CHAPTER 23

INTEGRATED ASSESSMENT OF AGRICULTURAL SYSTEMS AT MULTIPLE SCALES

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Abstract. Agricultural policies are increasingly replaced by agro-environmental and rural-development polices. The rationale behind this evolution is that the policies seek to enhance the sustainability of agricultural systems and contributions from these systems to sustainable development at large. The same can be argued for agricultural innovations; they are increasingly aimed at serving a range of sustainability objectives, rather than only improving productivity and quality. As a result, resource use issues related to agriculture must be analysed and addressed from an integrated and multi-scale perspective. Both the introduction of alternative agricultural resource use options and agro-environmental policies would benefit from their *ex ante* assessment. Contributions from agronomy to such integrated assessment have strong implications for its research agenda. This chapter presents an extensive example of a multi-scale assessment methodology (SEAMLESS) in which agronomy plays a significant but partial role. The methods allow the investigation of different kinds of policies and innovations and their effects on economic, environmental and social objectives of stakeholders and decision makers at farm, regional and sector level.

INTRODUCTION

Globalization, liberalization of markets, novel agro-technologies, economic development, changing societal demands and climate change drive a continuous evolution of agricultural systems around the globe. Agricultural and societal stakeholders try to influence the evolution such that sustainability of agricultural systems themselves and contributions of agricultural systems to sustainable development at large are promoted. In this context and paper, sustainable development stands for meeting the needs of present generations without jeopardizing the needs of future generations – a better quality of life for everyone, now and for generations to come, both in terms of economic, environmental and

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social issues (World Commission on Environment and Development 1987). Sustainable development, in this paper, is interpreted as a broader concept than sustainability of agriculture. The latter may imply developments within the agricultural sectors (or for specific types of farms) that are not positively contributing to sustainable development of society at large.

The factors that can be varied to achieve the objectives associated to sustainable development are merely the adoption of novel agro-technologies, the (re-)design of agricultural systems, and introduction of agricultural, environmental and rural-development policies implemented at various hierarchical levels. Institutional changes are simultaneously required to create incentives and consistency between the multi-scale and multi-objective changes (Spangenberg et al. 2002). Despite the obvious trend of liberalization, there is consensus that policies are needed to support achievement of sustainability objectives, and that these must be cost-effective and efficient (EC 2002). These policies, however, increasingly have an integrated nature: they are not solely targeted at agricultural issues, but try to achieve multiple objectives (e.g., ‘cross-compliance’ in the reform of the Common Agricultural Policy of the European Union). Agricultural policies are increasingly replaced by rural-development policies seeking to enhance the sustainability of agricultural systems and contributions from these systems to sustainable development of societies (Brouwer and Lowe 2000).

Sustainability and sustainable development are relative notions that are scale-dependent, i.e., what is good for the environment or economy at farm level may not be advantageous for the national or global environment or economy, or what is beneficial for the agricultural sector in general may not be desirable for the individual farmer. This implies the need for both multi-scale and integrated analysis that captures the effects of specific developments at field, farm, regional and even global level, and the effects in terms of economy, environment and social factors (Dalgaard et al. 2003; López-Ridaura et al. 2005; Verburg et al. 2006). Usually such analyses make use of indicators that characterize the pressure on systems or characterize the attributes of sustainable development (Gallopin 1997).

Both the introduction of new agro-technologies, the lay-out and design of agricultural fields, farms and sectors, and the design of agricultural, environmental and rural development policies would benefit from *ex ante* assessments to estimate their (relative) contributions to sustainability and sustainable development. Assessing the strengths and weaknesses of new technologies, systems or policies prior to their introduction would greatly facilitate transparency and consistency in decision making at the various scales. The European Commission, for instance, has introduced Impact Assessment of its policies as an essential step in the development and introduction of new policies since 2003 (EC 2005). It explicitly calls for assessment of the economic, environmental and social impacts of policies *and* consultation with stakeholders. This implies in many cases establishment of a so-called Inter-service steering group (across various Directorates General, e.g., Agriculture, Environment, Economics and Finances) that is responsible for the Impact Assessment. Impact Assessment is anticipated to contribute to a more coherent implementation of the European strategy for sustainable development (EC 2005).

