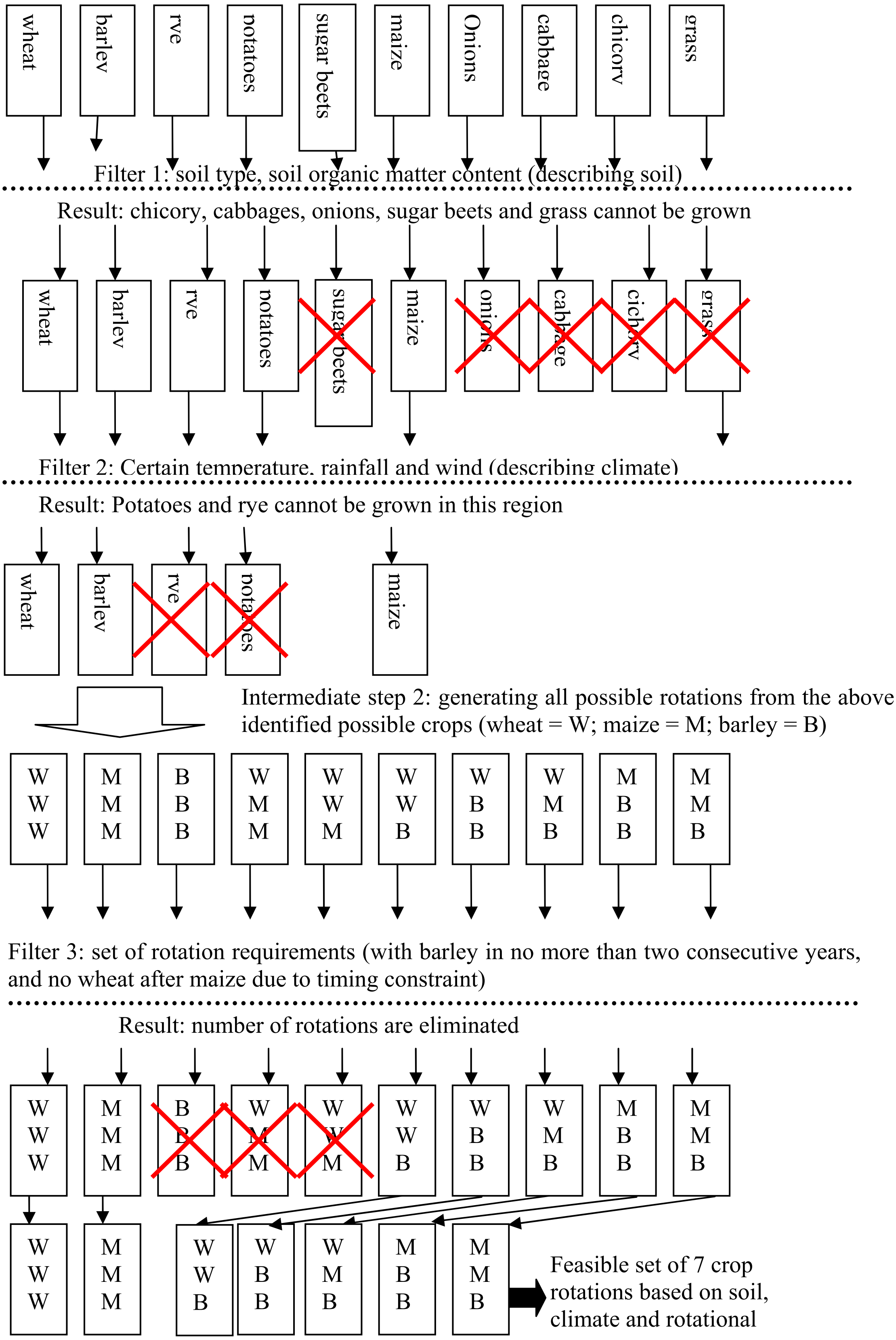
[1] This is an example, like all other examples in this paper it is not tried neither to be complete nor comprehensive in the inclusion of all relevant factors nor to achieve a close correspondence with reality.

Step 2. (Intermediate): Generating possible rotations on the basis of possible crops generated through soil and climate constraints.

Filter 1. Rotation requirements (timing, frequency and sequence), which in this example exclude enterprises with barley in more than two consecutive years, and enterprises with wheat after maize (due to winter wheat being sown in early autumn, when it can not be ensured that maize has already been harvested).

Step 3. Result: Feasible production enterprises given soil, climate and enterprise limitations; in this example 7 feasible production enterprises are identified.

Figure 4.2: An example of the application of the production enterprise generator



4.2 Crop suitability filters

Whether a crop can be grown in a certain region depends on regional climate and soil characteristics (see filter 1 in Figure 4.2). Through the 'crop suitability filters' we eliminate crops that are not possible in the first place and secondly, we design a set of activities that are feasible (even at low output, high pollution levels, or if not societal desirable). Crop requirements will be defined for a list of crops. In a two step procedure, these crop requirements will be confronted with, firstly climate data and secondly soil data. Considering the limitations and uncertainty of the EU soil data, it is doubtful whether appropriate compound filters can be identified, for example, the exclusion of poorly drained soils only when also the rainfall pattern is unfavourable as proposed by Reinds *et al.* (1992).

4.2.1 Soil Requirements

Starting point in the suitability screening is the establishment of a database with the properties of the land units, which need to be evaluated. The EU soil database has a grid scale of 1 to 1 km and needs to be combined with a climate map to identify land units characterized by both soil and climate properties. Subsequently, these land units can be screened on their suitability to grow a crop. During the project, we have to evaluate whether these soil-crop characteristics are appropriate considering the limitations of the European soil database for EU-25 countries, i.e. differences in the details of mapping, the use of ambiguous soil type definitions, uncertainty in derived pedotransfer functions, etc. (Van Diepen, 2005)

In the SINFO project[2] Alterra and INRA aimed to define a set of soil suitability rules for each major crop group (Alterra and INRA, 2005). The parameters used in the SINFO project are rooting depth, slope, and volume of stones, texture, drainage, salinity and sodicity (alkalinity). However, they conclude that *'the application of uniform soil unsuitability criteria across Europe is possible only for the broad selection of the least productive soils on the basis of extreme adverse soil conditions. Any refinement in criteria in order to focus on the soils of the most important centres of agricultural production leads to inconsistent selections of soils across Europe, due to a lack of uniformity in the soil map of Europe between the countries. It is in particular not justified to apply crop group specific or even crop specific sets of unsuitability criteria, as the differences in criteria are rather small, while the precision of the soil indicators derived from the soil map is rather low.'* In the SINFO project uniform criteria were used, however due to incompatibility of the soil maps of different countries in the European soil map the suitability results were not uniform. It will be difficult to exclude crops on certain soils on the basis of the European soil map. A country-specific approach should be used, which is laborious.

A comprehensive mixed qualitative/quantitative land evaluation procedure has been carried out for the EU-12 as part of a larger study on production potentials of various crops within the EU (Reinds and Van Lanen, 1992). In the study of Reinds *et al.* (1992) three crop groups have been identified, i.e. cereal crops, root and tuber crops and (intensively managed) grassland. For each group a set of soil parameters have been identified representing the minimum crop (group) requirements (Table 4.1). If a given land evaluation unit (i.e. combination of soil type, agro-climatic and administrative region) does not meet one of the requirements of a specific crop group, it is assumed to be unsuitable for that crop group. These rules implicitly take the production technique into account, for example, the type of grassland management. For the vast grassland area extensively managed in the EU, these rules probably should be released or a different crop group should be added. Also the rules

[2] The SINFO project concerns the development of a framework for incorporating the latest version 4.0 of the Soil Geographical Database of Europe (SGDBE) in the Crop Growth Monitoring System (CGMS), see also http://agrifish.jrc.it/marsstat/related_projects/sinfo.htm

for the other crop groups seem to be based (implicitly) on mechanized production techniques. If altitude is a property of the soil/terrain unit, this could act as additional filter.

Table 4.1 Crop requirements with respect to soil characteristics (Reinds and Van Lanen, 1992)

Requirements for grassland (intensively managed)	
Texture	< 60% clay (EC fine or coarser)
Slope	< 15%
Drainage	Better than very poor
Rooting depth	> 10 cm
Phase	Gravelly and concretionary phase allowed
Salinity	No excessive salinity
Alkalinity	No excessive alkalinity
Requirements for cereals	
Texture	< 60% clay (EC fine or coarser)
Slope	< 15%
Drainage	Better than temporary poor
Rooting depth	> 10 cm
Phase	Gravelly and concretionary phase allowed
Salinity	No excessive salinity
Alkalinity	No excessive alkalinity
Requirements for root crops	
Texture	< 35% clay (EC fine or coarser)
Slope	< 15%
Drainage	Better than temporary poor
Rooting depth	> 10 cm
Phase	No phase allowed
Salinity	No excessive salinity
Alkalinity	No excessive alkalinity

Fischer *et al.*, (2002) used a different approach by identifying classes of constraints covering the entire world, i.e. suitability ratings are defined for combinations of soil unit, crop and inputs/management. In this study the production technique explicitly determines the level of suitability of a soil-crop combination. The constraints are tighter at a higher input level, i.e. the (qualitative) suitability rating is lowered compared to a low input system. Although the approach with suitability ratings is not very appropriate within the quantitative SEAMLESS framework, the study of Fischer *et al.* (2002) contains an interesting database on soil characteristics and suitability criteria which may be useful as comparison to our set of minimum requirements to be defined.

Based on crop requirements as mentioned by Reinds *et al.* (1992), 7 crop suitability filters with respect to soil (Appendix 1) were developed and will be further evaluated on the quality of their results after applying the filters to 2 to 4 sample regions. Also, it could be considered to link crop suitability filters to regions or crops, so that not in all regions or for all crops all crop suitability filters are applied.

4.2.2 Climate Requirements

Crops have certain climate requirements and these can be compared to location-specific climate data. Climate data are generally available over long time periods and can be flexibly used in different formats (Van Diepen, 2005).

Climate factors of importance in crop production are, for example:

- Temperatures (maximum and minimum)
- Frosts (number, duration and severity)
- Heat waves (duration and probability of occurrence)
- Rainfall (amount and distribution)
- Relative humidity (seasonal variation)
- Wind (direction, strength and seasonal occurrence)
- Hail (seasonal occurrence)
- Storms and cyclones (seasonal occurrence)

Regional crop calendar tables exist that specify crop suitabilities. However, quantitative knowledge on how climate factors constrain crop production is limited. In addition, information on the climate factors is not evenly available throughout Europe. Therefore, we may focus on the most determining factor(s) for which knowledge and data are available.

In the Crop Growth Monitoring System (CGMS) (Alterra and INRA, 2005), the accumulated mean temperature above a crop-specific threshold temperature (temperature sum) is used as a requirement to complete a full phenological crop cycle from emergence to maturity. There is also an upper average daily temperature above which daily temperature sum does not increase any longer. The CGMS is linked to the crop growth simulation model WOFOST (Boogaard *et al.,* 1998), which distinguishes two development phases: from emergence to flowering and from flowering to maturity. In the model both development phases are represented by temperature sum requirements TSUM1 and TSUM2, respectively, both measured in an number of day degrees (°C.d[3]). Every day the mean temperature is above the minimum required temperature (TMIN) for a specific crop, the difference between the mean temperature and minimum temperature is added to the accumulated temperature sum (TSUM). The accumulated temperature as defined by TSUM1 must be met to reach flowering, and TSUM2 must be met to reach crop maturity. In SEAMLESS, we only use one TSUM value, which is TSUM1 plus TSUM2 for reasons of simplicity. Since WOFOST, a crop growth simulation model used within CGMS, does not simulate the growth period in autumn and winter for winter crops, temperature sum requirements are calculated from January 1. For winter crops grown in NW Europe this date can be considered an approximation of emergence, as crop growth during the preceding autumn and winter is negligible. For winter crops grown in Southern Europe, it is less appropriate to consider 1st of January as an approximation of emergence, as the crop growth of such crops is substantial during autumn and winter (Wolf *et al.,* 2004). For our purpose, i.e. identification of unsuitable (i.e. too cold) climate conditions, still TSUM calculations starting from January 1 can be used, because TSUM requirements in Southern Europe will be met anyway. However, for summer crops always a region-specific sowing date needs to be known and used in the calculations.

Temperature sum requirements of, for example winter wheat, show a decreasing gradient going north in Europe, associated with the use of different varieties. In general, spatial

[3] As temperature sum is an accumulated temperature over a time period, it can be expressed as °C. Here the .d, which signifies days, is added to indicate that it is an accumulated temperature over days.

variability in TSUM2 (grain filling phase) is less than in TSUM1 (vegetative phase) (De Wit *et al.,* 2004). Note that even within climate zones considerable differences may occur in these parameters due to differences in altitude (see also below).

Within the PEG, we only need to identify northern crop borders above which the given crop is not found. In principal, there may also be southern borders as the temperature may be too high for a crop, but such information is not always available.

Country-and sometimes region (NUTS1)-specific TSUM values are given for different crops in (Boons-Prins *et al.,* 1993) (Table 4.2). Such TSUM values can be derived from experimental data sets given that dates of emergence, anthesis and maturity, and mean daily temperatures are known. However, large variations for winter wheat have been reported within country due to climate variation (Wolf *et al.,* 2004). Also largely unexplained variation between countries has been identified, which may be attributed to the used expert knowledge and TSUM calculated from mean climate databases. The values shown in Table 4.2 are based as much as possible on the reported lowest TSUM values which are required to fulfil a complete crop cycle. Lower crop requirements in terms of TSUM are more easily met under cooler conditions (Northern Europe), as less degree days are needed. The threshold temperatures (TMIN and TMAX) signify that mean daily temperatures below TMIN do not contribute to the accumulated TSUM, while contributions of mean daily temperatures above TMAX to the TSUM are limited to the difference between TMAX and TMIN.

Table 4.2: Minimum TSUM (°C.d) and threshold temperatures (TMIN and TMAX) values (in °C) for a range of crops

Crop	TSUM1	TSUM2	TMIN	TMAX	Source/comment
Winter wheat [1]	800	750	0	30	Wolf *et al.* (2004); For Southern Scandinavia
Spring barley	620	750	0	30	Wolf *et al.* (2004); For Southern Scandinavia
Rice	875	620	10	25	Boons *et al.* (1993); For Southern Europe
Sugar beet	650 [2)]	1400	3	21	Boons *et al.* (1993); For NW Europe
Potato	150 [3)]	1550	2	13	Boons *et al.* (1993); For NW Europe
Grain maize	695	800	6	30	Boons *et al.* (1993); For Germany
Field bean	461	946	0	20	Boons *et al.* (1993); For North UK
Soybean	350	850	7	30	Boons *et al.* (1993); For North France
Winter rapeseed	240	600	4	35	Boons *et al.* (1993); For NW Europe
Sunflower	624	770	2	18	Boons *et al.* (1993); For West France

[1)] Lower values are given for the mountainous areas of Bosnia, Serbia and Eastern Turkey and other high altitude zones, but are questioned as wheat is grown on sunny/warmer sites of mountains while mean (cool) climate conditions are used in the TSUM calculations.
[2)] Indicates temperature sum from emergence to secondary tap root growth.
[3)] Indicates temperature sum from emergence to 150 °C.d.

These TSUM requirements can be supplemented with two other rules to avoid too late and unrealistic harvest dates, particularly in cooler regions of northern Europe (Wolf et al., 2004): a maximum growth duration and a fixed end date for harvesting. Both rules indicate that beyond the specified dates the harvested grains are not yet mature. Hence, when TSUM requirements are not met before the specified date, the given region-crop combination is classified as unsuitable. Table 4.3 contains some data for both additional rules.

