# A window of opportunities

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**Barbara Sterk**

# A window of opportunities

## The contributions of land use modelling to societal learning

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# Acknowledgements

Thesis-writing is often portrayed as a lonely activity. It is, and it is not. While writing, one cannot avoid at times to more or less withdraw from social life (skipping lunch at Zodiac, just to mention one sin), and to spend many hours with only a computer to socialize with. At the same time, the research itself brings one into contact with a great variety of people. And even when physically alone one tends to be in continuous imaginary debate with others. At this point, I will seize the opportunity to render thanks to a number of people who were involved in my work in some way.

I was very fortunate to have an excellent supervision team consisting of Martin van Ittersum and Cees Leeuwis. Every new phase in the research seemed to require a new configuration of the three of us in terms of relevant research approaches, expertise and competences. Without trying to retain the old habits and approaches that proved effective in the past, every time, the three of us moved and experimented till we felt comfortable again. For me, this ‘moving’ constitutes doing proper science. It is entirely due to the persevering attitude of Martin and Cees that I learned to move consciously.

In the first, very exploratory phase of my PhD trajectory I was in the comfortable position to be guided by an advisory board as well. This board consisted of Herman van Keulen, Walter Rossing and Gerrie van de Ven. Others functioning in the capacity of counsellor occasionally –though frequently not entirely voluntarily I am afraid– were my roommates Jochem Evers, Marc Metzger, Ilse Geizendorffer and Sander van Delden, mental roommates Sanne Heijting and Bart Timmermans and the Zodiac lunch group. I want to thank all of you for your support.

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‘The last mile is the longest one’. Not entirely to my happiness, it appeared true. This ‘last mile’ became a family business with grandparents taking care of grandchildren far more than usual, a husband taking over everything apart from the thesis writing, sleeping and eating, a daughter hinting her mother “maybe not to go to work today”, and the whole family being involved in those very final touches of a PhD thesis, such as a Dutch summary and the cover. What to say? I have been very lucky to be in such a supportive environment.

Barbara Sterk Wageningen, November 2007

# Contents

# 1

# General introduction

## 1.1 Scope

“Designing land use options and policies. Fostering co-operation between Kasparov and Deep Blue?” was the title of a paper of by Rossing and colleagues in 1999. The second part of the title referred to a match between the world champion chess and a famous chess computer at the time. In a later section of the paper (p. 51), the authors elaborate “The debate on the usefulness of computer techniques in areas where the experienced human mind serves perfectly well, aided by keen observation, is not exclusive to the issue of land use design. Numerous parallels can be named to join the playful duel paraphrased in our title, ranging from medicine to architecture, from optics to flight control, and many more. Skilled master mind or dumb repetitive power? We feel the need to move beyond the ‘mind or machine’ contrast, and focus on how human design capacities can be integrated productively with computer capacities. After all, even top chess players have come to use computers as analytical aids and sparring partners.” It was this premise of an enhancing effect of science-based land use systems models that forms the backbone of this thesis work. What is to be enhanced is the learning of, e.g., farm managers and/or land use planners at local, regional, national or international level, to solve a land use related problem, such as: the conservation of a diverse range of ecosystem services simultaneously, including biodiversity and the provision of food and fibre (e.g. DeFries et al., 2007), or undesired emission of nutrients from farms (e.g. Shepherd & Chambers, 2007). The aim is to develop guidelines for those who wish to pursue the use of science-based land use models to contribute to societal problem solving. In the following Sections, first land use modelling and its relation to societal problem solving is introduced in more detail, followed by an elaboration of the concept ‘learning’. Subsequently, the research question of the thesis is presented. This Chapter concludes with a history of the research trajectory, at the same time the outline of the thesis.

## 1.2 The decision-support ambitions of land use system modellers

Land use system modelling has its roots in land use system analysis. Land use system analysis identifies options for a more sustainable development of land use (Van Ittersum et al., 2004). Land use system analysis has its origins in soil science and agronomy. The term ‘land’ in land use system analysis refers to the biological and physical environment in which people make their living. It encompasses topography (landscape), the natural organisms living in and on the land (plants and animals), natural water resources (rainfall, streams and water bodies) and weather parameters, such as sunshine and air humidity (FAO, 1976). Many researchers in the domain of

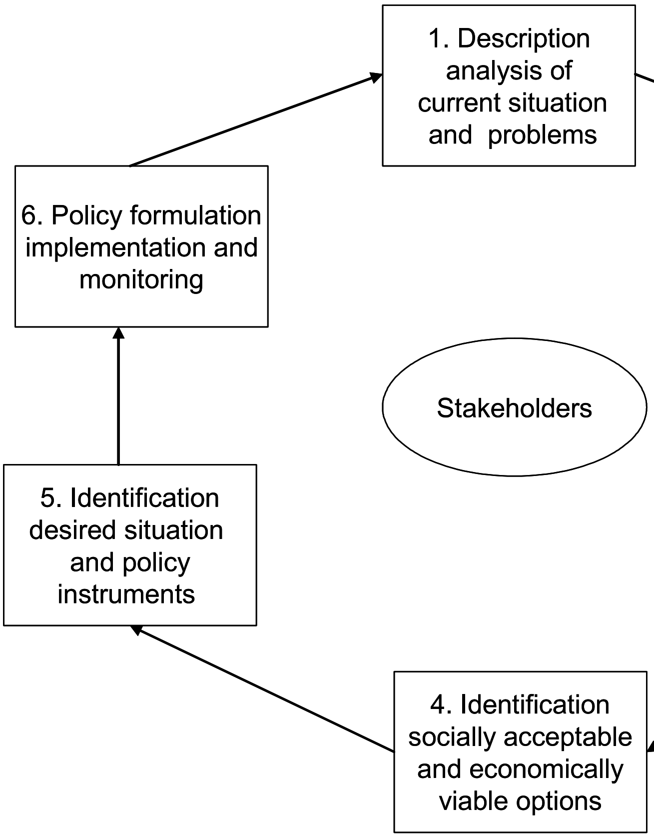

Figure 1. Development cycle of policies for natural resource management (Van Ittersum et al., 2004).