Contributions from agricultural research to integrated assessment (cf. Harris 2002, here integrated and impact assessment are used as synonyms) have distinct consequences for the agronomic research agenda, i.e., how to summarize and integrate knowledge on crop growth and management and its interaction with the environment and economy. By nature it is a contribution to interdisciplinary research in which agricultural research plays only a partial role, jointly with many other disciplines such as economics, geo-informatics, information technology and sociology. The aim of this chapter is to discuss the role of agronomic research in multi-scale assessment studies, and then to present the conceptual and methodological approach of a large research project (SEAMLESS) to provide a frame in which research on crops and cropping systems can be integrated and used to the benefit of *ex ante* integrated assessments of agro-environmental policies and innovation in European agriculture. In this chapter we will discriminate between agronomic research focusing on plant and crop science (the core theme of this book) and agricultural research that is much broader and includes, e.g., agricultural economics and rural sociology.

AGRONOMIC AND AGRICULTURAL RESEARCH FOR INTEGRATED ASSESSMENT

Agronomic research and integrated assessment of agricultural systems

Today's questions regarding agricultural systems, their sustainability and their contribution to sustainable development at large can only be addressed from a systems perspective. Agro-ecosystems are the interplay of ecosystems and human societies, and their behaviour is determined by interactions with the natural and human-resource base (see Figure 1). This unavoidably leads to the conclusion that by definition the role of agronomy can only be partial in analysing and solving problems of agricultural systems at farm, regional and continental scale. Answers to agronomic questions provide only limited insight into behaviour of agricultural systems and are only part of the problem-solving package for most systems around the globe. This is clearly demonstrated for many cases in Africa (e.g., Ojiem et al. in press), but it is not difficult to find equally illustrative examples from other continents. Well-known agronomic principles are not adopted because of socio-economic factors or only play a small role in the complex problems that farming communities face. At the same time, using agronomic knowledge in integrated assessment tools is indispensable: many future studies on natural-resource use, agricultural systems and their industries reduce the agro-ecological relationships to a mere econometric function, production function or, in general, statistical relationship between some set of inputs and output(s) (Lehtonen et al. 2006; Guan et al. 2006). This hinders process-based analysis, explanation of systems' behaviour, interactions with the environment and identification of future alternatives that outperform current activities in terms of productivity and realization of positive or negative externalities. To assess performance of agricultural systems and their contributions to sustainable development and to identify promising alternative pathways, process-based knowledge of agro-ecological relationships is essential, but only to a certain degree of detail and tailored to integration with other factors and systems. This constitutes the challenge for agricultural research and its role in contributing to sustainable-development studies (Bland 1999). To what extent can we synthesize agronomic knowledge to the appropriate degree of detail for integration in interdisciplinary and multi-scale analysis of agricultural systems and their interactions with ecosystems and societies?

Methods to deliver agronomic knowledge into studies of an integrated nature are generally model-based and amongst the methods available two can often be found in literature: dynamic crop or cropping-systems simulation models with different levels of detail (Keating et al. 2003; Van Ittersum et al. 2003) and approaches generating and using so-called input–output coefficients of agricultural activities (Van Ittersum and Rabbinge 1997). These coefficients are in turn often generated using dynamic cropping-systems models complemented with other sources of agronomic information, and then used as an input in bio-economic models studying farming systems or regional land use systems (e.g., Roetter et al. 2005).

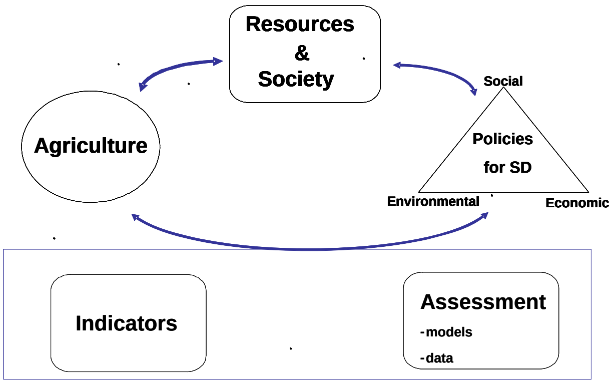

Figure 1. *The conceptual basis of integrated assessment of agricultural systems and associated policies for sustainable development (SD)*