Table 4.3: Maximum growth duration and end date for harvesting (Julian days, e.g. the number of days relative to another date. For example, the number of days between 1 January and 1st of March is 59, so 1st of March = Julian day 59)

Crop	Maximum growth duration	End harvest date	Source
Winter wheat	300 (from January 1)		Wolf *et al.*, (2004)
Spring barley	200 (from emergence)	275 (October 1)	Wolf *et al.*, (2004)

For summer crops region-specific sowing dates will be required to identify suitable crop-climate combinations. Boons-Prins *et al.* (1993) give for EU-12 at NUTS 1 level sowing dates for the crops shown in Table 4.2. GISAT (2003) gives sowing dates for the same and other crops at national level for 3 candidate countries (Bulgaria, Romania, Turkey) and 8 new member states (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Slovakia, Slovenia, Poland). Currently, information is lacking for Sweden, Finland, Austria, Malta and Cyprus.

In addition to the TSUM rules, altitude may be an appropriate filter in mountainous regions (Russel, 1990; Wolf *et al.,* 2004) to account for low temperatures, risks of climatic hazards (e.g. excess of water) and lack of suitable land in such areas. Low temperatures in mountains are not readily identified using observed weather data as such data may not account for the spatial variability in temperature due to altitude differences. High altitude zones may be identified using detailed Digital Elevation Maps (DEMs) and can be used as approximations of low TSUM zones. Wolf *et al.* (2004) suggested for winter wheat 2000m and for spring barley 1500m as upper altitude. Russel (1990) gives for barley in the EU-12 altitude maxima ranging from 2000m in the South of Spain to 140m in Denmark.

Additional filters suggested by Wolf *et al*. (2004) are low and high rainfall areas (possibly corrected for potential evapotranspiration). Since, we consider irrigation as one of the management options, exclusion of low rainfall areas seems less desired, but high rainfall may be an alternative filter. High rainfall limits product quality and, for example, results in (cereal) grains with too high moisture content, and reduces the number of workable field days during harvest.

In the quest for identifying potential climate filters, various issues come to mind: what are key climate factors limiting crop production, the adaptability of varieties of the same crop to different climate conditions and how to deal with inter-temporal variability, i.e. in some years crop requirements can be met while in other years not. Average weather data sets are used to identify unsuitable climate zones for particular crops. This means that in some years weather conditions still may allow the cultivation of a given crop, but on average yields will be low. We think that such marginal areas are not of interest for overall production within the EU (and thus for SEAMLESS), unless there are explicit indicators that breeding advances will overcome such constraints in the near future.

4.3 Rotational suitability filters

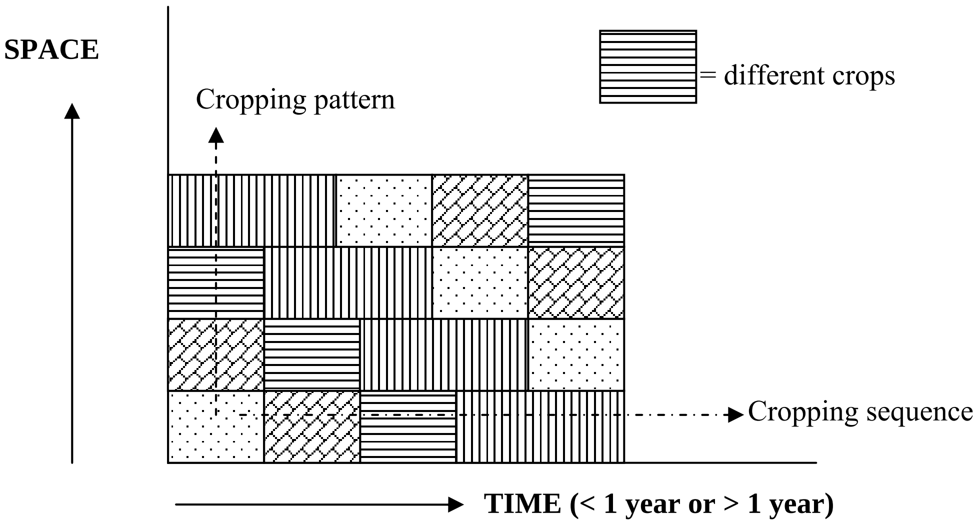
4.3.1 Rotations vs. Crops

FSSIM, the mathematical programming farm model, used within SEAMLESS is based on Linear Programming (PD3.3.11/PD3.3.8). An issue is whether agricultural activity modelling is done on the basis of crop or rotations, i.e. generate rotations outside the model or within the model. In a static LP-model (linear programming model) like FSSIM it would be better to offer rotations to the model. In contrast, in dynamic LP models it would be better to offer individual crops allowing the model to generate rotations. In the following a discussion is presented on modelling at crop or at rotation level (and some advantages and disadvantages of both approaches are identified with respect to FSSIM.

4.3.2 Background

A rotation[4] is defined as a sequence of crops in time and space, where the last crop is the predecessor of the first crop (creating a loop). The succession of crops over time is called cropping sequence, while the spatial distribution of different crops during the year is called a cropping pattern. A simple representation of this succession of crops in space and time is given in Figure 4.3 (Ewert, 2004).

Figure 4.3: Representation of a rotation as a combination of a cropping pattern and sequence in space and time



The model should be able to produce both the cropping sequence and cropping pattern in one year. Two approaches are possible:

1. **offer individual crops to the model**: each crop forms an activity and the LP model chooses a certain set of crops (activities) through the optimization procedure subject to rotational constraints, in other words the cropping pattern is the result of the optimization procedure. The cropping sequence is not necessarily determined, which depends on the incorporation of time as is discussed in the next Section 4.3.3. The cropping pattern is determined by the Linear Programming model, as for the total area of the farm a (limited) number of crops are selected. A farmer usually can handle only a limited number of different crops on his farm.

[4] Here only rotations are explicitly discussed, but similar issues refer to herds

2. **offer rotations to the model**: Each rotation forms one activity and the LP model chooses a feasible rotation in the optimization procedure. In other words: both the cropping sequence and cropping pattern are the result of the optimization procedure. Rules for defining rotations (e.g. considering suppression of diseases, nutrient use, etc.) are used to create rotations outside of the LP model. Within this procedure of creating rotations, the rotation length determines which rotations are feasible, as the farmer will choose his rotation length according to his preferences. This can be captured by the production orientation (Chapter 2).

4.3.3 Static versus dynamic LP model.

When offering individual crops to a LP model the cropping sequence is not necessarily established (although the cropping pattern is through optimisation). In this Section the possibility to generate a cropping sequence, when offering individual crops to the LP model will be explored. It will be argued that the type of LP model, i.e. dynamic or static, determines the possibility to generate cropping sequences. First, the difference between a dynamic and a static model will be explained. Then both model types will be discussed with respect to the possibility to construct a cropping sequence in case of offering individual crops. On the basis of this discussion a preliminary conclusion will be drawn.

A dynamic model explicitly takes account of time as some of the decision variables are functions of time, while a static model does not explicitly take account of time (Blanco Fonseca and Flichman, 2002). Of interest here, is the difference between models optimizing over just one year or period (with one time step) (= static) and models optimizing over a time horizon of a number of years with several time steps (= dynamic).

When crops are offered to **a dynamic model**, the cropping sequence follows from the sequence of crops selected for the consecutive growing seasons during optimization over the whole time horizon[5]. In a dynamic model the cropping pattern and sequence should be flexible so that farmers can adapt cropping patterns and cropping sequence between two growing seasons (Belhouchette *et al.,* 2005). In this case, the crop sequence is determined by the LP model through the annual selection of a cropping pattern. However, the crop areas in the cropping pattern are constrained to be equal between two years, thus creating a fixed cropping pattern over the years: ‘the area of each crop in the second year is equal to the area allocated to allowed previous crops during the first year’ (Belhouchette *et al.,* 2005). If a dynamic model would be initialised every year with the same values, such as prices and weather conditions, the cropping pattern and cropping sequences would be the same each year. It would also be possible to work with rotations in dynamic models, only year specific yields and environmental effects of the crops within the rotation would have to be available in the LP model.

In **a static model** (with a single time step) the cropping sequence is not automatically determined by the succession of crops over the optimization years as the optimization is only carried out over a single time step and subsequently no succession over the years exists. To determine the cropping sequence in a static model, an assumption has to be made: the cropping sequence is equal to the cropping pattern. If the cropping pattern is wheat-barley-potatoes, this is also the cropping sequence. Consequently, the static model has to

1. capture the temporal interactions between the crops, e.g. the interactions between wheat and barley, between barley and potatoes and between potatoes and wheat. This can be done by accounting for the impact of a crop grown in previous years (previous crop) on the crop that is currently grown (current crop), implying that each activity in the LP should hold information on the current crop and possible previous crops and

[5] Provided that different activities for the same crop are offered for the different possible previous crops

their effects. By adding previous crops for each current crop, extra sets of activities and coefficients are created, as more information needs to be given to the LP model and as a barley crop with wheat as a previous crop is a different activity as a barley crop with potatoes as a previous crop An example of linking previous crops with current crops is described by Gibbons *et al.* (2005), who constructed pairs of crops (two year crop sequences), which were offered to the LP model. A set of constraints should then dictate which crops are incompatible as a previous and a current crop. Other constraints should link the feasible combinations of previous and current crop to a complete cropping sequence.

2. allocate areas to the crops in the cropping pattern, which are proportionate, for example, 1/3 of the total area under wheat, 1/3 under barley and 1/3 under potatoes. Otherwise the cropping sequence cannot be equal to the cropping pattern, as the cropping sequence would be different on a part of the farm area. For example if the model allocates 1 hectare of wheat, 1 hectare of barley and 5 hectares of potatoes, this would imply that 3 hectares of potatoes in the current year will again be potatoes in the next year, while the cropping sequence should actually be wheat-barley-potatoes instead of potatoes-potatoes.
   The areas assigned to each crop in the cropping pattern should thus be proportionate, in other words a cropping pattern with 5 ha of wheat, 5 ha of barley and 5 ha of potatoes could also be the cropping sequence, as the next year the area devoted to each crop does not change. The constraints of the model should make sure that these crop areas are equal to each other.

A large set of constraints with integers and binary variables should be built to capture the temporal interactions and allocate equal areas to each crop. It is a complex and rather cumbersome task to build such a set of constraints and it does not enhance model flexibility. Even if the correct set of constraints is constructed, probably only the interaction between the current crop and previous crop can be taken into account and not the interaction between the current crop and the crop of two years ago. Also, if FSSIM needs to be applied in many different locations, it is laborious to adapt the constraints of the model every time, thus creating a specific model for each location.

In short, it is complex to generate a cropping sequence using individual crop activities in a static LP. At the same time, the cropping sequence has large effects on productivity, economic and environmental performance.

The decision on whether to offer rotations or crops to the LP model depends on the type of LP-model (static or dynamic) and on some other issues. An overview of the advantages and disadvantages of the two approaches is given below:

1. Crop level:
   - Advantages
     i. The LP-model selects a cropping pattern on the basis of individual crops, which is theoretically sound. Whether this cropping pattern also defines the cropping sequence depends on whether the model is static or dynamic or whether interactions are mimicked via constraints.
   - Disadvantages:
     i. The LP model becomes very complex as all constraints to get a feasible sequence of crops need to be incorporated in the LP model. In other words, filters in the form of constraints need to be incorporated to avoid infeasible cropping patterns and to consider interactions (compare the discussion on filters in the earlier note).
     ii. Long solution time of the LP model due to the increased complexity.

iii. The cropping sequence can be generated in a dynamic model, however development of a dynamic model is more complex than a static model.

iv. If the cropping sequence in a static model is generated via a set of constraints, then these constraints need to be adapted for every location, which is laborious and makes the model location specific.

2. Rotation level

- Advantages:

  i. Modular approach: first rotation design tool and then optimization procedure, which enhances the transparency of the followed approach.

  ii. By offering rotations to the static LP model, temporal interactions between crops can be incorporated in the rotation, as these temporal interactions are modelled outside the LP-model in the PEG.

  iii. The LP model is less complex and requires less time to be solved.

  iv. Responsibility to construct valid rotations placed with production experts, who have the expertise.

- Disadvantages:

  i. Danger of missing out on feasible rotations, if the pre-screening is biased. However, in the crop approach this problem is moved to the LP-model in which constraints need to be defined taking care of the feasibility of rotations.

In conclusion, the choice for a static or dynamic LP model determines to a large extent the choice for rotations or crops in the optimization procedure. In a static model it is better to work with rotations, as then both the cropping sequence and cropping pattern can be established at once and temporal effects are taken into account. In a dynamic model, the activities can be offered at the crop level, as the model itself can establish the cropping sequence and cropping pattern. Developing a dynamic LP model at crop level is much more time consuming and leads to a more complex and larger model, but may represent better reality as farmers respond to external conditions by adjusting their rotations over time. APES calculates TCs for entire rotations, which have to be offered to the LP model. In PD3.3.11 a static LP is used for FSSIM-MP, which implies that it is better to offer rotations instead of individual crops as then temporal interactions can be incorporated in the rotations without creating an overly complex LP.

4.3.4 Description of the rotation suitability filters

Through crop suitability filters a predefined list of crops is generated that are possible given regional climate and soil characteristics (section 4.2). This predefined list can then be used to generate production enterprises subject to rotation requirements. The rotation generation tool is based upon ROTAT (Dogliotti *et al*., 2003), which 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. An adapted and extended version of ROTAT has been developed, which uses part of the ‘rotation filters’ of the original ROTAT. The following filters in ROTAT have also been implemented in the PEG (Appendix1):

1. Timing constraints

   1.1 Sowing and harvesting dates (Sowing and Harvesting Dates Filter; Appendix 1).

   1.2 Minimum intercrop period between the harvesting of one crop and the sowing of the next crop, needed for soil preparation. (Sowing and Harvesting Dates Filter; Appendix 1).

2. Sequence and frequency constraints

2.1 Restrictions on crop successions, i.e. that result in negative effects on physical, chemical and biological soil fertility; CropSequenceFilter; Appendix 1).

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. (CropFrequencyFilter, CropGroupFrequency filter, Crop Repetition Filter and Crop Group Repetition Filter; Appendix 1; Example: See Table 4.3 in Dogliotti *et al.* (2004).

3 Farm specific feasibility and applicability

3.1 Maximum length of crop rotation r. (Refers to the 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) (Maximum Number Of Different Crops Filter; Appendix 1)

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. This is part of ROTAT, but not of the PEG.

ROTAT is based on 12 Boolean checking functions, divided into three stages. The Boolean checking functions control whether a rotation meets the user-defined crop suitability filters. If the rotation does not meet the requirements of one of the Boolean checking functions it is rejected and changed to another rotation by changing the crop in the last position to the next crop on the list or by adding another crop at the end of the cropping sequence. An algorithm changes the rotation to a new rotation, when a certain rotation is rejected. A rotation is a closed loop of crops, so the first and last crop are equal. In ROTAT, one by one, the crop rotations are constructed and checked until all possibilities are exhausted. A similar algorithm is used in the PEG, which creates one by one all possible rotations from the list of crops. When a rotation is created, it is first evaluated using the rotation filters. If it is a suitable rotation, it is stored. Second, a new rotation is created from the set of all possible rotations.

Additional rotation filters (Boolean checking functions) could be introduced, such as economic constraints, for example less than three cash crops or only one high risk crop per rotation.