land use system analysis have been motivated to generate innovative solutions to societal problems. In the 1960s and 1970s, land use suitability maps provided rough indications of the agronomic potential of different types of soil and landscape to feed land use policy. The first quantified land use system analyses were technical-economic feasibility studies for regional policymakers. Soon after, computer technology enabled the integration of additional environmental and societal objectives (Van Paassen, 2004, p. 13). In 1991, Sage established the potential of computer-based models as a source of advice for tackling management problems with the concept of the Decision Support System or DSS (McIntosh et al., 2007). This potential was also recognized within the land use systems research community. As a result, a large number of computer-based models and tools have been produced over the past decades with the aim of providing support to policy and management (Walker, 2002). Different types of land use models were envisaged for distinct phases in policy making (Fig. 1): so-called projective and predictive land use models would play a role in the phase of problem identification; so-called explorative models would help to define objectives and explore the solution space; and again predictive models were to facilitate the assessment of the feasibility and desirability of possible measures (Van Ittersum et al., 1998). At the farm level, modelling was expected to support decision-making because it allows for the exploration of alternative management options (Rossing et al., 1997; Herrero et al., 1999; Ten Berge et al., 2000; Bernet et al., 2001).

## 1.3 From decision- towards learning support

At first, modellers referred to the potential decision-support function of their product. The shift from ‘decision support system’ to ‘learning tool’ in literature reflected a change in conceptualization of how decisions come about (Walker, 2002). Instead of rational decision-making as a rule, regular decision-making became regarded as “the final outcome of longer lasting learning processes with varying degrees of deliberateness and consciousness” and rational decision-making as the exception (Leeuwis, 2004, p. 152). Here ‘learning’ does not refer to the compulsory classroom situation. It is less of a goal in itself. Rather, the learning takes place in the context of a professional practice and is immediately connected with diverse human values (Leeuwis, 2004). Learning through experience has been coined ‘experiential’ learning. The widely referred to model of experiential learning of Kolb (1984) indicates that such learning occurs from a continuous interaction and iteration between thinking and action. Actions result in certain experiences, which are reflected upon, and subsequently generate learning, from which new actions can emerge. Because this way of learning occurs in and from practice, it can touch a broad range of issues, varying from the state or functioning of social, economic, biophysical and technical systems to perceptions regarding an actors’ own (and other actors’) aspirations, capacities, opportunities, responsibilities, identities, duties, etc. (Van Mierlo et al., in press). The conceptualization of land use models as learning tools was accompanied by a growing interest in participatory modelling. The reasoning was that the participatory mode of model development creates facilitating conditions for learning. Participation was to add to the model development process the necessary relevance, credibility, and commitment for effective learning (Parker et al., 2002; Jakeman et al., 2006).

## 1.4 Current challenges

Though there is still optimism about the potential of land use modelling to contribute to societal problem solving (e.g., Santé & Crecente, 2006; Matthies et al., 2007; Van Delden et al., 2007), from recent publications a less unambiguous image arises. A number of scholars perceive the impact to societal problem solving as too limited. An unbalanced attention for model development at the cost of investments in model utilization is seen as one of the main causes (McCown, 2002a; Van Ittersum et al., 2004; McIntosh et al., 2007; Rossing et al., 2007). Others, reporting model use outside the scientific sphere, do not explicitly analyze this use for its impact, and the reasons for this impact (e.g. Rossing et al., 1997; Jansen et al., 1999; Stoorvogel et al., 2004a). For one thing, the link between participatory modelling and learning for change still needs to be convincingly demonstrated. Furthermore, frequently, ‘critical success factors’, such as the representation of uncertainties in computer models, the need for proper timing, the ease of use of graphical user interfaces and transparency are reported (e.g. Saloranta et al., 2003; Oxley et al., 2004; Mysiak et al., 2005; Van Delden et al., 2007). However, apart from the little researched participation approach, there are no suggestions how to integrate those success factors in an operational approach to develop and apply land use models for societal problem solving.

## 1.5 Research question

This thesis investigates the contribution of land use models to learning for societal problem solving. The objectives were to develop understanding about impacts of land use models on societal problem solving, and the reasons for those impacts that can guide future arrangement of model development and application. The key question that the present study sought to answer is: *How, when, and for what reasons does land use modelling enhance learning in the context of societal problem solving?*

## 1.6 Methodological approach

Unlike many other research projects, we did not deem it necessary to develop a model ourselves to investigate the contribution of land use models to learning. We opted for a mixture of approaches and disciplines encompassing model design as well as social science theory and methodology. The above presented research objectives were geared towards gaining an in-depth understanding of the learning practices of social actors in model supported change trajectories. A research tradition that allows a contextual analysis of social dynamics and interrelations is the case-study approach. For our purpose, it meant the close following (or reconstruction) of events and interactions in and around a selected change process, using qualitative research methods, such as participant observation, in-depth interviewing, qualitative literature analysis. The Plant Production Systems Group of Wageningen University had available a number of operational goal-based farm system models that had been developed in collaboration with a number of other groups of Wageningen University and Research centre. Goal-based land use models may be defined as objective-oriented tools for exploration of alternative, promising land use systems. The available and operational goal-based farm models were the starting point of the empirical work in the first phase of the research. Later, we broadened our scope, a development which is further clarified in the outline of this thesis.