Tools for integrated assessment of agricultural systems

Although precise documentation is scarce, it seems evident that today research tools for integrated assessment of policies and technological innovation in agriculture are still rarely used in practice (cf. McIntosh et al. 2006). Also, most of the approaches developed by research that are being used, or can be used potentially, are still largely disciplinary and focused on specific issues and/or hierarchical levels (e.g., EuroCARE 2002; EC 2003). Hence their use to assess policies and innovations, which by definition impact on different hierarchical levels (e.g., the globe, developing countries, EU25, administrative region in a country, specific farms and fields) and across economic, environmental and social domains, is restricted. They may lead at best to partial conclusions as to the behaviour of the agricultural systems. The gap between analysis at micro-level (farms) and macro-level (region or market) is still largely unresolved. Most research models are targeted at specific scales of analysis, e.g., farm (Kruseman et al. 1995; Veysset et al. 2005), watershed (Barbier and Bergeron 1999), region (Lu and Van Ittersum 2004; Bouman et al. 1999), national or continental (Deybe 1998; Lehtonen et al. 2006) or global scale (Van Tongeren et al. 2001). Also, they have been developed for specific purposes, such as evaluation of new technologies (Barbier and Bergeron 1999), macro-economic policies (Lehtonen et al. 2006; Jansen et al. 2005), nutrient policies (Wolf et al. 2005) and climate change (IMAGE team 2001). As a result possibilities for re-use for different issues are limited, whereas political agendas can evolve rapidly. Few methods were designed to deal with multi-scale assessments (Bouman et al. 1999; Jansen et al. 2005; Laborte et al. in press) and such that they can be used for a broad range of issues, e.g., breeding strategies, technological innovation, market policies, environmental policies, climate change and rural-development issues.

Another typical feature of agricultural research models is their *ad hoc* solutions in terms of software architecture and implementation. Some examples exist of cropping-systems models with significant investments in software design (e.g., Keating et al. 2003; Stöckle et al. 2003), but to our knowledge no such models have been designed to be (re-)usable in integrated frameworks. Generally, possibilities for integration, re-usability and easy maintenance of models for agricultural systems are restricted; software solutions being often targeted at a particular model, study and application. Rizzoli et al. (1998) and Van der Wal et al. (2005) argue about the advantage of modelling frameworks allowing easy maintenance and re-use of models in integrated assessment systems.

Research agenda for agronomic and agricultural research

From the previous section a research agenda for *agronomic* research aimed at contribution to integrated assessment can be derived. We think that the most important features of such an agenda are:

- Methods to enable a synthesis and summary of agronomic knowledge such that it can be used in integrated studies of a bio-economic nature. Processes and systems need to be modelled (either statically or dynamically) at the proper level of detail for specific purposes;
- The need for generic agronomic methods capable of contributing to assessments at different hierarchical levels and related to different issues;
- Software designs and implementations of agronomic models, which allow re-usability, linkage to other models and easy maintenance.

For *agricultural* research supporting integrated assessment in general we arrive at the following key features:

- Methods capable of assessing, at the proper level of detail, the economic, environmental and social issues at stake;
- Multi-scale capabilities of research methods: the methods should allow investigation of interrelationships between scales of analysis;

- Robust and open software architecture and implementation that allow linkage, re-use and maintenance of models.

In our view these features are best served by a computerized framework for integrated assessment, using individual models that can be linked, re-used and maintained through a software infrastructure using state-of-the-art developments from information technology. The individual models and some of the linkage procedures can be derived from existing studies as listed in the previous paragraph but must be amended such that they can be used in an integrated framework. The SEAMLESS project aims at developing such a framework and it will be presented in the next section. At the end of that section we return to the role of agronomic components in such a framework.

A FRAMEWORK FOR INTEGRATED ASSESSMENT OF AGRICULTURAL AND ENVIRONMENTAL POLICIES AND INNOVATION

Introduction and methodology

The European Union Integrated Project, SEAMLESS (System for Environmental and Agricultural Modelling; Linking European Science and Society, 2005–2008, Van Ittersum et al. 2006, www.seamless-ip.org) aims at developing a computerized, integrated and user-friendly framework (SEAMLESS-IF) to assess and compare, *ex ante*, alternative agricultural and environmental policy options and technological innovations. Following an analysis of requirements, the framework must allow:

- Analysis at the full range of scales (farm to EU and global), whilst focusing on the most important issues emerging at each scale;
- Analysis of the environmental, economic and social contributions of a multifunctional agriculture towards sustainable rural development and rural viability;
- Analysis of a broad range of issues, such as climate change, environmental policies, food production and costs, rural-development options, effects of an enlarging EU, international competition and effects on developing countries.