One optional rotation filter has been added which allows rotations having at least two crops with a lower frequency as the other crops in the rotation. This additional set of rotations is created because some crops have a lower frequency than 1/maximum rotation length, which would mean that these crops will not appear in any rotations. An option to incorporate these crops in a rotation is to grow one of these crops in the first loop through the rotation and then grow another crop during the second loop through the rotation: For example, a rotation could be Potato-Sugarbeet-WinterWheat-Pea/Flax, where pea and flax are the low frequency crops. In the first loop through the rotation the sequence is Potato-SugarBeet-WinterWheat-Pea, while in the second loop the sequence is Potato-SugarBeet-WinterWheat-Flax. The actual frequency of Pea and Flax is then once every eight years, while the actual frequency of the other crops is once every four years. A different way of saying the same would be that Pea and Flax are only grown on one-eight of the area, while Potato, Sugarbeet and WinterWheat are grown on one-fourth of the area.

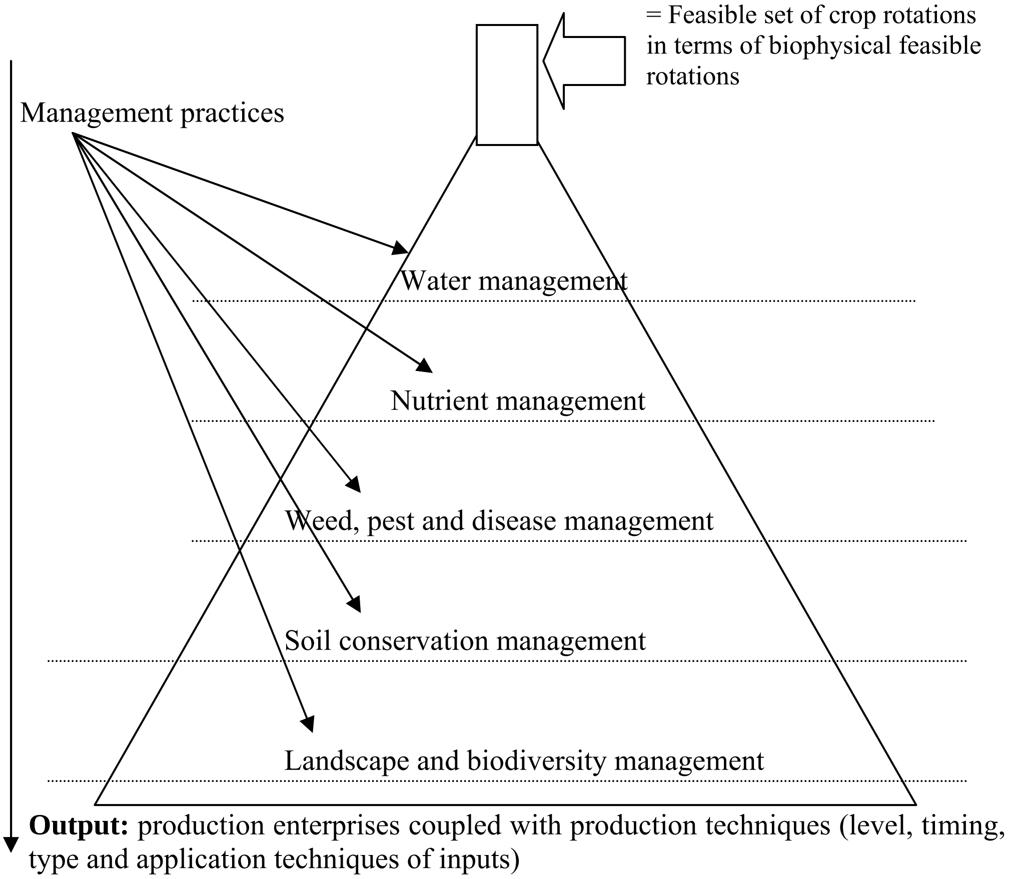
5 Production Technique Generator

5.1 Conceptual approach

The PTG is a tool to describe production techniques of agricultural activities for the feasible set of production enterprises. A production technique is a complete set of agronomic inputs characterized by type, level, timing and application technique (Van Ittersum and Rabbinge, 1997). The PTG combines different management practices to production techniques and takes out infeasible production techniques according to production orientations. Each management practice is characterized by a set of management aspects. There is a danger of too much detail and over-specification. Thus, it is important to determine the major inputs affecting outputs. The complete set of inputs consists of the following management practices (Figure 5.1):

- General Management
- Water management
- Nutrient management
- Weed pest and disease management
- Conservation Management (includes Soil conservation management and Landscape and biodiversity management)

Figure 5.1: Procedure within the Production Technique Generator



Each of these management practices consists of several aspects, for example, the method of application and the level of application (full replacement of water, e.g. 100% or allowing some water shortage, i.e. 50% of field capacity), the timing of the application (both time window and timing rule used, for example irrigate every 14 days starting from the 1st of July) and input type (for example, manure or fertilizers). Each production technique encompasses for each crop a set of different management practices, each of which can be characterized by such management aspects. The coherence between production technique, management practice and management aspects is shown in Figure 5.2 and Figure 5.3. For water management, an example of possible management aspects is shown. Figure 5.3 shows how production orientations can be linked to management practices and aspects, so that they combine internally logical management aspects of the different management practices.

One of the management aspects is the decision variable that depends on the preferences of the user and determines the level of application. The other management aspects describe the technical efficiency of the management based on application technique and type of input (e.g manure versus fertilizer). The technical variables determine the application efficiency and their values can be kept constant for different levels of the decision variable, allowing comparability. The PTG is based on an output-oriented approach, as levels of decision variables depend on target yield levels determined by water and nutrient availability.

Figure 5.2: coherence between production technique, management practice and management aspects

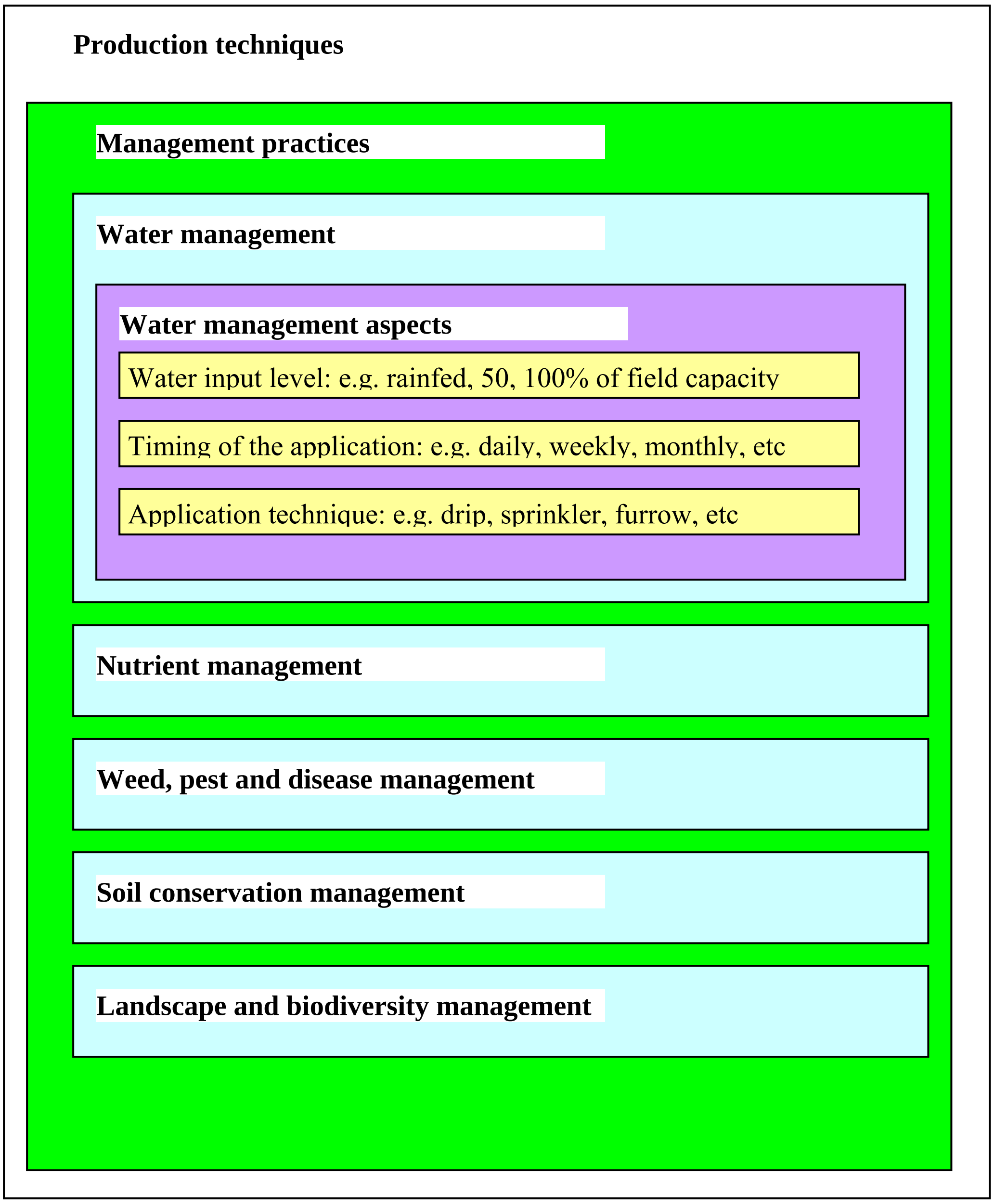
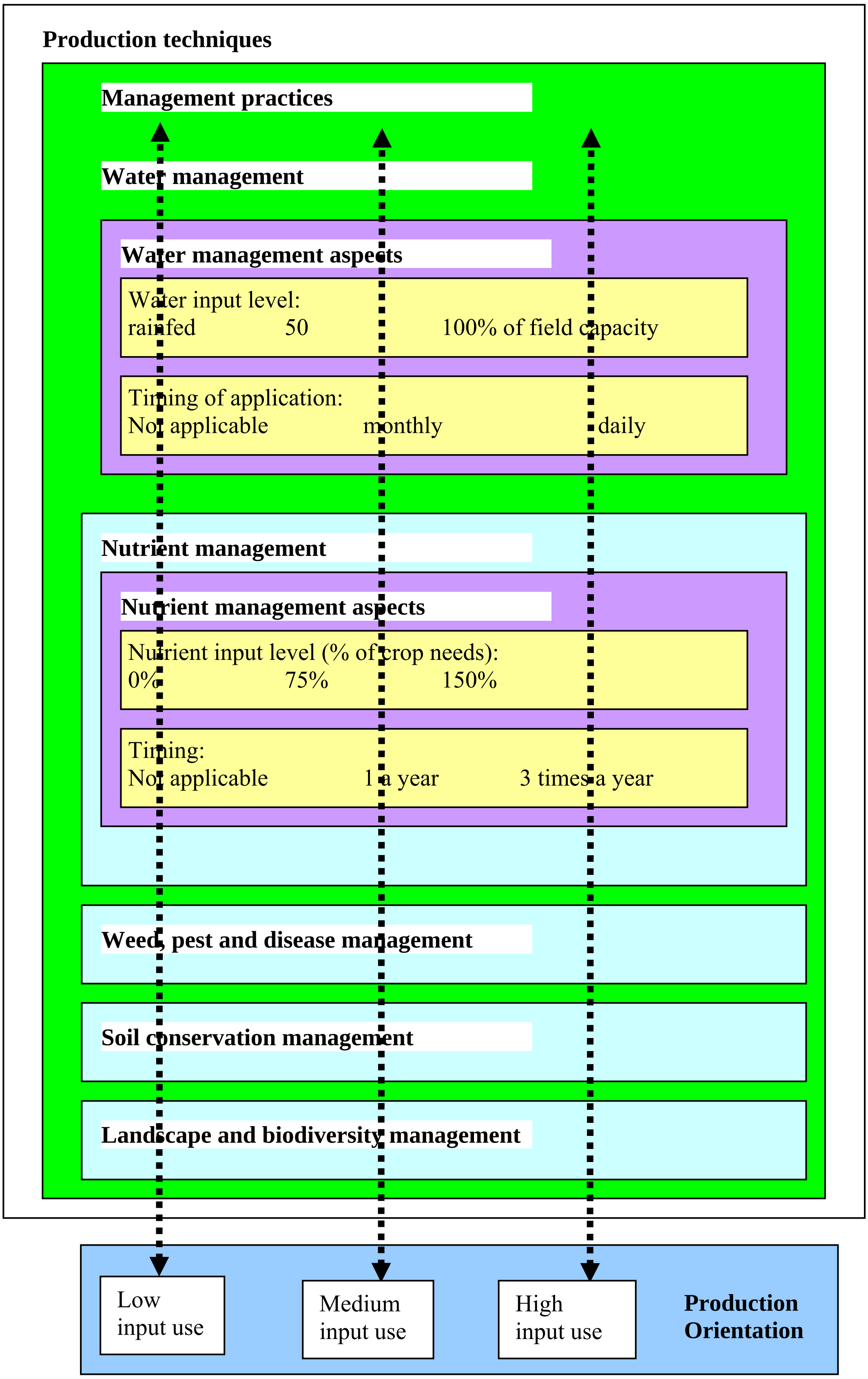


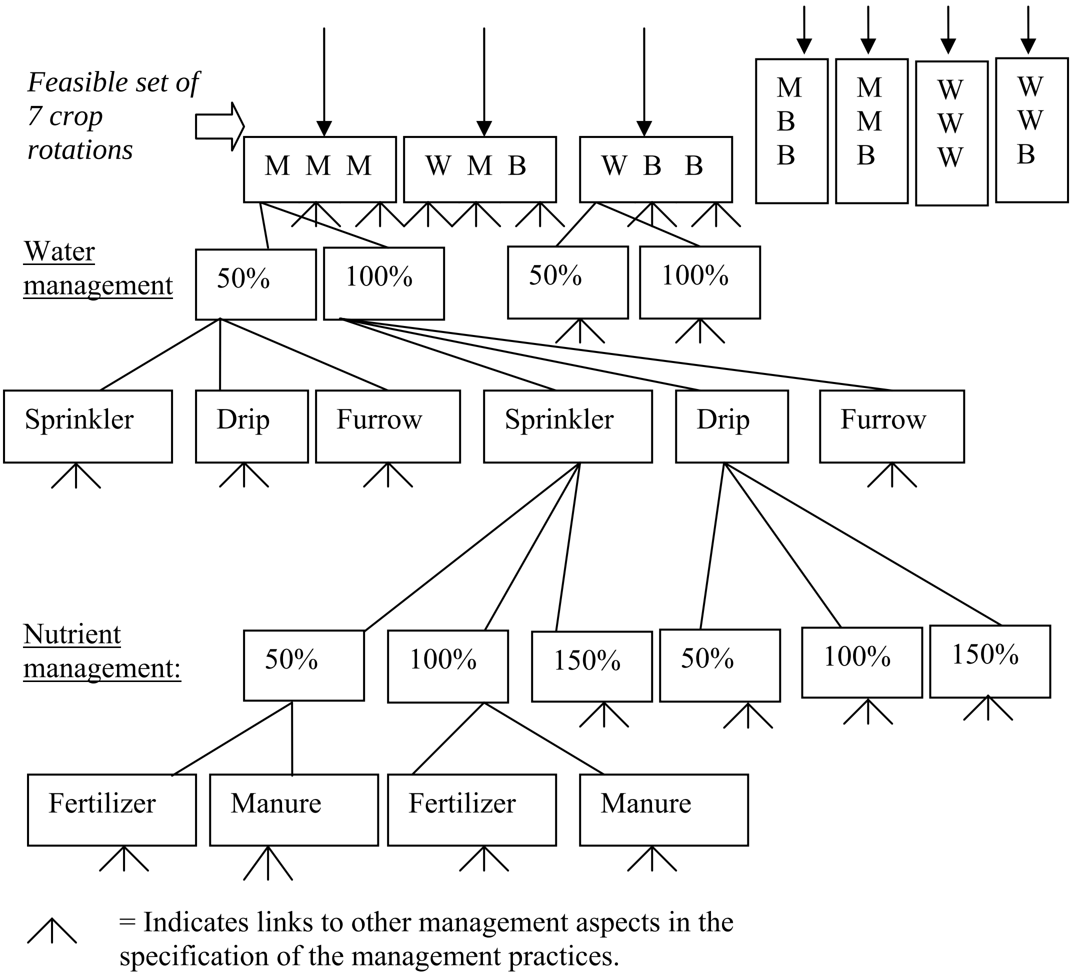
Figure 5.3: An example of the relation between production orientations and management practices and aspects



5.1.1 Combinatorial explosion

Figure 5.4 shows how on the basis of 7 rotations combinations of two management practices lead to production techniques. The number of production techniques increases rapidly with increasing management practices. In Figure 5.4 the total number of different crop management options for each crop with two management practices is 36 (= 2 water input levels × 3 water application techniques × 3 nutrient input levels × 2 nutrient input sources). Still three other type of management practices (weed, pest and disease management, conservation management and general management) and timing of the different applications need to be added, indicating that the final number of crop management options per crop will be far larger than 36 as in this example. The number of production techniques increases rapidly by identifying different management aspects, as each alternative leads to a doubling of the production techniques and a tripling or quadrupling of the agricultural activities (dependent on the rotation length). This is called a combinatorial explosion. It is important to be explicit about the relevancy of management practices to be incorporated to avoid a combinatorial explosion, which leads to extremely large numbers of agricultural activities, increased computing time and difficulties in processing and analysing the results.