## 1.7 Outline of the thesis

Our original position was that "Today, availability of a number of operational farm modelling tools and of large farm innovation ('prototyping') programmes offers excellent opportunities to carefully assess the potential of explorative farm modelling in strategic innovation trajectories *and* to initiate development of a next generation of explorative farm models" (PhD proposal, 2002). Those 'explorative farm models' were the above introduced goal-based farm system models. Protoyping refers to the systematic development of farming systems following a well-defined methodology, either on experimental farms or with commercial farms (Vereijken, 1997)." The second and third Chapter report on the assumed complementarity of the two approaches in the Netherlands. In Chapter 2, the learning practices in Dutch prototyping projects form the core of the analytical work to find a niche for goal-based farm system models. Chapter 3 provides an analysis of the application of the prototyping methodology on commercial farms over the years to assess opportunities for farm system models for enhancing this prototyping work. In Chapter 4, an effort is made to integrate goal-based farm system modelling and on-farm research similar to prototyping in Uruguay. The Uruguayan case complemented the research in The Netherlands for two reasons. Firstly, the context for the thesis work in Uruguay deviated in several possibly relevant aspects from the Dutch work: the on-farm research was starting up and national agriculture-related policies had relatively low impact on farm management. Secondly, already existing and fruitful scientific collaboration with the Uruguayan researchers offered opportunity for the calibration and subsequent experimentation with a goal-based farm system model in the on-farm research.

The research reported in Chapters 2 to 4 yielded valuable insights, in particular what and when land use models can add to learning. However, the question how model development and application need to be arranged to enhance learning received less attention. Therefore, rather than developing a new model ourselves and to test its application as foreseen in the above introduced PhD proposal, we preferred to study experiences of others with the contributions of land use models to societal problem solving. To this end, the focus was broadened from solely goal-based farm models to land use models in general. In Chapter 5, we propose and test a conceptual framework that relates the work done preceding and parallel to model use to the roles models have in multi-stakeholder contexts. Chapter 6 addresses policy-oriented land use modelling work. In this Chapter, the concept ‘boundary arrangement’ is introduced to identify a number of existing modeller-policy arrangements and their consequences for model functions and methods that facilitate effective model use. Chapter 7 gives the general discussion on how and for what reasons land use modelling enhances learning, several grips for those who wish to pursue the use of science-based land use models to contribute to societal problem solving, and a research outlook.

# 2

# Finding niches for whole-farm design models – contradictio in terminis?

**Abstract**
Whole-farm design models quantitatively analyse the effects of a variety of potential changes at the farm system level. Science-driven technical information is confronted with value-driven objectives of farmers or other social groupings under explicit assumptions with respect to exogenous variables that are important drivers of agricultural systems (e.g. market conditions). Hence, farm design is an outcome of objective specification and the potential of a system. In recent publications, whole-farm design modelling has been proposed to enhance (farm) innovation processes. A number of operational modelling tools now offers the opportunity to assess the true potential of whole-farm design modelling to enhance innovation. In this Chapter, we demonstrate that it is not trivial to find niches for the application of goal-based farm models. Model outcomes appeared not to match questions of farm managers monitoring and learning from their own and other farmers' practices. However, our research indicates that whole-farm design modelling possesses the capabilities to make a valuable contribution to reframing. Reframing is the phenomenon that people feel an urge to discuss and reconsider current objectives and perspectives on a problem. Reframing might take place in a situation (i) of mutually felt dependency between stakeholders, (ii) in which there is sufficient pressure and urgency for stakeholders to explore new problem definitions and make progress. Furthermore, our research suggests that the way the researcher enters a likely niche to introduce a model and/or his or her position in this niche may have significant implications for the potential of models to enhance a change process. Therefore, we hypothesize that the chances of capitalizing on modelling expertise are likely to be higher when researchers with such expertise are a logical and more or less permanent component of an ongoing trajectory than when the researchers come from outside to purposefully search for a niche.

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Paper by B. Sterk, M.K. Van Ittersum, C. Leeuwis, W.A.H. Rossing, H. Van Keulen, G.W.J. Van de Ven; Agricultural Systems 87 (2006), 211-228.

## 2.1 Introduction

Traditionally, agricultural research has a firm rooting in empirical and experimental work. However, since the early 1970s this has been increasingly complemented by tools and methods from systems analysis (De Wit, 1978; Maat, 2001, pp. 225-246). Systems analysis and mathematical modelling enhanced the capabilities for testing new hypotheses through design and analysis of specific experiments and enabled explanation of results in terms of underlying processes. Following this phase of theory development and model testing, models were increasingly applied for extrapolation of location-specific knowledge and results in time and space (Van Ittersum et al., 2003). Gradually, modelling and empirical approaches have become integrated, mutually supportive research activities, as agricultural research became synthetic, rather than purely analytical. Since the 1990s, cropping system models have been successfully used in the farming context. Particularly the APSRU group in Australia has been involved in studies to examine which biophysical ánd social factors have to be considered in making generic simulation models applicable to location-specific problems and appealing to farmers with farm-specific interests and issues (Keating & McCown, 2001; Carberry et al., 2002; McCown, 2002a). Cropping system models are particularly powerful in addressing plot scale issues, or for analysis of relatively simple cropping systems, comprising only a few crops. They are, however, less suitable for redesigning entire farming systems and complex crop rotations, in which yield-defining, yield-limiting and yield-reducing factors strongly interact and determine ultimate production options (Van Ittersum & Rabbinge, 1997).