SEAMLESS-IF will have the following specific features and capabilities:

- A multi-perspective set of economic, social and environmental indicators of the sustainability and multifunctionality of systems, policies and innovations in agriculture and agroforestry;
- Quantitative models, tools and databases for integrated evaluation of agricultural systems at multiple scales and for varying time horizons;
- A software architecture, SeamFrame, that allows reusability of models, data and other knowledge, also ensuring transparency of models, their linkages and integration with other procedures.

In summary, SEAMLESS-IF aims to facilitate translation of policy questions into alternative scenarios that can be assessed through a set of indicators that capture the key economic, environmental, social and institutional issues of those questions. The indicators are assessed using an intelligent linkage of quantitative models. These models have been designed to simulate aspects of agricultural systems at specific organizational levels, i.e., point or field level, farm, region, EU and world. SEAMLESS aims at integrated use of partly existing and partly newly designed models of agricultural systems. These models use pan-European databases for environmental, economic and social issues. Some indicators, particularly social and institutional ones, will be assessed directly from data or through a post-model analysis with specific procedures going beyond the extrapolation of present trends. Smooth linkage of models designed for different scales and from biophysical and economic domains requires software architecture, and a design and technical implementation of models that allows this. The software backbone of the project, SeamFrame (Van der Wal et al. 2005; Van Ittersum et al. 2006), serves that purpose. It is also developed to facilitate re-use, maintenance and documentation of the models.

Prototype 1 of SEAMLESS-IF, including agronomic models

The first working prototype of SEAMLESS-IF, which was completed in 2006, includes an indicator calculator that draws information from the model chain provided in Figure 2 to compute selected indicators. Examples of such indicators are: farm income (for the different farm types in a region and for the EU25), nitrate leaching and contribution to global warming. The model chain comprises the agricultural sector model, CAPRI (Common Agricultural Policy Regionalised Impact), which simulates supply–demand relationships in the EU25 for agricultural commodities (Heckelei and Britz 2001). CAPRI is a comparative static-equilibrium model, solved by iterating supply and market modules. CAPRI has a supply module that consists of supply models at different scales, from farm to the European level. These are non-linear programming models allowing direct implementation of most policy measures with highly differentiated sets of agricultural activities. Allocation

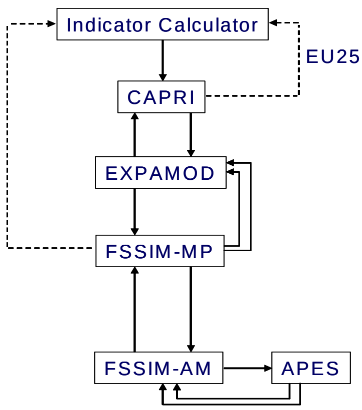

Figure 2. *Models and model chain in Prototype 1 of SEAMLESS-IF*

is based on profit-maximizing behaviour and estimated multi-product cost functions. CAPRI also estimates nutrient balances and gas emissions with global-warming potential using a matrix of coefficients linked with the levels of the activities.

In SEAMLESS-IF, CAPRI derives information on price–supply relationships from a farm model, FSSIM (Farm System SIMulator, Deybe and Flichman 1991). A restricted number of simulations of supply responses to prices with FSSIM are extrapolated through an econometric up-scaling procedure (EXPAMOD) that estimates price-supply elasticities. FSSIM is a bio-economic farm model developed to quantify the integrated agricultural, environmental and socio-economic aspects of farming systems. FSSIM includes an agricultural management module (FSSIM-AM), which computes the input–output coefficients for agricultural activities and a mathematical programming part to capture resource endowments, policy constraints and farmers' objectives (FSSIM-MP). Applied at farm (micro) level, FSSIM seeks to represent the actual farmer's behaviour using the knowledge of technical and socio-economic constraints, agro-environmental policies, the relation between production factors, the amount of output obtained and the costs of each agricultural activity (= growth of a crop rotation or livestock system) and future market prices (simulated by CAPRI). The principal characteristic of this type of model is the application of production functions, i.e., relationships between agricultural inputs (water, nitrogen, labour, etc.) and outputs (yields or emissions), partly derived from mechanistic simulation models (APES) capturing agro-ecological processes. FSSIM also uses information from surveys and expert knowledge for assessment of activities currently practiced by farmers.