Figure 5.4: Simplified description of two management practices (water and nutrients) as part of the production technique of an activity



5.1.2 Input-oriented or output-oriented approach

The input-oriented approach implies that inputs serve as a basis for the calculation of outputs, which together form the Technical Coefficients (TCs), while in the output-oriented approach the production target (output) is set dependent on the most limiting growth factor and on the objectives of the agricultural activity and then the most efficient set of inputs to realize this target is defined (Van Ittersum and Rabbinge, 1997; Hengsdijk and Van Ittersum, 2002). Characteristics of both approaches are:

1) Input-oriented approach:
   a) Inputs serve as a basis for the calculation of outputs, which together form the Technical Coefficients (TCs)
   b) Variation in performance of activities between years is caused by weather. In an input-oriented approach the variation in performance due to weather ends up in the outputs as the inputs are fixed at a certain level.
   c) Advantages are:
      i) a straightforward method of generating sets of inputs (production techniques), when they must be run through APES to obtain the outputs.
      ii) APES is geared towards an input-oriented approach
   d) Disadvantages are:
      i) variation in inputs cannot be taken into account.
2) Output-oriented approach:
   a) The production target chosen determines the set of inputs needed and there are many different possibilities for the production target: potential yield, water limited yield, nutrient limited yield, actual yield, etc.
   b) The output-oriented approach is more commonly used in normative studies as it is based on what is technically possible. This can be understood in relation to the nature of alternative activities in normative approaches (Hengsdijk and Van Ittersum, 2002): they must be possible from a biophysical point of view and feasible from a technical point of view (either 'on the shelf' or 'in the pipeline'). Their economic and environmental feasibility will be assessed in the optimization procedure of the farm model.
   c) Variation in performance of activities between years is caused by weather. In an output-oriented approach a certain target yield is chosen. Inputs needed to achieve this target yield are calculated; however, whether this target yield is achieved with the calculated inputs depends on the weather and price-conditions during the growing season. Thus, variation in performance is both captured in input and in output levels.
   d) Advantages are
      i) that resources are used in an efficient way;
      ii) that the selection of inputs is not arbitrary, but based on an objective (a certain level of output).
   e) Disadvantages are
      i) that APES is partly geared towards an output-oriented approach as on the basis of knowledge of the systems some aspects of crop management may be simulated in a more or less output-oriented approach. For example, if the potential production (as determined by radiation and temperature) is the goal of an activity, irrigation rules can be applied in APES so that no water stress occurs during the growing season. There is sufficient knowledge about the system available to set such rules required for attaining this production goal, for example, based on soil water content during the growing season.

To quantify inputs and outputs of a production technique, the following output-oriented procedure will be used within the PTG: At the start of the growing season, the management will depend on a target yield level, for example 8 t/ha for wheat or 80% of the potential yield level. Consequently, the amount of nutrients that needs to be applied is calculated *a priori*. On the basis of these inputs APES is run, with information on threshold values for water management (like soil water content remaining above 75% of the maximum soil water content), and a management scenario leading to 95% control of all weeds, pests and diseases, which does not cause associated yield reductions. APES calculates the achieved actual yield level and the amount of water needed. In summary, the proposed steps in the procedure are:

1. Set the target yield.
2. Estimate nutrient inputs, inputs for the control of weeds, pests and diseases, and conservation management
3. Simulation with APES.
4. Simulated yield and input levels for water management.

5.2 Management practices

5.2.1 General Management

General management refers to operations that always have to take place for a successful harvest, i.e. sowing, harvesting, clipping, pruning and field inspection. Sowing is defined by a timing and the amount of seed needed, while harvesting is defined by a reduction in biomass or Leaf Area Index of the crop, just as clipping and pruning with the difference that harvesting indicates the end of the growing season. Field inspection requires labour, while its timing is not relevant within the SEAMLESS framework.

5.2.2 Water Management

Table 5.1: Parameter values for three levels of water management as they can be used by APES

	Water Management		
	Option 1 Rainfed	**Option 2** Water unlimited, start irrigation at 80% of field capacity	**Option 3** Water unlimited, start irrigation at 60% of field capacity
Irrigate Crop	False	True	True
Set Automatic Irrigation	False	True	True
Plant Available Water Threshold	0.5	0.8	0.6
Plant Available Water Target	1	1	1
Irrigation Method	-	Furrow	Furrow

During the growing season it is possible in APES to keep track of the growing conditions for the crop in terms of water availability, so that non-water limited yields are possible. The amounts of water required to achieve non-water limited yield vary from year to year. Two extreme target yield levels are possible: rainfed (water-limited yields in most cases; no irrigation) and fully irrigated (water-unlimited yield). An intermediate yield level can be attained with water stress occurring only during part(s) of the growing season, e.g. partial irrigation.

Relevant management aspects for water management are:

1. Method of application: (1) drip, (2) furrow, (3) sprinkler.
2. Level of application: Irrigate to field capacity when soil water content drops for example below 80, 60 or 50% of plant available water in a soil profile (Table 5.1).
3. Timing: depending on well-defined soil water threshold values, or fixed dates within the cropping season.

Information offered to APES is whether irrigation is used, the method of application (sprinkler, furrow, etc.) and the timing rule used to initiate an irrigation event combined with a plant available water threshold for irrigation. APES can then calculate the achieved yield level and the amount of water needed. An example of the parameter values offered to APES for irrigation is given in Table 5.1. The levels of water management in Table 5.1 are based on those mentioned in Figure 5.3.

5.2.3 Nutrient Management

Here only nitrogen is considered as the relevant processes are modelled in APES. Hence, phosphorus and potassium management are not explicitly quantified and specified. Before the growing season the farmer decides about the amount of nutrients to be provided through fertilizer or manure based on past experiences, target yield and expert knowledge. During the growing season the farmer can apply a relatively small second fertilizer gift depending on prevailing weather and price conditions. It is assumed that farmers supply the minimum amount of nutrients required to fulfil crop needs under given conditions. Given that soil nutrient availability depends on many aspects, it seems likely that the farmer supplies an excess of fertilizer or manure to make sure that enough nutrients are available to the crop, which represents risk-averse behaviour by the farmer. The level of nutrient input depends on past experiences and a target yield, i.e. crop needs during past seasons and expert judgement. This approach can take into account, for example, two input levels, in each of which crop needs are established *ex-ante*:

1. Full replacement of crop needs plus a large excess to make sure that nutrient availability remains at a high level during the growing season.
2. Full replacement of crop needs plus a small excess to make sure that nutrient availability remains at a sufficient level during the growing season.

Both input levels could still lead to nutrient-unlimited yield, but this depends on the growing season.

The relevant management aspects for nutrient management are:

1. Level of application: full replacement of crop needs (100%) plus a large excess (20%), full replacement of crop needs (100%),
2. Nutrient source: (1) inorganic fertilizer, (2) organic manure, (3) green manure
   2.1. Type of inorganic fertilizer: urea, Ammonium Sulphate, Rock Phosphate, Potassium chloride, NPK fertilizers, etc. All characterized by ammonium and nitrate content.
   2.2. Type of organic manure: (1) farm yard manure, (2) slurry specified per animal, (3) compost. All characterized by ammonia, nitrate and organic nitrogen content.
   2.3. Type of green manure: (1) yellow mustard, (2) legume, (3) grass, (4) grass/clover
3. Method of application: (1) broadcast, (2) drilled
4. Dose/timing of application: timing rule and number of applications, either (i) all at once, (ii) in splits

To APES the application level, nutrient source, method of application and dose/timing of application is offered on the basis of which . APES calculates the achieved yield levels. The input parameters for the nutrient application events in APES are calculated on the basis of expected target yield, expected recovery, surplus of nutrients supplied, distribution between first and second nutrient application and distribution between organic and inorganic fertilizers. Organic fertilizers can only be applied during the first nutrient application event, while only one organic and inorganic fertilizer type can be defined per nutrient management alternative.

5.2.4 Weed, Pest and Disease Management

For weed, pest and disease management control packages are defined that describe all measures required to achieve a certain control level of weed, pests and diseases for a certain crop. These packages are based on expert knowledge. APES cannot quantify the effect on yield of a certain level of weed, pest and disease pressure. Therefore, weed management control packages are based on an average 95% control of weeds. This control level does not affect the simulated yield level. For pests and diseases such a control level is probably impossible for all control packages (e.g. organic) and yield reductions are inevitable. As organic farming has few options to control pests and diseases in case of an outbreak, yield losses easily occur. A possibility could be to introduce a (stochastic) yield loss factor based on the yield-difference between conventional and organic farming.

The relevant management aspects for weed, pest and disease management are:

1. Chemical control
   - 1.1. dose rates and frequency
   - 1.2. timing: rule based, dependent on weather conditions and desired control level
2. Mechanical control
   - 2.1. type and number
   - 2.2. timing: rule based, dependent on soil water content and desired control level
3. Weed, pest and disease prevention
   - 3.1. characterisation of prevention measures
   - 3.2. timing: ex-ante the growing season

As indicated in the discussion note of Bert Lotz (Appendix 2), different types of weed control packages can be described for well-defined production-orientations. For example, integrated weed control may comprise chemical as well as mechanical methods. Timing rules to initiate weed management operations may be fixed days after sowing, crop phenological stage, temperature sum and humidity during the growing season. Possibly air humidity and temperature could serve as a threshold value for spraying against some pests and diseases e.g. phytophthora infestants causing potato late blight. For pest and disease management in organic agriculture an alternative approach needs to be developed, and an effect on yield will need to be quantified to account for inadequate control.

Weed, pest and disease prevention control depends on choices the farmer deliberately makes before the growing season. These measures lead to a lower pressure during the growing season, as compared to production techniques that do not incorporate these measures. Consequently, the levels of chemical and mechanical control applied during the season could be lower. These prevention measures can be accounted for in the generation of production enterprises. For example, an organic farmer is likely to use prevention measures against weed, pests and diseases, using specific cultivars, longer rotations, green manures, etc, leading to different production enterprises, e.g. rotations.

In short, different management alternatives can be offered to APES, which can then quantify the environmental effects of each control package (e.g. bioicide leaching). These control packages will achieve 95% control of weeds. For some pest and disease control packages a slightly different approach may be used including yield reduction factors.

5.2.5 Conservation Management

An important difference with the before mentioned management practices is that conservation management is not primarily aimed at improving environmental conditions to facilitate the production of food or fibre products, but serves other objectives (which might have an effect on production of food or fibre products), like:

1. For soil conservation management:
   1.1. carbon management/sequestration;
   1.2. prevention of erosion (water and wind);
   1.3. maintenance of soil structure (avoiding of compaction);
   1.4. soil and water conservation (rainfall water harvesting, improving water infiltration, etc.);
   1.5. prevention of salinisation;
   1.6. prevention of acidification.
2. For landscape and biodiversity management:
   2.1. creation of an aestethic landscape including small fields, enclosures, tree rows, landscape elements;
   2.2. creation of new nature/biodiversity elements including hedges, ponds, tillage free zones around arable fields, trees;
   2.3. nature management including modified grassland mowing regime to protect meadow birds, managing meadows extensively, maintaining hedges, etc.

Two types of policy can have an effect. Mandatory requirements that reduce the options for farmers, and incentive-based policies that are linked to some support/fine mechanisms. Also farmers will have strong personal preferences on these matters and will accept a certain trade-off with profitability, which is hard to model in an LP model based on profit maximization. However, the model can assess the costs of conservation management.

A farmer deliberately takes measures to achieve these objectives. An example of a typology of actions for some of these objectives is developed by Liniger *et al.* (2004):

- Overall Management (M)
  - Change of land use type (M1): for example, change from arable land to pastures
  - Change of management/intensity level (M2): introducing rotations, instead of mono cropping, adjusting stocking rates
  - Layout according to natural and human environment (M3)
  - Major change in timing of activities (M4): land preparation, planting, mowing
  - Control/ change of species composition (M5): reduce invasive species, selective clearing, encourage desired species, residue burning
- Agronomic/ soil management (A):
  - Vegetation/soil cover (A1): better soil cover by vegetation, early planting, mixed/intercropping, cover cropping, mulching, retaining more vegetation cover
  - Organic matter/ soil fertility (A2): legume inter-planting, green manure, applying manure, compost, residues, applying mineral fertilizers, applying soil conditioners.
  - Soil surface treatment (A3): conservation tillage, contour ridging, contour tillage, breaking compacted top soil.

  - Subsurface treatment (A4): breaking compacted subsoil, deep tillage
- Vegetative (V)
  - Three and shrub cover (V1): dispersed (tree, wetlands) , aligned (hedges, live fences, hedgerows), blocks (woodlots, perennial crops)
  - Grasses and perennial herbaceous plants (V2): dispersed, aligned (grass strips), in blocks.

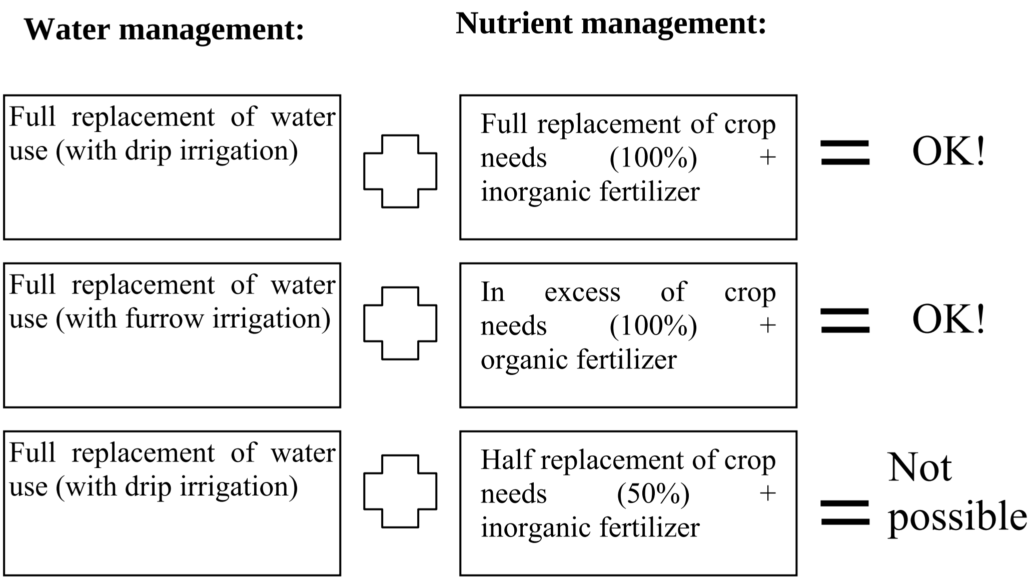
Some of these measures are also part of other management practices, like applying fertilizers or manures. A conservation management option can be defined by constructing sets of measures, which contribute to the above mentioned objectives for soil conservation management and landscape and biodiversity management. These sets of measures can then form part of certain production orientations. For example the set of measures including 'late mowing', 'not mowing close to pools/ ditches/wetlands' and 'fallow strip around arable fields' for the objective 'creation of biodiversity elements' could be the basis of the production orientation 'farming with respect for biodiversity.'