Economic developments, environmental degradation, maintenance of a social infrastructure are some of the reasons for (inter-)national, regional and/or local administrations/policy makers to actively pursue formulation and implementation of land use policies. As a result, at micro-scale farmers in The Netherlands and other parts of Europe are continuously provided with incentives to innovate their systems, to meet shifting economic, environmental and societal objectives (Falconer & Hodge, 2000; Lütz & Bastian, 2002; Schröder et al., 2004). The growing concern about food safety and environment has led to new initiatives in the agricultural network (Hansen, 1996), such as integrated farming (Wijnands & Vereijken, 1992) and increased attention for the potentials of organic farming (Rigby & Cáceres, 2001; Michelsen, 2001). The search for more sustainable farming systems included a stronger emphasis on increased efficiency of internal cycling of resources and restricted use of external inputs. Anticipating this trend, researchers have developed conceptual frameworks to support the analysis of entire farming systems (Altieri, 1995; Ison et al., 1997). Dutch farming systems research has elaborated two main system analysis and design methodologies, i.e. on-farm prototyping (Vereijken, 1997) and goal-based farm modelling (Ten Berge et al., 2000).

Goal-based farm models may be defined as objective-oriented tools for exploration of alternative promising farming systems. Directed by the formulation of conflicting objectives (e.g. economic profit, minimal nitrogen leaching) and the potential of a system, the consequences for farm management of a preference for one of the objectives are explored. Thus, farm design is a consequence of objective specification and the potentials of the system. Multiple Goal Linear Programming (MGLP) is the most widely used integrated modelling approach in goal-based farm models.

The goal-based farm models developed for the Dutch agricultural sector highlight agronomic, environmental and economic dimensions of issues at stake in the Dutch arable, bulb and dairy farming sectors (Ten Berge et al., 2000; for non-Dutch examples see Nicholson et al., 1994; Herrero et al., 1999; Bernet et al., 2001; Castélan-Ortega et al., 2003; Dogliotti et al., 2005; Veysset et al., 2005). The models provide a quantitative description of the trade-offs between different objectives, for instance gross margin, nitrogen surplus and use of chemical crop protection agents. The models integrate production ecological component knowledge at crop and/or animal scale (Hengsdijk & Van Ittersum, 2002). This component knowledge (Van de Ven et al., 2003) is aggregated to farm scale and translated into selected indicators of farm performance. Linear programming is applied at farm scale to design optimal farm systems with respect to specified target values of the formulated objectives (Fig. 1). The Dutch goal-based farm models typically allow addressing ‘what-if’ questions with respect to alternative visions on the potentials of the system and the consequences of policy objectives. Such models generate a range of *possible* designs rather than probable or plausible developments.

Goal-based farm modelling has been developed as an *academic* means to analyze the effects of a variety of potential changes at the farm system level. The results define a ‘window of opportunities’ for farm performance. It raises the question whether this unique capability could be of value to actors involved in farm innovation processes ‘in the field’ such as farmers, extension officers, policy makers and applied researchers. In working towards optimization, a number of choices have to be made of which the effects are difficult to ‘predict’, but can have a considerable impact on farm performance. In this context, goal-inspired questions like “Is this crop rotation scheme the most optimal set-up given my objectives?” or “Are our goals attainable?” seem opportune. The explorative capacity of goal-based modelling could be supportive by broadly demonstrating consequences of a preference for specific objectives. The integrating nature of goal-based modelling and the possibility to ‘play’ with the system might enhance learning about the different components, their mutual relations and the