FSSIM assesses both currently practiced agricultural activities and alternative ones. These alternative activities can either be on-the-shelf activities, i.e., those available but currently not practised by farmers, or in-the-pipeline activities, which may become available to farmers within the time frame of the study.

The Agricultural Production and Externalities Simulator (APES) is a modular simulation model estimating the biophysical processes of agricultural production systems, at point level, in response to weather, soil and different options of agro-technical management (cf. Van Ittersum and Donatelli 2003). APES computes the yields, as well as several inputs and externalities of crop rotations; both averages and variability across years can be generated. The processes are simulated in APES with deterministic approaches mostly based on mechanistic representations of biophysical processes. The criteria to select modelling approaches is based on the need of: (1) accounting for specific processes to simulate soil–land use interactions; (2) input data to run simulations; and (3) simulation of agricultural production activities and their management of interest.

Farm and agro-environmental typologies play an essential role in linking the models (e.g., FSSIM and CAPRI), for up- and down-scaling and for the calculation of many indicators.

Further prototypes of SEAMLESS-IF will introduce a broader diversity of agricultural activities, e.g., tropical and perennial crops in APES, animal production in FSSIM, landscape models, rural employment models and a linkage with the global trade model GTAP (Van Tongeren et al. 2001).

Examples of possible SEAMLESS-IF application

Evaluation through applications to realistic questions is an essential step in the process of development of each SEAMLESS tool (indicators, databases, typologies, models, software architecture, qualitative tools and participatory methods) and of SEAMLESS-IF as a whole. This evaluation is based on two 'Test Cases' representing the major types of questions that SEAMLESS-IF is designed to address. In each Test Case we analyse how the agricultural systems and their contribution to sustainable development will be affected by EU policies and global developments. Test Case 1 focuses on the impacts of economic policies at the EU/World level, and Test Case 2 on the impact of environmental policies and agro-ecological changes at the farm level. Analyses will be conducted both at EU level and, with more details allowed by data availability and stakeholder interactions, for typical regions of the EU representing a territorial entity with respect to environment and rural development. Examples of these typical regions are (1) the 'Neste region' in southwestern France, which represents an agricultural region where water availability and quality is a key issue; (2) the 'Pyrzyce region' of Poland, which is a typical case of an intensive cereal-based region where agriculture is still a major driver of the local economy but which is confronted with specific circumstances related to EU accession and water quality issues; and (3) the 'Massif Central region' in France, which is a mountainous area with high recreational value where agriculture is dominated by dairy production, playing a major role for landscape, grassland biodiversity, and water quality. Significant changes in the CAP related to the milk market will most likely affect this region considerably, but cheese with Certified Origin and regional policies may mitigate its effects.

To demonstrate the applicability of SEAMLESS-IF to least developed countries, two contrasting regions of Mali (Sikasso and Koutiala) have also been selected, where EU policies and trade liberalization (especially on cotton and meat) may have a significant impact on farming systems and rural development.

Test Case 1 is driven by economic-policy changes, analysing the impact of further trade liberalization as currently discussed in World Trade Organization negotiations. For this purpose, the behaviour of EU and global markets and farms in the test case regions will be compared between a baseline scenario under currently agreed policies until 2012 and a policy scenario based on a likely outcome of trade liberalization in the DOHA round of the WTO. The policy is applied at EU level through the CAPRI model and the FSSIM model. The CAPRI model simulates prices, whereas the FSSIM models for the major farm types simulate supply and externalities given certain prices. Economic, environmental and some social indicators are assessed at relevant scales using output from FSSIM and CAPRI models.