5.3 Combining Management practices

Management practices have to be internally consistent. This means that a high level of nutrient management most likely is not applied 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. In this last step of the PTG management options for water, nutrient, weed, pest, disease and conservation management can be combined to arrive at internally consistent production techniques.

An example in line with the above summation of management aspects is shown in Figure 5.5.

Figure 5.5: An example of internal consistency of management practices on the basis of the identified management aspects



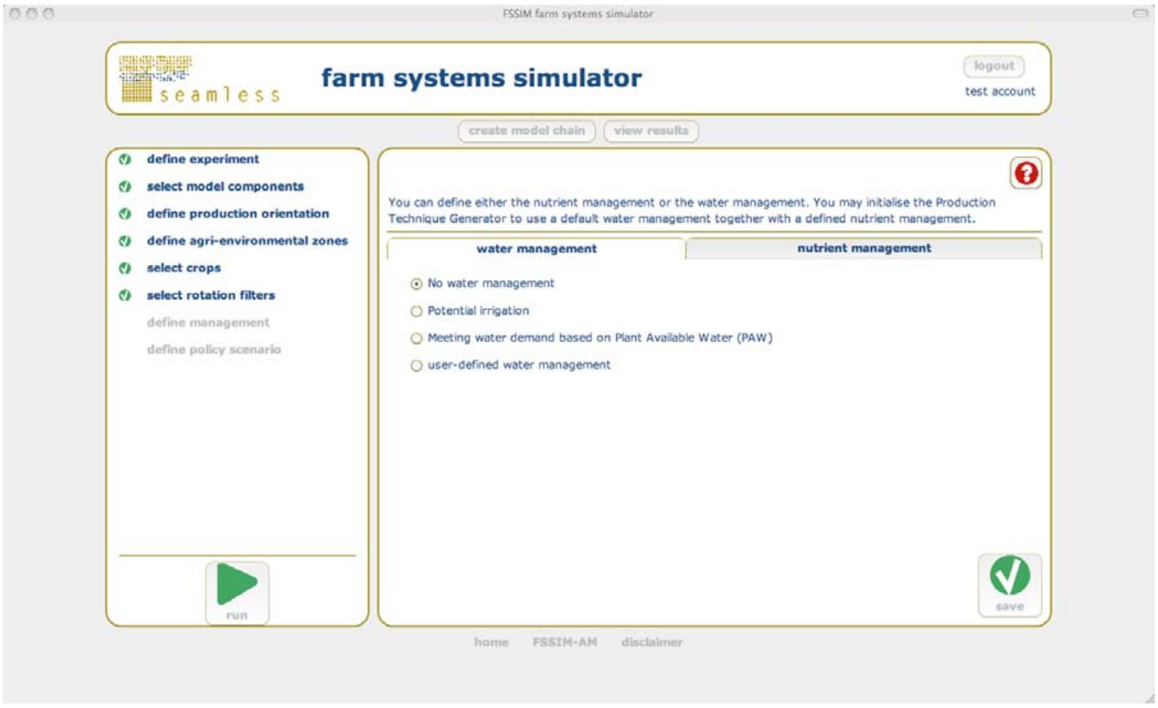
5.4 Current implementation

Currently the PTG component implements algorithms for a nutrient and water management. It consists of three parts: 1) an irrigation management generator 2) a fertiliser management generator. 3) a component making a factorial combination of all irrigation and fertilisation alternatives.

5.4.1 Water management

Water management comprises four aspects: 1) maximum number applications 2) amount of water per application 3) time window in which irrigation is possible 4) Soil plant available water threshold triggering irrigation. The actual combination of these aspects needs to be specified by the model user. The model user can always choose which crops to irrigate and which not, i.e. rainfed (Figure 5.6). Three predefined sets of alternative water aspects have been specified: Demand based irrigation, potential irrigation and user defined irrigation.

Figure 5.6: A GUI screen showing the current options for water management.



Demand based irrigation is assumed to provide just the amount of water necessary. The following parameter values ensure that just the amount of water necessary is provided:

- The irrigation window as specified in the default crop management rules (Section 3) is not changed.
- The number of applications from Simple Survey (PD3.3.9) and the default soil plant available water (PAW) threshold are used.
- Amount of water per application is calculated to refill to from the PAW threshold to field capacity.

Potential irrigation is assumed to provide ample water, whenever the soil becomes somewhat dry. This is used to simulate production without any water limitation, application number and amount of water used are most likely not realistic. The following parameter values ensure that the potential amount of water is provided:

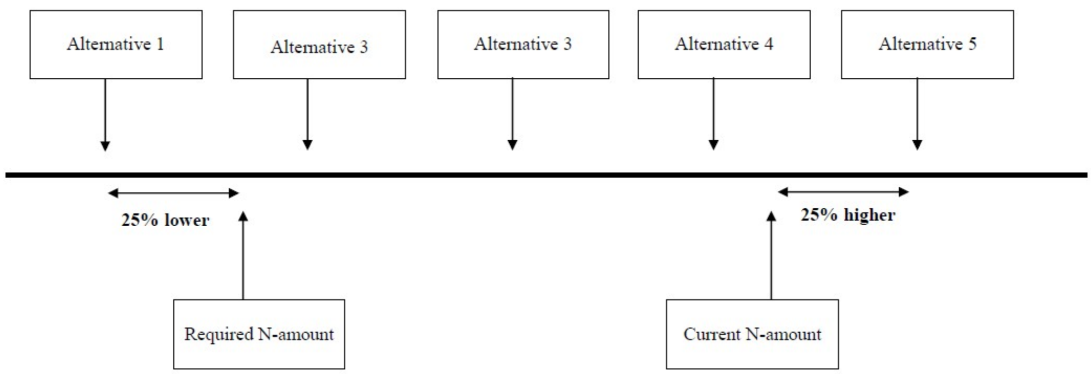
- The irrigation window as specified in the default crop management rules is not changed.
- Number of applications is 20 (maximum allowed by APES).
- A PAW threshold of 0.95 is used.
- Amount of water per application is calculated to refill to from the PAW threshold to field capacity.

User- defined irrigation implies that the user defines all four irrigation aspects based on his knowledge and the research question. The irrigation window is based on a start and end day instead of the default phenological stages from the default crop management rules.

5.4.2 Nutrient management

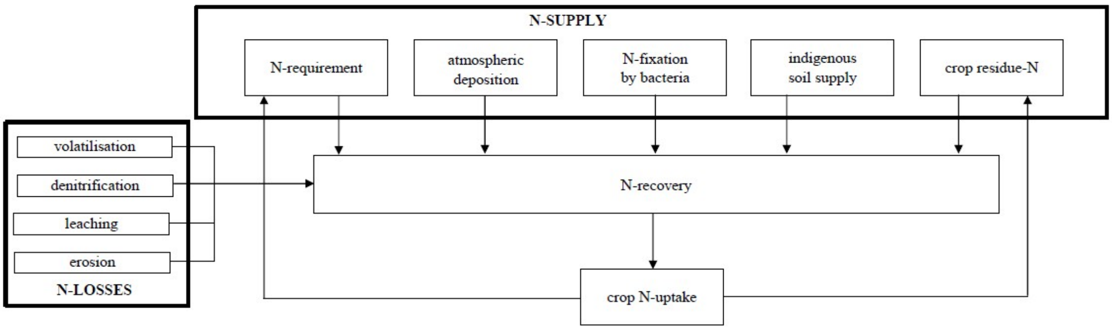
Alternative nutrient management aims to create alternative fertiliser rates around the current fertiliser rate. First, the theoretical required nitrogen amount to achieve the current yield is calculated. Second, based on a user-defined percentage of variation (25, 33 or 40%) a range around the current and calculated N-amounts is calculated. Third, a range can be calculated: the minimum, the maximum, current fertiliser rate and required fertiliser rate (Figure 5.7). Maximum and minimum rates are 25, 33 or 40% (user-defined) higher and lower, respectively, than the current and calculated N requirements. Fourth, on the basis of this range, 5 equidistant N rates are calculated. The user chooses on a per-crop basis whether or not to create fertiliser rates for that crop. Costs for alternative N management are computed as the difference in current fertilizer rate and alternative fertilizer rate times the costs of N fertilizer. Costs of N fertilizer is per kg N and an estimation of these costs is calculated by dividing the fertilizer costs for a crop by the nitrogen supply for the same crop as found in the Simple Survey (PD3.3.9).

Figure 5.7: Schematic representation of nutrient fertiliser rates based on current and calculated N-amounts



In the first step of this procedure to generate alternative fertiliser rates, a theoretically required nitrogen amount per growing season per hectare is calculated based on soil texture, precipitation deficit and crop characteristics. Figure 5.8 gives a schematic representation of the calculation. The N-losses in this figure, however, are not explicitly calculated, but are implicitly accounted for in the supply formulas.

Figure 5.8: Schematic representation of the calculation of N-requirements.



Available N = (atmospheric deposition + N-fixation + soil supply + crop residue-N) * N-recovery

N-requirement = (crop N-uptake - available N) / N-recovery

Indigenous soil supply is calculated using a procedure described in PD3.3.4, as the grassland module of the livestock component uses the same procedure. Parameters used for the calculation are: C/N ratio = 15, net N mineralisation = 0.02, Rooting depth = 30 cm.

N_{soil} = [*Indigenous soil N supply*] *** 0.5** (Correction factor for unused deposition outside growing season).

$N_{recovery}$ = Depending on crop, soil texture and precipitation deficit (see Appendix 2).

$N_{deposition} = 30 kg/ha$ *** 0.5** (correction factor for deposition outside growing season).

$$M_{product} = \frac{Yield * 1000 kg/ton}{HarvestIndex} * f_{drymatter}$$

With:

$M_{product}$ = Total aboveground biomass in kg

Yield = Harvestable fresh yield in t/ha

$F_{drymatter}$ = Dry matter fraction

HarvestIndex = Ratio harvestable yield and total aboveground biomass

$$N_{gross Required} = \frac{M_{product} * NitrogenContent}{N_{recovery}}$$

$N_{gross Required}$ = Gross N requirements in kg N/ha

Nitrogencontent = N content aboveground biomass in kg N/kg

$N_{residue} = 30 kg/ha$ for leguminosa and sugar beet, otherwise 0, or (for potato):

$$N_{residue} = \frac{Yield * 1000 kg/ton}{HarvestIndex} * (1 - HarvestIndex) * f_{drymatter} * NitrogenContent$$

$N_{fixation} = 0.75 * N_{gross Required}$ for leguminosa, otherwise 0

$$N_{available} = N_{deposition} + N_{fixation} + N_{residue} + N_{soil}$$

$$N_{net\,\mathrm{Re}\,quired} = N_{gross\,\mathrm{Re}\,quired} - N_{available}$$

These generic calculations rules provide an estimation of the theoretical crop nitrogen requirements. Optimisation of the crop returns taking into account fertiliser costs, crop yields and possibly nitrogen emission penalties for a range of fertilisation options as described in Section 5.3.3 lead to an economically optimal nitrogen application.

6 Agricultural Production and Externalities Simulator (APES)

This chapter introduces briefly the conceptual approach of APES, which is a model component used in the Agricultural Management module to simulate yields and environmental effects of agricultural activities. This section is based on D3.2.19 'Agricultural Production and Externalities Simulator (APES) prototype to be used in Prototype 1 of SEAMLESS-IF.'[6] APES is a modular simulation model targeted at estimating the biophysical behaviour of agricultural production systems taking into account the interaction among weather, soil and crop characteristics and different options of agricultural management. APES is developed in such a way that other components can be added in later stages which might be needed to simulate processes not yet included in the present version, or that existing components can easily be replaced by other components simulating the same processes, using for example a different approach. Biophysical processes in APES are simulated with deterministic approaches which are mainly based on mechanistic representations of biophysical processes. Criteria for selecting modelling approaches are based on the need for: 1) simulation of specific soil-land use interactions, 2) input data to run simulations, which may be a constraint at EU scale, 3) simulation of agricultural activities of interest (e.g. crops, grasses, orchards, agroforestry), and 4) simulation of agricultural management and its impact on the system.

The components within APES include:

1. Agro-management component initializes events as part of agricultural activities within the APES component system. Each event must be initialized at run time via a set of rules, which can be based on the state of the system, on constraints of resources availability, or on the physical characteristics of the system.
2. AgroChemicalsFate component predicts the fate of agrochemicals in the environment. The model considers five potential storages of pesticides: canopy surface, plant, available fraction of the soil, aged fraction of the soil and bound fraction of the soil. It is possible to exclude the bound and aged fractions.
3. SoilWater component describes the infiltration and redistribution of water among soil layers, the changes of water content, fluxes among layers, the effective plant transpiration and soil evaporation, and the drainage if drains are present.
4. SoilErosionRunoff component simulates dynamically water runoff and soil erosion. It has as variables among others the runoff volume, the amount of soil eroded, the interception by vegetation, and the water available for infiltration.
5. Weather components estimate variables subdivided in five domains:
    a. AirTemperature: The generation of daily maximum (Tmax, °C) and minimum (Tmin, °C) air temperatures is considered to be a continuous stochastic process with daily means and standard deviations, possibly conditioned by the precipitation status of the day (wet or dry).
    b. Evapotranspiration: evapotranspiration for a reference crop (ET0) is calculated from alternative sets of inputs and for different canopies, conditions and time steps, using one-dimensional equations based on aerodynamic theory and energy balance.
    c. Rain: the occurrence of wet or dry days is considered to be a stochastic process, represented by a first-order Markov chain.

[6] We are grateful to the authors of D3.2.19 for their comprehensive description of APES in this deliverable.

d. Solar radiation: solar radiation outside the earth's atmosphere is calculated at any hour using routines derived from the solar geometry.
e. Wind: daily mean values of windspeed, are generated by sampling from alternative probability distribution functions.

6. Crop component simulates the biomass production and crop yields as a function of intercepted radiation and its conversion efficiency. The crop growth is limited by two factors, water and nutrient availability.
7. Grassland component simulates biomass accumulation for a wide range of grasses species and allows to simulate management practices, such as defoliation and fertilization.
8. Vineyards and Orchards component. Modelling orchards are very specifics to one species and theoretically, formalisms can be extended to every woody perennial crop.
9. Soil Carbon-Nitrogen component: The nitrogen and carbon dynamics are described in the routines of the Soil Carbon-Nitrogen component,. This model simulates all of the major processes of C and N turnover in the soil/plant system using simple input data.
10. Soil Water 2 component represents in detail the water dynamics within the soil profile. It differs from SoilWater component mostly in that it accounts for preferential water flow in the soil profile.
11. Agroforestry component. The agroforestry component predicts both the productivity of agroforestry systems, and some of their environmental impacts.