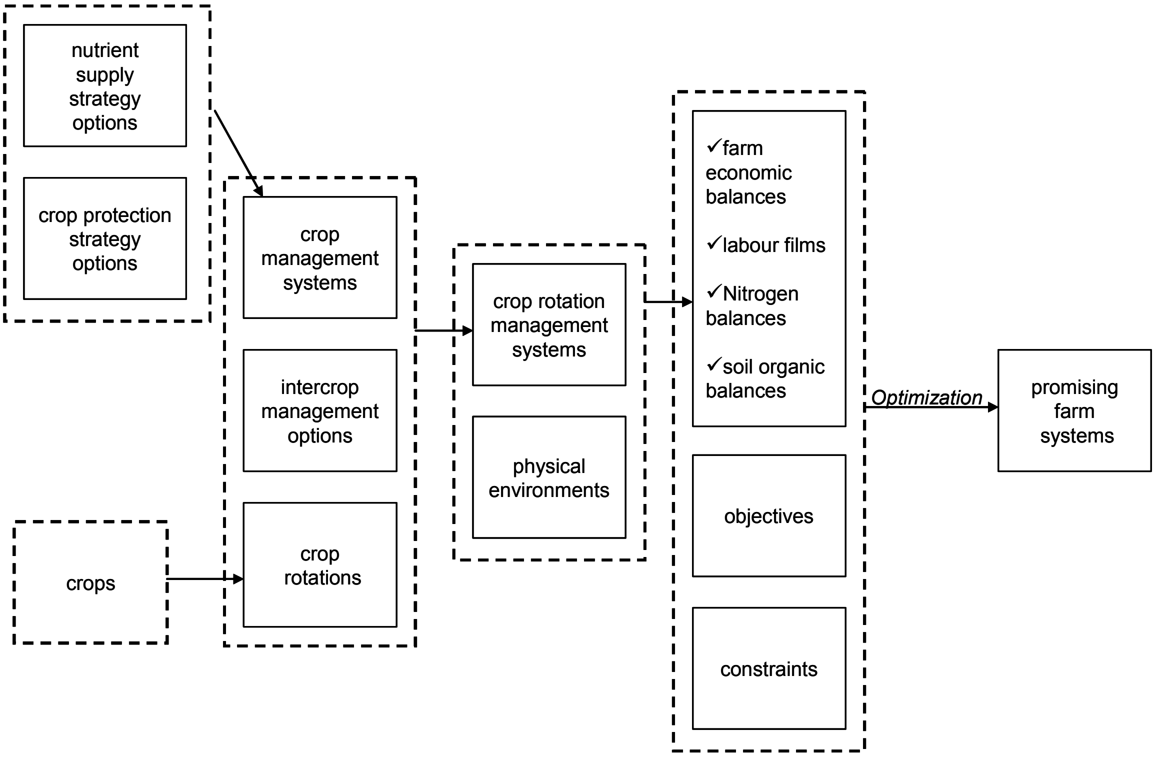

Figure 1. Outline of the model structure of a goal-based farm model for Dutch arable farming (adapted from Dogliotti, 2003). Broken line block incorporates input data for calculation procedure; Arrows indicate calculation procedures.

potentials of the farm system.

Repeatedly, researchers have suggested that goal-based modelling would be a useful method to support (farm) innovation processes (Herrero et al., 1999; Zander & Kächele, 1999; Bernet et al., 2001; Veysset et al., 2005). As far as the authors know, only two attempts to actually use the capabilities of goal-based farm modelling outside the academic community have been reported, i.e. one in The Netherlands (Rossing et al., 1997) and one in Burkina Faso (Van Paassen, 2004). We judged this evidence too ‘thin’ to draw general conclusions about the practical value of goal-based modelling. As a further step in that direction, in this Chapter we assess the potential of goal-based farm modelling to enhance innovation processes. In the next two sections, criteria to select likely niches and the conditions under which the research took place are presented. Subsequently, the quest for a niche to integrate one of the available goal-based farm models in an innovation trajectory is described. In Section 2.5, the two reports (Rossing et al., 1997; Van Paassen, 2004) on actual use of goal-based modelling are revisited to strengthen analysis of the research data. In the last Section, the contours of a likely niche for goal-based modelling are sketched.

## 2.2 A priori criteria to select likely niches

The starting point of research was the goal-based farm modelling methodology. We had two prepared farm models (Ten Berge et al., 2000; Van de Ven et al., 2002) for Dutch arable farming at our disposal and one which could be easily amended to Dutch conditions (Dogliotti et al., 2003; 2005). The first step was identification of suitable farm innovation trajectories offering the possibility to assess the potential of the methodology to enhance innovation processes. We hypothesized that a likely niche had to meet four basic conditions, hereafter referred to as 'niche criteria':

1. Actors contemplating change, i.e. actors taking part in an innovation trajectory;
2. Lay out and management of the entire farm, rather than management of single crops, is an issue;
3. Functioning discussion platform;
4. The researcher is allowed to become involved as participant observant (definition in Section 2.3).

In relation to the first two conditions, the focus on *change* was inspired by the experiences of Carberry et al. (2002) in the FARMSCAPE project. They found that farmers' interest in information 'from outside' (i.e. a new source of information) is high when they are contemplating changes to their management or search for means to improve their decision-making. Furthermore, we assumed that the information 'from outside' (in our case a goal-based farm model) should be relevant in connection to the activities of the farmer. As the methodology is developed to address problems at the level of the farm as a whole, we hypothesized that its application domain would include situations in which whole-farm management issues (e.g. crop rotation, conversion to organic farming, balancing nutrients at the farm level) are at stake.

Concerning criterion 3, experiences in agricultural practice with a variety of computer-based decision support systems (DSS), ranging from almost pure farm registration to cropping system simulation, suggest that DSS have to be embedded in wider support activities and networks (Leeuwis, 1993; Cox, 1996; Carberry et al., 2002). DSS output must be 'translated' (i.e. 'contextualized' or 'situated') by users. In this process, wider support activities and networks seem to have an important enhancing function. Manifestation of the wider activities and networks can vary from a decades-old farmers' study club to a (short) research project, but the discussion platform has to be characterized by a dialogue-enabling atmosphere, i.e. actors meet on a regular basis and discussions on farm management related topics are part of these meetings.

Regarding the last niche criterion on the list, our research approach was inspired by two related notions about the role of DSSs in change processes. First, a computer model might have the potential to *contribute* to a change process but it does not encompass the process itself. To reach the point of ‘a contribution to’, scholars nowadays agree that it is essential to view the integration of a computer model in a change trajectory as a *learning experience* for all involved actors (Cox, 1996; Argent & Grayson, 2001; Walker, 2002). McCown (2002b) describes the implications of this learning perspective for the position of a researcher: “[…] shift in emphasis from ‘design’ to ‘learning’, without abandoning design. Users must undergo an iterative learning and practice change process. The researchers must be prepared to be involved in, lend support to, and learn from this process – learn what the farmers are learning and learn what this means for conduct of their own future activity.” None of the members of our research team actively participated in a user-oriented ‘iterative learning and practice change’ process at the time of this research. Participant observation allowed us to get involved in and learn from a change trajectory to identify an opportunity to integrate goal-based farm modelling.