Test Case 2 analyses what would happen if the EU countries, regions and farmers would effectively apply the EU directives on water, pesticides and biodiversity. The impacts will be assessed with the economic, social and environmental indicators at the various levels represented in SEAMLESS-IF. Specific attention will be paid to the interactions between these policies and the various agro-ecological technologies (such as integrated or organic farming, conservation agriculture and agro-forestry) under different scenarios with respect to existence and degree of specific policy incentives to use these technologies. The bio-economic approach (APES-FSSIM-farm typology chain) is designed to reproduce the major factors that determine farmers' selection of alternative production systems and it will be used to identify whether or not agro-ecological technologies will be favoured by the implementation of environmental directives.

Analysing the interactions between EU environmental policies and agro-technical innovations implies the definition of complex scenarios and of a wide range of alternative agricultural activities. European agriculture and rural development are already constrained by a large and complex set of environmental directives, among which we have selected those affecting water quality and quantity (water, nitrate and pesticide directives) and biodiversity (Belhouchette et al. 2006). Deriving from these directives a set of variables and constraints that can be applied to a farm model like FSSIM is a complex task, because each country and most often each region has the freedom to define the actual application of the environmental directives. It is essential to capture this diversity because it reflects the EU strategy based on the assumption that a more ecological agriculture must be tailored to the environmental and social characteristics of each agricultural region. For the purpose of testing/improving SEAMLESS-IF and because of lack of data, the scenarios applied to EU level are simplified but the specific regions have been selected to work with national and regional decision makers and stakeholders to collect sufficient information to capture the complex constraints and incentives actually faced by the farmers. This information will be used to define realistic scenarios based on simultaneous implementation of the nitrate, water framework and bird habitat directives, but also cross-compliance rules from the CAP reform and specific regional agro-environmental schemes.

Model-based assessment of agro-ecological innovations

Integrated policy assessment tools should be able to represent the fact that new techniques become available or feasible to farms within the time horizon of the study, such as introduction of genetically modified crops (e.g., herbicide-resistant maize), a new cropping technique promoted in the region, and a new market for certified products with ecological techniques. Will such agro-ecological innovations be selected by the farmer as a response to EU environmental directives or other policies? What will be the impact on water quality, on water use by agriculture, or on biodiversity in the regions where these techniques are adopted? What effects will they have on competitiveness of EU agricultural products in the world market?

Following the approach of Rapidel et al. (2006) the cropping system is considered here as a combination of a biophysical subsystem (a plants–soil–weeds–pests combination) for each field of the farm, and a technical system (a coherent combination of management options applied on each field and allocated within a farm). As shown by Wery and Ahlawat (in press) for an example with grain legumes in Europe and in India, this approach can be used for the integrated assessment of agro-technical changes on farming-systems' sustainability, but it requires specific models to represent the biophysical and the technical subsystems. For this purpose, agro-technical innovations can be clustered:

1. Changes in the management of inputs of the biophysical system, e.g., shifting from predetermined applications of water, pesticides and nutrients to split applications based on the actual status of the biophysical system;
2. Changes in the structure of the biophysical system, i.e., shifting from pure stands to mixtures of varieties, species or crops in the same field, including intercropping and agro-forestry;
3. Diversification of the biophysical and technical systems, through inclusion of more and other crops in the crop rotation or production enterprise;
4. Institutional changes, including specific markets providing technical support and economic value to technical systems targeted at the protection of the farm environment in a specific region. The certification of origin is a typical example but it is still mainly targeted at quality of the product with limited incentives to protect the environment; and
5. Combination of the previous clusters, where the institutional environment of the farm is organized to promote agro-ecological innovations and their recognition and economic valuation by the society. Despite its limitations, organic farming is still the best example of a form of agriculture forcing farmers to adopt diversified crop rotations, crop associations, soil and nutrient management and providing recognition of these efforts and risks in a specific market.

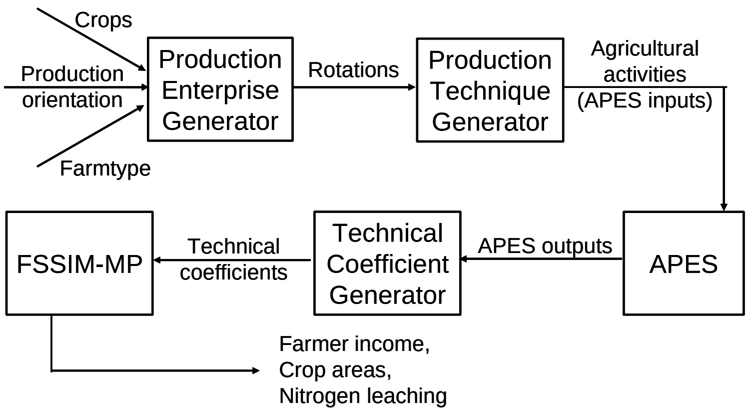

Figure 3. *Methods and tools to capture agronomic knowledge in SEAMLESS-IF. For an explanation, see the text*