7 Technical Coefficient Generator

7.1 Conceptual approach

The Technical Coefficient Generator (TCG) links the agronomic input and output coefficients generated by the simple survey, SMT and APES or the PEG, PTG and APES to socio-economic inputs and outputs by simple calculations. The TCG quantifies other or remaining inputs of each crop in each agricultural activity, i.e. the inputs not simulated through APES. These inputs, for example, refer to all inputs associated with management operations not considered critical for the performance of crop activities (e.g. harvesting operations), and labour and machinery requirements associated with management operations simulated with APES. In addition, the TCG may be used to convert physical inputs into monetary values and to calculate compound environmental performance indicators, for example, incorporating human toxicities and environmental damage related to biocide use. An important task of the TCG is to summarize output generated by APES into information and formats suitable for FSSIM-MP. For example, N leaching losses are calculated on daily basis in APES, while only seasonal or annual losses will be of interest for FSSIM.

The result of the TCG is a fully quantified set of agricultural activities (Technical Coefficient Matrix) that can be offered to FSSIM. For example, a rotation including a potato crop has been linked to a certain production technique which has been evaluated by APES: 150 kg N is used, together with 3 herbicide sprayings in which 4 kg of active ingredients are used. On the basis of this info, the TCG calculates labour and machinery requirements, specific costs of each input item, and possibly other characteristics/indicators of agricultural systems (e.g. biocide index).

7.2 Output level of the TCG: per rotation, crop, year, or lower resolution levels (e.g. days, months or decades)

The most appropriate resolution level of inputs and outputs depends on the needs defined by FSSIM, but most are expressed per year or crop. Lower resolution output levels could be required, for example, for matching irrigation water use with regional water availability in some parts of Europe. The TCG is flexible to provide FSSIM with output data using other resolution levels, for example, per rotation, single crop in a rotation, or single event in the crop management. At the moment FSSIM requires the resolution level of a single crop in the rotation. Therefore, other resolution levels of outputs have not yet been developed.

7.3 Variable costs and labour requirements

The TCG adds information on variable costs and labour requirements to the simulated agricultural activities by APES. We opted for the collection of aggregate cost and labour requirements for a crop in a rotation in the Simple Survey (PD3.3.9). Advantages are that it is feasible to collect this data for a limited sample of regions and the estimation of the aggregate might be better as a calculated on the basis of disaggregate variables. Disadvantages is that costs of alternative or changed management can not easily be estimated as it is not known how the aggregate number is build up.

In developing the TCG, we considered the use of a rental price approach for machinery costs, but we did not use this approach due to the high data demands and difficulties in collecting a consistent set of data. For future reference the rental price approach is further explained. A rental price approach is used for machinery costs, so that for each implement in each region a rental price need to be specified, which captures all the costs of the use of that implement per hectare for the number of hours required. Rental prices in our approach consist of costs for maintenance, depreciation, energy and tractor use (if applicable). Labour costs are excluded, as these are calculated in FSSIM-MP and as labour is part of a constraint for family labour. Specifying individual implements associated and labour requirements for individual operations requires a detailed description of all management operations in which machinery is involved. In the rental price approach it is assumed that all machinery is available since farmers can hire implements from contractors or borrow them from neighbouring farmers. The rental price approach does not allow to use the economies of scale of machinery at farm level but defines machinery requirements independent of farm size. Next to machinery costs, the input costs are calculated and considered in the variable costs. These input costs are based on input prices and amounts of inputs required in the different management practices.

Labour requirements (Table 7.1) are calculated based on the required labour (per hectare) for using each machine. The labour requirements for different management practices are summed to arrive at total labour requirements, per specific crop or per rotation. An example of rental price and labour requirements data is given in Table 7.1, which is derived from farm management handbooks available in the Netherlands (Dekkers, 2002)

Table 7.1: Some implements and their characteristics as found in the database

Implement (database name)	**Variable costs (Euro/Ha)**	**Labour requirement (Hours/ha)**	**Machine description**	**Hourly costs (Euro/hour)**
BeetHarvester	357,1	1,1	Sugarbeet harvester (1-phase with container, 6-rows)	334
CarrotHarvester	455,28	2	Chicory/carrot harvester(3m)	237
ChicoryCarrotDrill	70,11	0,8	Chicory/carrot sowing-drill	97
Chiselplow	127,28	2	Chisel plow (5-elements)	73
CombineHarvester	369,64	1	Combine harvester (6m)	379
CultivatorFixed	50,11	0,8	Cultivator, fixed harrows (4m)	72

7.4 Preparation of farm data

The TCG processes FADN based farm data into compatible inputs for FSSIM by calculating an average over several years for the observed cropping pattern, product price and yield variability for these farm types using data from the FADN-based farm typology (Andersen *et al.,* 2007).

8 Software design

The PEG, PTG, SMT and TCG have been implemented and designed in Java™ programming language to facilitate integration with SeamFrame and to develop a set of flexible components, which can be easily replaced by other software components. Objectives during software development were to separate algorithms, data and user interface to facilitate linkage to other databases and user interfaces, to modify and expand algorithms easily, and to increase the transparency and comprehensibility of the software. These objectives were achieved by (i) linking algorithms to databases through an ontology (Horridge *et al*., 2004), (ii) using strategies for software design that allow flexible use of algorithms in components, so called design patterns (especially factory and strategy patterns) and (iii) developing the user interface after having developed the algorithms and data structure. The development has thus been distributed over several smaller tasks: development of the ontology, set up of a databases and implementation of the algorithms. In these tasks close cooperation with a knowledge engineer was needed, who developed the domain manager, a tool to link the ontology with the database and the algorithms.

8.1 Data-types and use of the ontology

An ontology in computer science is a specification of a conceptualization (Gruber, 1993) and can be used to make knowledge and relationships between concepts used in a component explicit in a machine readable format. An ontology was used to formalize the data-types of FSSIM-AM in a structured and logically way. This helped to describe and define many of the concepts used by FSSIM-AM by making the properties of each concept explicit and relating concepts to each other. The ontology is developed in Protégé – OWL (Knublauch, 2005) and can be found on http://delivered.seamless-ip.org/svn/seamless/trunk/agroscienceplugin

With the aid of a knowledge manager the structure of data-types in the ontology was made available in Java™ source code, where each data type is a Java-interface and the properties of the data type are accessible (Code snippet 8.1).

Code snippet 8.1: An example of part of a java interface 'NutrientOperation' that is exported from the ontology

```
package org.seamless_ip.ontologies.agrirule;

import java.io.Serializable;
import org.integratedmodelling.persistence.annotations.ConceptURI;
import org.integratedmodelling.persistence.annotations.PropertyURI;
import org.seamless_ip.ontologies.agrirule.FertiliserApplicationMethod;

import org.seamless_ip.ontologies.agrirule.Fertiliser;

/**
 *
 * Generated code for concept agrirule:NutrientOperation originally from
 * http://ontologies.seamless-ip.org/agrirule.owl#NutrientOperation an operation
 * that supplies nutrients to a crop in the form of organic or inorganic
 * fertiliser
 *
 * @author Thinklab Persistence Plugin
 * @since Dec 22, 2008
 **/

@ConceptURI("http://ontologies.seamless-ip.org/agrirule.owl#NutrientOperation")
public class NutrientOperation implements Serializable,
org.seamless_ip.ontologies.agrirule.IOperation {
```

```
        private Long id;
        private FertiliserApplicationMethod fertiliserapplicationmethod;
        private Fertiliser fertiliser;
        private String label_aps;
        private Float applicationno3nrate;
        private Float applicationnh4nrate;

        public NutrientOperation() {
        }

        public Long getId() {
                return id;
        }

        public void setId(Long id) {
                this.id = id;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#hasFertiliserApplicationMethod")
        public FertiliserApplicationMethod getFertiliserApplicationMethod() {
                return fertiliserapplicationmethod;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#hasFertiliserApplicationMethod")
        public void setFertiliserApplicationMethod(FertiliserApplicationMethod arg) {
                this.fertiliserapplicationmethod = arg;
        }

        @PropertyURI("http://ontologies.seamless-ip.org/agrirule.owl#hasFertiliser")
        public Fertiliser getFertiliser() {
                return fertiliser;
        }

        @PropertyURI("http://ontologies.seamless-ip.org/agrirule.owl#hasFertiliser")
        public void setFertiliser(Fertiliser arg) {
                this.fertiliser = arg;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#applicationNO3Nrate")
        public Float getApplicationNO3Nrate() {
                return applicationno3nrate;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#applicationNO3Nrate")
        public void setApplicationNO3Nrate(Float arg) {
                this.applicationno3nrate = arg;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#applicationNH4Nrate")
        public Float getApplicationNH4Nrate() {
                return applicationnh4nrate;
        }

        @PropertyURI("http://ontologies.seamless-
ip.org/agrirule.owl#applicationNH4Nrate")
        public void setApplicationNH4Nrate(Float arg) {
                this.applicationnh4nrate = arg;
        }
[more ...]
}
```

In addition to enabling the export of the ontology to Java™ source code, the knowledge manager is used to manage the creation of new objects, and to link algorithms and databases. The knowledge manager is developed by the knowledge engineer. Once the class structure from the ontology is exported to Java source code, the agricultural scientist can use this generated Java source code to formulate the required algorithms. These algorithms are called methods that can be grouped in classes. As these method classes do not have any attributes, the grouping of methods in classes is to some extent arbitrary. This allows for the flexible use of design patterns. The algorithms can instantiate objects of the Java-interfaces where needed via the knowledge manager.

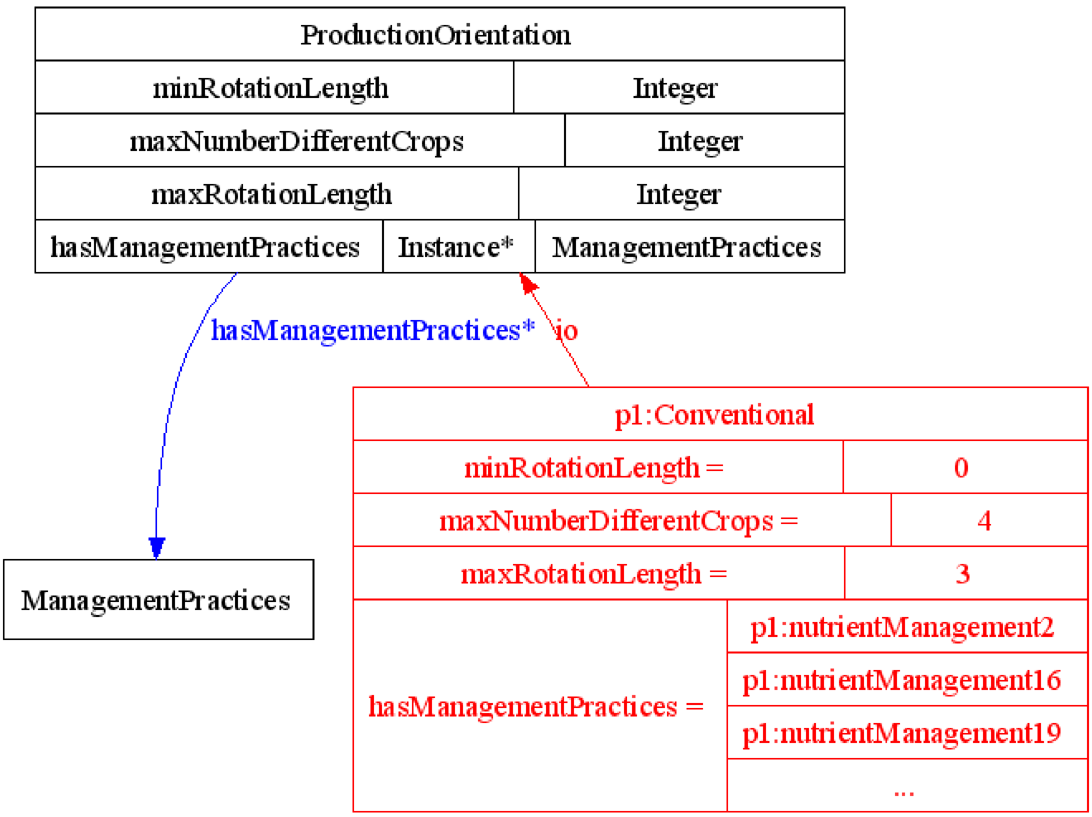
8.2 Algorithms in Java

With the aid of the generated java-interfaces based on the ontology, sets of algorithms were written for each of the components PEG, PTG, SMT and TCG.

8.2.1 PEG software design

The Production Enterprise Generator (PEG) is a component to generate a feasible set of crop rotations based on crop and rotation suitability filters. The PEG requires as inputs the production orientation, set of crops and farm type. The farm type is allocated to agri-environmental zones, which contain climate and soil data. The production orientation has properties, which determine the composition of crop rotations, for example, through constraints on the length (duration) of the rotation and on the maximum number of different crops in a rotation. In addition, the production orientation determines the set of management practices that describe nutrient, water and conservation management of crops (Figure 8.1).

Figure 8.1: The production orientation class with its properties and an example of an instance 'conventional' of a production orientation

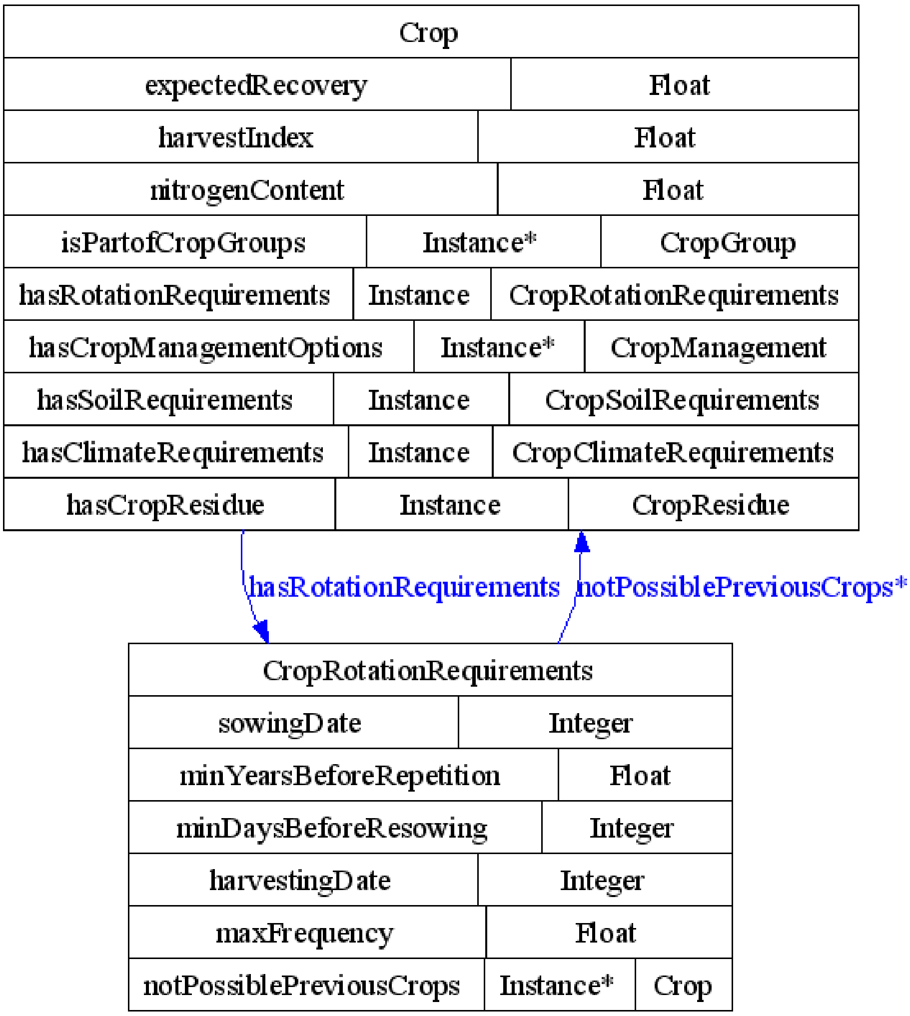


The PEG creates rotations by a four step procedure:

1. Identification of a set of suitable crops from the list of possible crops using suitability filters. The list of possible crops is an input to the PEG and as such user-dependent. (For a list of the suitability filters currently implemented in the PEG, see Appendix 1.)
2. Generation of all possible combinations of suitable crops in rotations by the RotationGenerator.java class. Such a matrix is called a Cartesian matrix. Through an iterator possible rotations can be obtained from the RotationGenerator.java.
3. Identification of all feasible rotations from all possible rotations using rotation suitability filters. These filters use properties of crops and of crop groups that are related to the requirements of rotations (Figure 8.2). (For a list of rotation suitability filters currently implemented in the PEG, see Appendix 1.).
4. Attaching information on farm type and production orientation to the feasible set of rotations. Each set of rotations is thus linked to a farm type and production orientation. One rotation might be linked to more than one farm type and production orientation.