## 2.3 Methodology

The quest for a likely niche was executed by a research team with good contacts in several Dutch on-farm innovation initiatives. One researcher acted as participant observant; the team monitored the research findings and guided the research process. The researcher always entered the initiatives as an outsider without a specific task in the initiatives themselves, unfamiliar with the major part of its participants and its internal state of affairs. The term ‘participant observation’ comprises both passive observation and a more active involvement from the side of the researcher. Passive observation led to questions and findings which were then actively fed back to the actors of the investigated activity. The active part took the form of informal talks during meetings and arranged interviews. The participant observations were reflected upon in the research team meetings, which subsequently formed the basis for a new cycle of questions, verification of findings and feedback. The iterative procedure of participant observation, permanent reflection and formulation of new questions enabled the research team to develop coherent understanding of the investigated activities.

Four cases were investigated, all meeting our niche criteria:

- A project aimed at developing options for the redesign of experimental farms, in which the university, a strategic research institute and an applied research organization were involved (hereafter referred to as the ‘BLOEM’ case);
- Farmers’ study groups; and
- Two pilot farm-based projects, i.e. ‘Farming with a future’ and ‘BIOM’, both co-ordinated by researchers and the extension service.

In three cases, a number of group meetings were observed in 2002 and 2003: BLOEM, Farming with a future and BIOM. The participant observation included all project participants (i.e. farmers, extension officers and researchers), though farmers constituted the major source of information. To research farmers' study groups, a new group of growers was approached. Through a search on the internet, a list of Dutch arable farmers was composed. From this list and geographically spread, persons were approached by telephone with the question whether they were a member of a study group. All respondents were conventional (i.e. mainstream, non-organic) farmers. All identified members of study groups agreed to give a short interview of about 15 minutes. After fifteen interviews, the data were saturated, i.e. the data were coherent, complete and no more new insights were gained.

## 2.4 The quest

The four cases briefly introduced in Section 2.3, were investigated to identify a possible niche to integrate and subsequently assess the added value of goal-based farm modelling outside the academic community. In the end, the combination of the four cases formed a meaningful quest, not the individual cases, as none of the four cases eventually offered a suitable entry point for application of the methodology. Therefore, the data presentation focuses on the role of each case in the entire quest rather than on the details of the individual cases. The cases are presented in chronological order. Some cases overlapped in time. These cases are ordered in such a way that they illustrate the authors' line of reasoning. Table 1 summarizes the main features of each case.

### *2.4.1 Case 1: Redesigning experimental farms (BLOEM)*

In the first half of the 1990s, the term 'prototyping' was introduced to define a systematic approach to designing and evaluating entire farm systems at both experimental and commercial farms (Vereijken, 1997; 1999). Ten Berge et al. (2000) suggested that goal-based farm modelling could provide an effective complement to empirical work as only a few selected farm prototypes can be tested empirically. To select the most promising option(s), it would be helpful to perform different optimizations in order to generate new angles and get a quantitative insight in the consequences of emphasis on specific objectives. The Farming Systems Research group of the Dutch Applied Research Organization employed the prototyping procedure to develop innovative integrated and organic farm systems (Wijnands et al., 2002a). After members of this group developed an active interest in the potential contribution of modelling, a joint research project of the farming system research

Table 1. Summaries of the four cases which were part of the quest.

| Cases | Relevant features | Main observations |
|---|---|---|
| BLOEM | Potential users formulated questions about options in the frame of the redesign process of experimental farms<br>Cooperation of three research groups for several years | Question had already been answered in a different way, at the time the model was operational |
| Farming with a future | Aim of the project was to optimize crop and farm systems performance<br>Part of the project activities took place in regionally organized small groups<br>Closely related research groups were responsible for project coordination thus permission to do research was relatively easy to obtain | Participants discussed mostly specific crop- and field-related issues together<br>Participants were keen on gaining more insight in biophysical processes in time and space<br>Monitoring-inspired questions, no interest in a discussion about the project goals or the potential of a specific farm system |
| Farmers' study groups | Farmers usually participated for several years or even decades in a group<br>Not directed by a research project set-up | Management of the entire farm was a non-issue in these study groups of conventional arable farmers |
| BIOM | Project had just started<br>Four years of meetings of fairly stable groups were planned<br>Organic sector<br>One of main objectives of the project was optimization of farm performance | Monitoring-inspired questions (similar to Farming with a Future)<br>Marketing, field and crop management were the major issues of group discussions |

group and goal-based farm modellers (hereafter referred to as 'modellers') of the university and a strategic research institute was initiated in 1998 to generate inspiring alternatives for arable farming prototypes to be implemented at experimental farms. The modellers, therefore, developed a goal-based farm model, designated 'BLOEM' (cf. Ten Berge et al., 2000). In 2003, output of BLOEM was presented to applied researchers, who at this occasion indicated that the modellers had missed the chance to contribute ideas to the design of a new farm system. The main point of criticism was that the development period of the model had taken too long. In the five years between initiation of the collaboration and model presentation, the problems that had been at stake in 1998, had largely been sorted out. Hence, the collaboration was dissolved without follow-up.

### *2.4.2 Case 2: Farming with a future*

'Farming with a future' (Fwf) (2000–2004) was a Dutch project aiming at improving environmental performance in arable farming. The government financed the project and determined that special attention had to be paid to nitrogen management in relation to groundwater and surface water quality and ammonia emissions (Langeveld et al., 2005). In Fwf, farmers, researchers and extension officers worked on optimization of farm systems in seven regional teams. Research and extension-service staff was paid for its efforts; farmers basically collaborated on voluntary basis, they received a modest compensation for their investments. Fwf comprises of a range of activities at the individual and group level, e.g. personal advice and support by a regional extension officer, field visits in summer, national and regional discussion meetings in winter and monitoring of various aspects of farm performance based on intensive farm registration (Langeveld et al., 2003). Fwf seemed to meet all our niche criteria: working on optimization (i.e. change) in groups and a focus on nitrogen management, partly a farm-level topic. Admittance to the project was facilitated by the fact that one of its co-ordinators was well acquainted with several members of our research team and with goal-based farm modelling.