Following Figure 3, a broad range of such agro-technical innovations can be generated using the so-called Production Enterprise Generator, which can generate crop rotations from a list of crops and pre-defined filters (cf. Dogliotti et al. 2003) and a Production Technique Generator, which adds production techniques to the production enterprises as combined variants of general, nutrient, water, pest and disease, and conservation management (Janssen et al. 2006). Such generated enterprises and production techniques (i.e., agro-technical innovations) can then be assessed in terms of input–output coefficients through the use of APES, which is capable of simulating defined cropping systems and production techniques, complemented with formalized expert knowledge on, e.g., labour, pest and disease management and machinery in a Technical Coefficient Generator. The derived input–output coefficients are then used in a bio-economic farm model (FSSIM-MP) to simulate allocation of current and/or alternative activities to a farm, given a set of constraints and farm objectives. That model then provides income and other indicators for the farm level.

THE ROLE OF AGRONOMY IN INTEGRATED AND MULTI-SCALE ANALYSIS

The SEAMLESS methodology has been presented as an example of a method for integrated assessment of agro-environmental policies and new technologies in agriculture. We believe it meets some key aims associated with research for integrated assessment identified in the first part of this chapter (Bland 1999). The example also illustrates both the essential and the partial role of agronomic research on plants, crops and cropping systems in integrated analysis. Too often the agronomic part is replaced by statistical relationships derived from surveys or census data, hiding or ignoring any causal relationships based on insight in agro-ecological processes, and hence rendering it impossible to forecast future developments and technological innovation. This is often the case in analyses dominated from social or economic science or carried out from a non-agricultural perspective (e.g., a nature-conservation or environmental viewpoint). On the other hand, the use of expert knowledge to assess agro-technical innovations (e.g., from farmers or farm advisors) is generally biased by the partial information they derive from their experiments (mainly production and economic aspects) and their strong dependency on the local pedo-climatic conditions. At the same time, the example illustrates that agronomic knowledge must be integrated with information on, e.g., resource endowments, variation in farm households, farmers' objectives, agricultural markets, and a variety of market and agro-environmental policies.

Agronomic principles and processes must be summarized to the proper level of abstraction, such that only the essential information is included in the analysis. This is far from trivial and depends much on the questions at stake and the scaling methods adopted (Ewert et al. 2006). Hence, it is neither easy to prescribe general procedures for this, nor to develop generic tools. In the SEAMLESS Integrated Framework it is attempted to develop stand-alone components for each hierarchical level and a flexible modelling framework to assemble the model-typology-indicator chains required to assess complex scenarios. For point and field scales, agro-ecological knowledge is captured in mechanistic simulation models. In the bio-economic farm models agronomic knowledge is summarized in input–output coefficients of discrete agricultural activities. Finally, at agricultural-sector level (EU25) agronomic knowledge is further summarized from multiple runs of the farm models, resulting in price–supply relationships or so-called elasticities.

An important question, not addressed in this paper, is the uncertainty associated with summarizing agronomic knowledge and how this affects (accumulates) in a modelling chain underlying integrated assessment. Although individual model components at field and farm level can be evaluated fairly well, this is far more complicated in a series of linked models, used for forecasting purposes. This will constitute an important research challenge.

Obviously, the SEAMLESS example only provides one of the multiple ways of dealing with the integration of agronomic knowledge in multi-scale assessment studies. There are many fundamental questions underlying this integration, which are much related to problems of up- and down-scaling and interdisciplinarity (Ewert et al. 2006; Dalgaard et al. 2003). We anticipate that agronomy must play an increasing role in pushing the envelope of such fundamental scientific questions, if it wants to play a key role in a changing research and policy agenda in which agriculture is no longer a separate activity but increasingly part of integrated economies, resource use problems and policies.

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