Crop and rotation suitability filters can be switched on or off as desired by the user.

Figure 8.2: The crop-class and the crop rotation requirements class with its properties



8.2.2 PTG software design

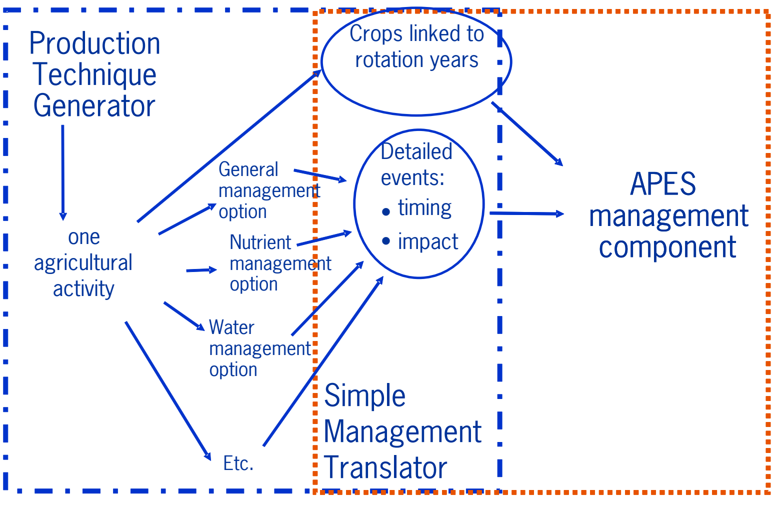
The Production Technique Generator (PTG) is a component for generating alternative agricultural activities on the basis of either current rotations from the simple survey or a feasible set of rotations from the PEG. A Production Technique is a set of agronomic inputs, that can be characterized by type, level, timing and application technique at different levels of detail (Van Ittersum and Rabbinge, 1997). The PTG creates for the crop management of each crop-year combination in a rotation a set of new management practices. This crop management can consist of five major management practices: water management, general management (sowing, harvesting and field inspection), nutrient management, conservation management and weed, pest, disease management (Figure 8.3). For each of these management practices, the PTG can have a management generator to define different management options. These generators can be stacked, i.e. applied after each other, with each generator creating a new set of alternatives for all its input management. This way, the number of alternatives created by each generator has to be multiplied by the numbers of alternatives of all other generators, i.e. three generators that each create 3 alternatives return in total 3*3*3=9 alternatives.

Currently, two management generators are implemented:

- Water Management Generator in class 'IrrigationManagementGenerator.java'
- Nutrient Management Generator in class 'NutrientManagementGenerator.java'

When for each crop-year combination a set of alternative managements is determined, the option exists to factorially combine all the alternatives of a rotation year with all other alternatives in the other rotation years. This would for example for a rotation with 6 alternative managements per rotation, a common situation, already result in 6*6*6=216 alternative activities. As currently computer power and model efficiency do not allow the simulation of these numbers of activities, the factorial combination of alternatives per rotation year is left out and only alternative 1 of rotation year 1 is combined with alternative 1 of rotation year 2, etc, keeping the number of alternative activities the same as the number of alternative managements in one year. A module filtering very large sets of alternatives, based on rules determining what range and steps of variation are of interest, is foreseen, however.

Figure 8.3: The link through crops in rotations with associated detailed agro-management events between the PTG, the SMT and APES



8.2.3 SMT software design

The Simple Management Translator (SMT) is a component for translating simple agromanagement, as used in the simple survey and handled by the PEG and PTG components, into detailed agromanagement, which then can be simulated by APES. For input it requires agricultural activities with simple agromanagement, either unmodified simple survey data, or data from the PEG and/or PTG components. It outputs the same agricultural activities, but with detailed agro-management added to it.

The groupings of the agro-management rules as described in chapter 3.2 are reflected in the component design through the subsequent processing of each agricultural activity by three translators:

- The 'TillagePlantHarvestManagement.java' class (cf. chapter 3.2.2).
- The 'IrrigationManagement.java' class (cf. chapter 3.2.3).
- The 'FertiliserManagement.java' class (cf. chapter 3.2.4).

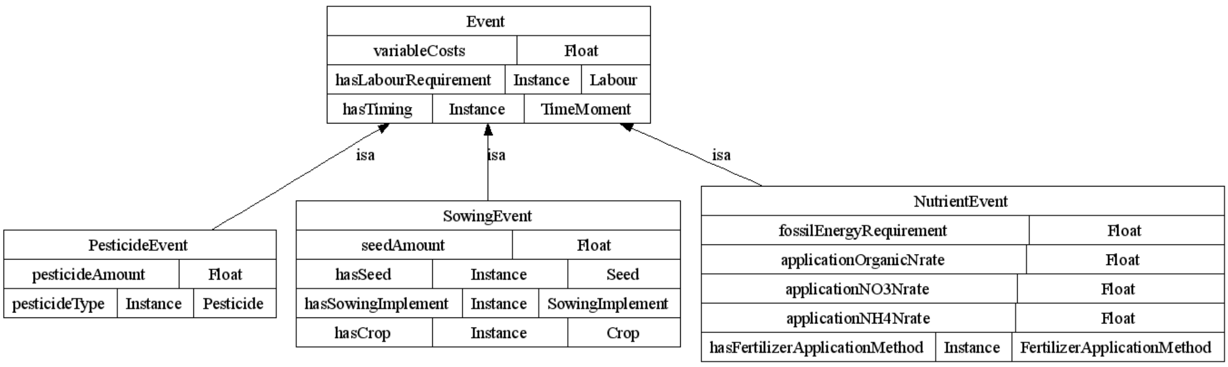
In each translator the rotation years of the activity are processed, applying the simple management rules to the simple agro-management found. While handling a crop-year combination (i.e. an occurrence of a crop in a rotation), the translators also keep track of preceding and following crops, adjusting agro-management where necessary and making sure agro-management does not overlap between crops.

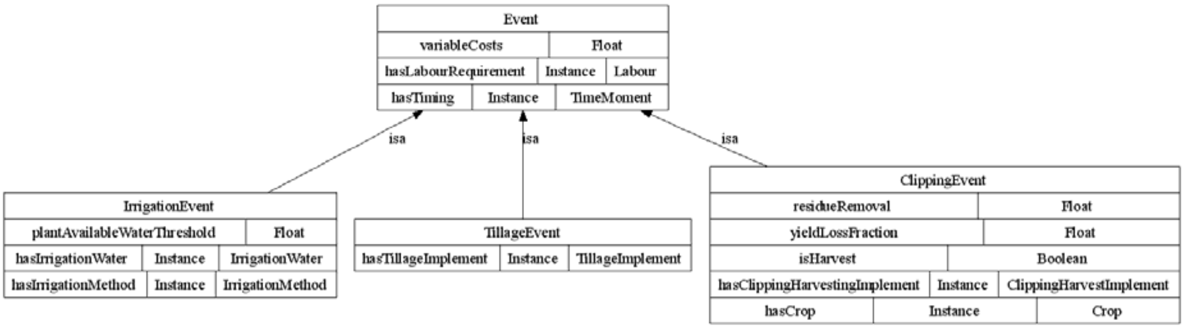
An important feature of these translator classes is that the simple agro-management of a winter crop, specified within a rotation only for its harvesting year, is divided into detailed management over two rotation years: the planting year and the harvesting year. For example winter wheat specified by simple agro-management in rotation year two will be split in detailed agro-management for both rotation year one (planting and tillage) and for rotation year two (most nutrient applications, irrigation and harvest).

8.2.4 Linking to APES

The APES model simulates yields and environmental effects for each crop with associated management in a rotation. The link between APES and the SMT is an agricultural activity (Figure 8.3), which refers to a rotation, several crops in the rotation and a crop management for each of the crops in the rotation. The crop management of a crop exists of several events, for example two nutrient events, one irrigation event, a sowing event and a harvesting event. Each of these events has certain properties that are required by APES, for example a mean tillage depth, the irrigation implement used for irrigation, or the amount of organic N. The properties of the different events are given in Figure 8.4.

Figure 8.4: The different types of events and their properties





8.2.5 TCG software design

The Technical Coefficient Generator (TCG) links the alternative agricultural activities, generated by PEG, PTG, SMT and APES to socio-economic inputs and outputs by simple calculations and prepares the inputs for the farm model (FSSIM) in an input-output matrix. This input-output matrix contains sets of technical coefficients, which are organised by Production Activity (Code Snippet 8.2). A Production Activity represents a fully quantified agricultural activity and refers to a set of relevant properties (Code Snippet 8.2):

- Data on management, rotation and production by referring to ProductionCoefficient, Rotation and Production Technique;
- Link to the agri-environmental zone, for which the production activity is valid;
- A production orientation describing whether the production activity is current or alternative, and what assumptions were made for the alternative production activity.
- Data on environmental effects for the production activity in the agri-environmental zone.

The TCG consists of several java-classes, that each hold algorithms to perform calculations on either the survey data, farm types or APES or FSSIM inputs/outputs:

- SimpleCurrentActivitiesConstructor.java: converts simple survey data to either an APES compatible or FSSIM-MP compatible inputs.
- MonoCropActivityGenerator.java: makes mono-crop activities for those crops found in the Simple Survey data for a region.
- FarmDecider.java: decides on the basis of the farm specialization which type of activities and farm data need to be prepared, e.g. only arable, only livestock or both.
- FarmConverter.java: converts the FADN data from the farm typology to inputs to FSSIM by calculating the current cropping pattern, farm area, labour availability, farm area per agri-environmental zone, yield variability and price variability.
- VariabilityCalculator.java: calculates yield and price variability for the FarmConverter.java for a specific farm type.

Code snippet 8.2: An extraction of the description of the ProductionActivity in java source code

```
@ConceptURI("http://ontologies.seamless-
ip.org/farmopt.owl#ProductionActivity")
public class ProductionActivity implements Serializable,
org.seamless_ip.ontologies.activity.IAgriculturalActivity {

 private Long id;
private ProductionTechnique productiontechnique;
private ProductionOrientation productionorientation;
private Set<ProductionCoefficient> cropproductyearmanagements= new
HashSet<ProductionCoefficient>();
private Rotation rotation;
private EnvironmentalEffects environmentaleffects;
private AgriEnvironmentalZone agrienvironmentalzone;
```

8.3 Extensible and linkable components

PEG, PTG and TCG have been set up as components which can be easily extended and linked with other components. Extension is achieved by the use of design patterns, and specifically the use of the Factory Method in code development. The Factory Method is one of the construction design patterns and it controls the creation of objects by making object creation dependent on arguments given by the user (Metsker, 2002). If the user does not want to use the 'SowingHarvestingFilter' in the PEG, than he/she can switch it off by removing it as an argument when running the PEG. No changes of the code of the PEG are required. In the PEG a Factory Method is used for the selection of crop and rotation suitability filters and in the PTG a Factory Method is used for the selection of management generators. Code Snippet 8.3 gives an example of the Factory Method for rotation filters.

Code Snippet 8.3: An example of the RotationFilterFactory, which uses a Factory Method to create RotationFilter-objects at run time

```
package fssim-am.peg.rotation;

public class RotationFilterFactory {

      public AbstractRotationFilter getFilter(String which){
            if(which == "cropFrequencyFilter"){
                  return new CropFrequencyFilter();
            }else if(which == "cropRepetitionFilter"){
                  return new CropRepetionFilter();
            }else if(which == "cropSequenceFilter"){
                  return new CropSequenceFilter();
            }else if (which == "maxNumberOfCropsFilter"){
                  return new MaxNumberOfCropsFilter();
            }else if (which == "cropGroupFrequencyFilter"){
                  return new CropGroupFrequencyFilter();
            }else if (which == "cropGroupRepetitionFilter"){
                  return new CropGroupRepetitionFilter();
            }else if (which == "sowingHarvestingDatesFilter"){
                  return new SowingHarvestingFilter();
            }else {
                  return null;
            }
      }
}
```

Linking of components in FSSIM-AM is done via OpenMI+, which is 'the key to moving single domain modelling to integrated modelling' and 'when the (OpenMI) standard is implemented, existing models can be run in parallel and share information at each time step. This makes model integration feasible at the operational level' (HarmoniIT, 2005). Via OpenMI, components can be linked to each other as long as they share similar exchange items. Components can also be replaced by other components as long as the exchange items are respected.

9 Discussion, Conclusions and Recommendations

- FSSIM-AM uses a conceptual approach for the specification of agricultural activities in terms of rotations, crop management, yields, costs and labour requirements and this conceptual approach is implemented as a flexible, extensible set of components that can be adapted for livestock activities and perennial activities.
- FSSIM-AM is designed with the aim to be generic in its structure and can be applied to any region and any condition.
- The ontology has been used to formalize the data-types of FSSIM-AM in a structured, ordered and logical way. This helped to achieve a clear description and definition of many of the concepts used by FSSIM-AM, i.e. the properties of each concept are explicit and concepts are related to each other.
- The components PEG, PTG, SMT and TCG are linked to APES and FSSIM-MP, and can be linked to other components through OpenMI.
- A bottleneck in the use of FSSIM-AM might be the rapid increase of feasible combinations when rotations and agricultural activities are generated in the PEG and the PTG. Filters are available to limit the number of rotations and agricultural activities generated, but this might be insufficient to limit the number of activities to practical dimensions. Two examples show what might happen:
  - For 30 crops and a maximum rotation length of 6 years, the number of possible rotations is 729.000.000 (= 30^6). After using rotation suitability filters, possibly still some 1.000.000 rotations remain. Test runs of the PEG for 3 soil types in Flevoland showed variability in the number of rotations generated dependent on the number of crops and the maximum rotation length (Table 9.1).
  - In the PTG for each crop 6 different management alternatives can be defined. Based on 1.000.000 suitable rotations 46.656.000.000 different agricultural activities can be identified. A number that is much too large to be handled by FSSIM-MP.

Table 9.1: Number of rotations generated for Flevoland based on 20 crops without or with fallow as a crop

Number of rotations	4 Years		5 year	
	With fallow	Without fallow	With fallow	Without fallow
Clay	4887	3006	37934	19847
Loam	1902	771	10230	2800
Sand	1762	699	9061	2400

- The PEG and PTG are currently only operational for annual cropping activities. These need to be extended for livestock and perennial activities, and the methods can be the same as the current PEG and PTG. The PTG also needs to extended for more different management types (e.g. weed, pest and disease management, conservation and general management). Finally, a thorough testing needs to be done for PEG and PTG and their linking to APES and FSSIM-MP at least in two regions.