We learned that our interpretation of the project objective 'farm optimization' had been too one-dimensional. Indeed, in the course of the project, changes in farm management were implemented. However, a number of the participating farmers called in question whether they would continue on the same path, once the project had ended. Some measures, now subsidized or fully paid by the project, would then become rather expensive. Why did farmers participate in Fwf when not intending to innovate? The farmers mentioned a diverse range of reasons, including the wish to meet new people and make use of the opportunity to experiment with new techniques in a lease-construction. The following remark made by one of the participants adequately summarizes the wider view: "I don't think I perform technically or economically any better than the colleagues in my farmers' union study group because of the project, but I understand more of what I am doing, the background of things." What actually happened, according to our observations, was that participants were primarily interested to learn from others and to optimize their *knowledge*. As another farmer phrased it: "Because of Fwf I now farm more consciously." A goal-inspired type of question such as: "Is my crop rotation scheme the most optimal set-up for reaching the (project) objectives?" did not come to the fore. Instead, the farmers posed 'why' and 'how' questions inspired by quantitative and qualitative comparisons with colleagues, and over time. Their questions were inspired by the wish to monitor and learn from their own and other farmers' current practices (including some newly introduced variations), but not by an ambition to design a radically new farming system. The growers assessed their present position but this did not lead to any curiosity about a broader 'window of opportunities' than was reflected in the performance of other participants. In the rest of this Chapter, this type of learning, based on monitoring and comparing of qualitative data, is referred to as *monitoring-based learning.* In Fwf *monitoring-based learning* generated *monitoring-inspired questions*, not goal-inspired questions.

### *2.4.3 Case 3: Farmers' study groups*

One potentially explanatory factor for the finding that the Fwf participants were not actively pursuing farm redesign was the organizational and institutional history of the project. Researchers, extension officers and farmers were paid by the government to set up a temporary co-operation with support to policy-making as one of its objectives. Would farmers have acted differently in a discussion platform not officially linked to any policy or research organization? The most obvious candidates for helping to answer this question were members of autonomous farmers' study groups. These groups consist of farmers who know each other as friends, neighbours or colleagues and meet at the members' own initiative (Guijt & Proost, 2002).

Our limited investigation of activities of study groups started with the open question "What kinds of topics are addressed in the meetings?" None of the respondents listed a topic related to whole-farm management, such as the crop rotation, nutrient management at the farm level or conversion to organic farming. But how did these farmers then go about such change in their crop rotation schemes? "What do you mean by 'planning a crop rotation'? It is just there. Sometimes you fiddle a bit if that seems profitable." One respondent mentioned that he had started to grow gluten-free wheat after colleagues invited him to join a group producing this more profitable type of wheat on contract. Another was tipped off by the extension service to start growing a specific subsidized crop. When the subsidy was stopped, he reverted to his old crop rotation scheme. It became evident that also in a non-project environment farm management was not a topic of group discussion. Sometimes, an issue such as a change in the crop rotation was not even worth engaging the extension service. It was common knowledge, an “old fashioned topic”, one farmer commented, where little could be gained by discussing it.

### *2.4.4 Case 4: Optimizing organic farming (BIOM)*

The investigation of farmers’ study groups activities made clear that the Fwf farmers did not talk less or significantly differently about farm management change than their colleagues in study groups. In both cases, interviewees were mainly crop management oriented. The answers of the respondents suggested that management of the crop rotation as a unit was simply not worth much attention. Up to this point, the quest had not included organic farmers’ groups. In organic farming, the application of farm-external management instruments (e.g. fertilizers, crop protection measures) is far more restricted than in conventional farming (Wijnands et al., 2002b). Therefore, an organic farmer has to plan more strategically in comparison with conventional farmers, i.e., further ahead and more at the farm (instead of field) level. Hence, organic farming seems more complex in terms of farm management. Should we have directed our attention to the organic sector?

At the time of this research, an organic farming project, ‘BIOM’ was established. BIOM shares many features with Fwf: regionally oriented group work, same participating and funding organizations and an important role for farm registration as a monitoring tool. One of the main objectives of the project is to optimize practice (Sukkel et al., 2003). BIOM farmers were stimulated to work with what was often referred to as the ‘iron crop rotation’ concept as a means to optimize farm management. It implied a permanent ‘block system’, usually six blocks. Over the years, six crop blocks moved over six permanent plots in a fixed sequence. A block was defined by a group of crops with similar characteristics in relation to crop rotation demands (most importantly avoidance of soil borne diseases, nitrogen and weed management and soil structure) (Wijnands et al., 2002b). However, instead of the ‘rules’ of the crop rotation framework, the BIOM farmers preferred to discuss the market potential and management details of specific crops, just like the Fwf farmers. Contrary to our expectations, organic farmers investigated farm management similarly to their conventional colleagues, e.g., often crop-oriented and by means of monitoring-inspired questions. After four case explorations, the data were saturated. The findings were consistent and all practically possible diversity within the limits of the niche criteria had been captured. The quest to identify a likely niche to introduce a goal-

Table 2. Overview of comparative analysis of the quest, the Bulb Forum and the SHARES cases.