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Glossary

Agricultural activity: A coherent set of crops or animals plus the operations (also called 'production technique') with corresponding inputs and outputs, resulting in e.g. the delivery of a marketable product, the restoration of soil fertility, or the production of feedstuffs for on-farm use (Van Ittersum and Rabbinge, 1997; Ten Berge *et al.*, 2000).

Alternative activities: Activities that are not currently used, but might be technically feasible alternative for the future, often technological innovations or newly developed cropping or husbandry practices (PD3.3.1).

Crop (Suitability) Filters: a set of rules and parameters that constrain the production of a well-defined crop from an agronomical point of view

*Control packages: D*escription of all measures required to achieve a certain control level of either weeds, pests or diseases for a certain crop.

Current activities: Activities that are currently being practiced and can be derived from observed data.

Farming system: A combination of income generating activities that constitute a farm.

Input-oriented approach: Inputs serve as a basis for the calculation of outputs, which together form the input-output coefficients.

Management practice: A set of coherent management aspects.

Management aspect: A characteristic of a management practice (one characteristic of the application of agricultural input use).

Output-oriented approach (also called target oriented): The production target (output) is set dependent on the most limiting factor and on the objectives and then the set of inputs to realize this target is defined (Van Ittersum and Rabbinge, 1997; Hengsdijk and Van Ittersum, 2002)

Physical environment: Combinations of soil and climate properties in which production takes place.

Production Coefficient: A row in the input-output matrix of FSSIM-MP, which describes for a crop in a rotation with a certain management what the technical coefficients are.

Production enterprise: The description of a coherent set of crops (rotation) and animals without a specified (production) technique that form production systems of farming systems.

Production enterprise generator: A tool to generate a feasible set of farm production enterprises (rotations) based on crop suitability constraints (filters) related to soil and climate characteristics (or for animal husbandry systems herd composition constraints).

Production orientation: Value driven aims and restrictions of the agricultural activity that direct the input and output levels (Van Ittersum and Rabbinge, 1997), for example 'integrated', 'organic', 'conventional' or 'highly innovative.'

*Production technique***:** Complete set of agronomic inputs (e.g. management practices) characterized by type, level, timing and application technique (Van Ittersum and Rabbinge, 1997).

Production technique generator: A tool to describe production techniques of agricultural activities on the basis of the feasible set of production enterprises.

Rotation: A succession of crops in time (cropping sequence) and space (cropping pattern), where the last crop is the predecessor of the first crop (creating a loop); the same as production enterprise.

Rotation (Suitability) Filters: A set of rules and parameters that constrain the generation of rotations that are not possible or suitable from an agronomical point of view.

Simple Management Translator: A tool to translate simple, aggregate agro-management into detailed agro-management ready for simulation by a cropping systems model.

Technical coefficients: Coefficients describing the inputs needed to achieve one unit of output or the activity's contribution to the realisation of user defined goals (or objective in modelling terms) (Ten Berge *et al.*, 2000).

Appendix 1: Suitability Filters and Rotation Filters in the Production Enterprise Generator

Below the Suitability Filters and Rotation Filters are described as these are currently implemented in the PEG. As these are implemented in Java, the algorithm (method) will be shortly described, with a reference to the result of the algorithm. The algorithms for the different suitability filters all have the same name, which is necessary to allow for the flexible use of different suitability filters after each other.

Crop Suitability Filters

- Rainfall Surplus during Harvest in class 'SuitabilityFilterRainfalSurplus.java':
    - The algorithm 'getSuitabilityFilterResults' uses the property on average daily rainfall of the climate in a certain grid cell and the property on 'maximum rainfall during harvest' of the climate requirements of a crop together with a character(either 'l' or 'g') to see if crop can be harvested with the rainfall surplus occurring during harvest time. In this case the character is 'l', which means that the grid cell-climate value should be lower than the crop climate value.
    - Returns: true if crop is suitable for a certain grid cell in terms of rainfall surplus during harvest.
- Temperature Sum during growing season in class 'SuitabilityFilterTemperatureSum.java':
    - The algorithm 'getSuitabilityFilterResults' uses the property on average daily temperature of the climate in a certain grid cell and the properties 'temperature sum', 'maximum growing season length', 'minimum temperature needed for temperature sum calculation' and 'maximum temperature for temperature sum calculation' of the climate requirements of the crop, together with a character(either 'l' or 'g') to see if temperature sum requirement of the crop can be met during the growing season in the grid cell. In this case the character is 'g', which means that the temperature sum occurring during the growing season should exceed the temperature sum required by the crop.
    - Returns: true if crop is suitable for a certain grid cell in terms of temperature sum occurring during the growing season.
- Slope in class 'SuitabilityFilterSlope.java':
    - The algorithm 'getSuitabilityFilterResults' uses the property on slope of the soil in a grid cell and property 'slope' of the soil requirements of a crop together with a character (either 'l' or 'g') to see if crop can still be grown on the slope of the grid cell. In this case the character is 'l', which means that the slope in the grid cell should be lower than the slope that is accepted by the crop.
    - Returns: true if crop is suitable for a certain cell in terms of slope.
- Altitude in class 'SuitabilityFilterAltitude.java':
    - The algorithm 'getSuitabilityFilterResults' uses the property on altitude of the soil in a cell and the property 'altitude' of the soil requirements of the crop with a character(either 'l' or 'g') to see if crop can still be grown on the altitude of the cell. In this case the character is 'l', which means that the altitude of the soil should be lower than the altitude of the soil requirements of a crop.

- Returns true if crop is suitable for a grid cell in terms of altitude.

♦ Clay Content in class 'SuitabilityFilterClayContent.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'clay content' of the soil in a grid cell and property 'clay content' of the soil requirements of a crop together with a character(either 'l' or 'g') to see if a crop tolerates the clay content of the cell. In this case the character is 'l', which means that the clay content in the soil of a grid cell should be lower than the clay content required by the crop.
- Returns: true if crop is suitable for a certain cell in terms of clay content.

♦ Rooting Depth in class 'SuitabilityFilterRootingDepth.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'rooting depth' of the soil in a grid cell and the property 'rooting depth' of the soil requirements of a crop together with a character(either 'l' or 'g') to see if crop can root deep enough in the soil. In this case the character is 'g', which means that the rooting depth of the soil should exceed the rooting depth required by the crop.
- Returns: true if crop is suitable for a certain cell in terms of rooting depth.

♦ Roughness in class 'SuitabilityFilterRoughness.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'roughness' of the soil in a cell and the property value 'roughness' of the soil requirements of a crop to see if crop tolerates the stoneliness of the cell. With roughness is meant here the amount of stones being present, or whether or not the soil is in a concretionary phase. The roughness property is a classified property in classes as 'poor-medium-good-etc', also called an enumerator.
- Returns: true if crop is suitable for a certain cell in terms of roughness.

♦ Salinity in class 'SuitabilityFilterSalinity.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'salinity' of the soil in a grid cell and the property 'salinity' of the soil requirements of a crop to see if crop tolerates the salinity of the cell. The salinity property is a classified property in classes as 'poor-medium-good-etc', also called an enumerator.
- Returns: true if crop is suitable for a certain cell in terms of salinity.

♦ Alkalinity in class 'SuitabilityFilterAlkalinity.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'alkalinity' of the soil in a grid cell and the property 'alkalinity' of the soil requirements of a crop to see if the soil of a grid cell is not too alkaline for the crop. The alkalinity property is a classified property in classes as 'poor-medium-good-etc', also called an enumerator.
- Returns: true if crop is suitable for a certain cell in terms of alkalinity

♦ Drainage in class 'SuitabilityFilterDrainage.java':

- The algorithm 'getSuitabilityFilterResults' uses the property 'drainage' of the soil in a cell and property 'drainage' of the soil requirements of a crop to see if the cell-soil is well-enough drained for the crop. The drainage property is a classified property in classes as 'poor-medium-good-etc', also called an enumerator.
- Returns: true if crop is suitable for a certain cell in terms of drainage

Rotation Filters

- ♦ Crop Frequency Filter in class 'CropFrequencyFilter.java':
  - The algorithm 'checkCropFrequency' checks the frequency of all the crops in aa rotation, for each rotation in a set of rotations and compares these with the allowed frequency of the crops in the rotation. If the frequency of each of the crops is below the maximally allowed crop frequency of the crop, than the return statement for that rotation is true, else false.
  - Parameters:
    - Set of Rotations: an array of rotations which need to be filtered
    - Crops: the crops that are part of the rotations
  - Returns: Boolean array, which holds true for a certain rotation if the frequency of all the crops is below the maximally allowed frequency.
- ♦ Crop Group Frequency Filter in class 'CropGroupFrequencyFilter.java':
  - The algorithm 'checkCropGroupFrequence' checks for each crop group whether the frequency in a rotation of the crop group is higher than the maximally allowed frequency of the crop group. For each rotation a Boolean (true/false) is returned, which is false if one of the frequencies of the crop groups is higher than the allowed frequencies for that crop group.
  - Parameters:
    - Set of rotations
    - Crop groups
  - Returns: Boolean array: if a Boolean is false, then that rotation has a crop group with a too high frequency.
- ♦ Crop Group Repetition Filter in class 'CropGroupRepetitionFilter.java':
  - The algorithm 'checkCropGroupRepetition' checks for each crop in a rotation whether it is not repeated to shortly after another crop of the same crop group. If a crop in the rotation is repeated too shortly after another member of the same crop group, the rotation gets the Boolean false, else true.
  - Parameters:
    - Set of rotations
    - Crop groups
  - Returns: Boolean array: if a Boolean is false, then two crops of a crop group are grown too shortly after each other
- ♦ Crop Repetition Filter in class 'CropRepetitionFilter.java':
  - The algorithm 'checkCropRepetition' checks whether a crop is not repeated in a rotation before it is allowed to be repeated in the rotation, according to the 'minimum-years-before-repetition -property of the crop.
  - Parameters:
    - Set of rotations
    - Crops
  - Returns: Boolean array: if a Boolean is false, then the same crop is repeated too shortly after another instance of that crop in the rotation

- Crop Sequence Filter in class 'CropSequenceFilter.java':
  - The algorithm 'checkCropSequence' checks whether one crop is allowed to precede another crop by checking the set of crops, that are not possible as previous crop for the current crop.
  - Parameters:
    - Set of rotations
    - Crops
  - Returns: Boolean array. If a Boolean is false, then there is one crop in the rotation which can not be grown before the next crop in the rotation.
- Maximum Number of Crops Filter in class 'MaxNumberOfCropsFilter.java':
  - The algorithm 'checkNofDifferentCrops' calculates the number of different crops in a rotation and compares this number for each rotation with the maximum-number-of-crops property of the production orientation. If the maximum number of crops is less than the number of different crops in the rotation, than false is returned.
  - Parameters:
    - Set of rotations
    - Crops
    - Production orientation
  - Returns: Boolean array. A Boolean is false if the rotation has too many different crops
- Sowing and Harvesting Dates Filter in class 'SowingHarvestingFilter.java':
  - The algorithm 'checkSowHarvestDates' compares the sowing date of a crop in a rotation with the earliest possible sowing date of the crop. This earliest possible sowing date is based on the harvest date of the previous crop plus the minimum number of days needed for soil preparation. If the earliest possible sowing date of one of the crops in the rotation is after the desired sowing date of the crop, than the rotation gets a Boolean false attached to it.
  - Parameters:
    - Set of rotations
    - Crops
  - Returns: Boolean array. A Boolean is true if none of the sowing dates of the crops in a rotation overlap with the harvesting dates of a previous crop in a rotation.

Appendix 2: Nitrogen recovery based on crop, soil and precipitation

This section lists crop nitrogen recoveries for all soil types found used in the SEAMLESS soil database. Precipitation deficits have been calculated per agri-environmental zone using Equation A1:

$$A = \frac{\sum_{years} \left[\sum_{year} P - \sum_{year} PET \right]}{years} \qquad \text{(A1)}$$

With P being the daily precipitation (in mm) and PET being the daily potential evapotranspiration (in mm), both summed yearly and averaged over the whole climate series.

Soil texture definition

Texture	Definition
Coarse	18% < clay and > 65% sand
Medium	18% < clay < 35% and >= 15% sand *or* 18% < clay and 15% < sand < 65%
Medium fine	< 35% clay and < 15% sand
Fine	35% < clay < 60%
Very fine	clay > 60 %

Legumes

Soya, Other oilseeds, Beans, Lupin, Peas, Lentils, Vetch, Cow peas, Chick peas, Broad beans, Kidney bean, Peas (sugar), Mustard, Other pulses, Clover, Alfalfa, Serradella, Groundnut.

Precipitation deficit (mm)	Soil texture					
	Coarse	Medium	Medium fine	Fine	Very fine	Peat
>800	0.15	0.2	0.3	0.3	0.25	n/a
>600	0.2	0.25	0.35	0.35	0.3	n/a
>400	0.25	0.3	0.4	0.4	0.35	n/a
>200	0.3	0.35	0.45	0.45	0.4	n/a
>0	0.35	0.4	0.5	0.5	0.45	n/a

Vegetables

Tomatoes, Pumpkin, Paprica, Eggplant, Melon, Cucumber, Carrot, Garlic, Onion, Lettuce, Tulip, Mushroom, Isatis, Bastard Saffron, Cabbage, Cauliflower, Taro, Spice and herb (annual), Kenaf, Yams.

Precipitation deficit (mm)	Soil texture: Coarse	Medium	Medium fine	Fine	Very fine	Peat
>800	0.1	0.13	0.23	0.23	0.18	0.13
>600	0.13	0.16	0.26	0.26	0.21	0.16
>400	0.16	0.19	0.29	0.29	0.24	0.19
>200	0.19	0.22	0.32	0.32	0.27	0.22
>0	0.22	0.25	0.35	0.35	0.3	0.25

Root crops and others

Potatoes, Sweet Potatoes, Sugar beet, Flax, Tobacco, Chicory, Cotton, Other annual crops, Other fodder root crops, Beet and Turnip, Rape, Sunflower, Hop.

Precipitation deficit (mm)	Soil texture: Coarse	Medium	Medium fine	Fine	Very fine	Peat
>800	0.3	0.35	0.45	0.45	0.4	0.35
>600	0.35	0.4	0.5	0.5	0.45	0.4
>400	0.4	0.45	0.55	0.55	0.5	0.45
>200	0.45	0.5	0.6	0.6	0.55	0.5
>0	0.5	0.55	0.65	0.65	0.6	0.55

Grasses

Grass (ley), Grass (temporary), Grass (permanent), Fescue.

Precipitation deficit (mm)	Soil texture: Coarse	Medium	Medium fine	Fine	Very fine	Peat
>800	0.5	0.55	0.65	0.65	0.6	0.55
>600	0.55	0.6	0.7	0.7	0.65	0.6
>400	0.6	0.65	0.75	0.75	0.7	0.65
>200	0.65	0.7	0.8	0.8	0.75	0.7
>0	0.7	0.75	0.85	0.85	0.8	0.75

Grain crops

Winter soft wheat, Spring soft wheat, Winter durum wheat, Spring durum wheat, Winter barley, Spring barley, Rye, Meslin, Oats, Hemp, Maize, Maize pop corn, Sweet maize, Millet, Triticale, Sorghum, White Sorghum, Backwheat, Other cereals, Fodder Maize, Fonio.

		Soil texture					
		Coarse	Medium	Medium fine	Fine	Very fine	Peat
Precipitation deficit (mm)	>800	0.4	0.45	0.55	0.55	0.5	0.45
	>600	0.45	0.5	0.6	0.6	0.55	0.5
	>400	0.5	0.55	0.65	0.65	0.6	0.55
	>200	0.55	0.6	0.7	0.7	0.65	0.6
	>0	0.6	0.65	0.75	0.75	0.7	0.65