| Niche criterion | Quest | Bulb Forum | SHARES |
|---|---|---|---|
| Features of innovation trajectory | Overall, farmers made small, sometimes just temporarily adaptations while we had assumed significant and structural changes | To establish a dialogue as a first step towards developing systems that can meet both ambitious environmental and economic objectives | Project staff adapted work approach under pressure of donor; as consequence the staff became more dependent on the willingness of farmers to collaborate |
| Lay-out and management of entire farm is an issue | Entire farm management was a topic of discussion occasionally but the character of questions was such that they could not be evaluated by goal-based models | Questions about management options linked to new environmental and economic objectives | In first phase questions of both farmers and staff were monitoring-based; in second phase, perspectives on farm strategy became focal point of discussion for staff |
| Characteristics of the discussion platform | Farmers took part voluntarily, other partners were funded to participate<br>Projects were initiated by research organization and extension service at the request of government | New actor claiming a stake in the debate about the future of the flower bulb sector triggered establishment of consultation structure<br>Partners felt interdependent | Project staff was funded to develop activities in rural area; farmers were discussion partners on an ad hoc basis |
| Role of modeller | Visitor on a non-committal basis<br>Had operational model on offer | Researchers invited to make contribution to the current discussion in association | Permanent member of project staff<br>Introduces an operational model at own initiative |

based farm model was terminated. All promising pathways had turned out dead ends. In Table 2 the main observations from the quest are summarized.

## 2.5 Additonal sources for reflection: Two success stories

Though the analysis of the quest yielded several insights, we felt that it was not sufficient to fulfil the objective of the quest, i.e. to assess the potential of goal-based farm modelling for enhancing innovation processes. For one thing, it was impossible to evaluate the niche criteria on the basis of the quest data. The list of niche criteria directed the case selection. We could simply have selected unsuitable cases as a result of an incomplete list of criteria. To gain more insight in the unsuccessful quest and identify possible additional criteria, the quest (Section 2.4) was mirrored against the two earlier mentioned (Section 2.1) successful applications of goal-based models outside the academic community.

### *2.5.1 Case 5: The Bulb Forum (Jansma et al., 1994; Rossing et al., 1997, 1999)*

The first known case of practical application dealt with the design of flower bulb production systems in The Netherlands that could meet both environmental and economic objectives. The traditional stakeholders in the flower bulb sector were growers and parties involved in trade. In the beginning of the 1990s, environmental and consumers organizations claimed a say in the discussion about the future of flower bulb production. To facilitate the dialogue, the 'Bulb Forum', an association of growers and environmentalists, was established. The Bulb Forum observed that defending individual positions on income and environment played a larger role in the discussions than the development of a common view on the future. Moreover, the association felt that it lacked a systematic overview of management measures and their consequences for farm gross margin and environmental impact. To break the deadlock, the Bulb Forum approached the university with the question how environmentally friendly bulb production could be combined with economically viable farming. Fragmented agronomic information, value-driven objectives and other required input data were integrated in a goal-based farm model to assess agro-technical options for sustainable flower bulb production with a time horizon of 10 to 15 years. The involved researchers reported two informative observations about the role of goal-based farm modelling in the broader discussion about the desired development of flower bulb production systems: "[…] by separating objectives and agro-technical options, it became clear that polarization was caused by divergent views on poorly defined objectives, rather than by disagreement on agro-technical relations. Subsequently, the quantitative perspective on the trade-off between economic and environmental objectives enabled a transparent discussion on preferred developmental pathways." (Rossing et al., 1997, pp. 231-232). As a result "[…] not so much the model or the model results were made an issue of discussion, but rather the challenge in the results that farm management could be improved considerably beyond the current level without inherent and major financial consequences." (Rossing et al., 1999, pp. 68-69).

### *2.5.2 Case 6: 'SHARES', demand-driven development work (Van Paassen, 2004)*

In the frame of a Dutch academic research programme in Burkina Faso a goal-based model, 'SHARES', was developed in the late 1990s to integrate seven years of agro-silvo-pastoral research. During its development, the idea emerged to test its relevance for operational use. Parallel to the academic research programme there was a rural development project located in Burkina Faso funded by the Netherlands Development Cooperation. A member (further referred to as 'researcher') of the staff of this development project was approached to assess the value of SHARES for potential users. In a first phase, project staff members and later on the farmers, were invited to articulate problems and questions. The researcher failed to find questions SHARES could answer. Both staff and farmers brought forward monitoring-inspired agronomic questions. Consequently, the staff showed more interest in the crop growth models that were linked to SHARES than in the goal-based model itself. Then, the position of the staff of the rural development project changed. The main donors of the project insisted on all future project activities to be demand-driven. To be able to work demand-driven effectively, it was essential for the staff to improve their understanding of the strategies of the farmers. At this point, SHARES came to the fore again. The model was used to develop examples of the view of the staff on farm strategy, in the hope that presentation of these practical examples would trigger the necessary debate between farmers and project staff on farmer livelihood strategies and envisaged farm development. Model output was presented in the form of drawings to appeal to the farmers. Project staff met with farmers to talk about the SHARES drawings. As a result of both the modelling exercise and the subsequent discussions with the farmers, the staff felt that they had developed better understanding of the points of view of the farmers. First of all, the model results showed that the staff's estimates of the biophysical potential of part of the research area had been far too optimistic. This insight shed new light on the strategies of the farmers. Secondly, the discussions contributed to understanding of the significance of farmers' norms and values for farm strategies.

Comparing the Bulb Forum and SHARES cases, two aspects attract the attention. In both success cases related terms such as *objectives, perspectives, strategies* and *views* were introduced to explain the appreciation for goal-based modelling. Second, in both the SHARES and Bulb case, the *insight in the potential* of the discussed system served as an eye-opener to the target group. The model outcomes led the Bulb Forum to conclude that there was ample scope to improve environmental management without too many financial consequences. Similarly, in the SHARES case the project staff was surprised by the outcomes, in this case the calculated bio-physical potential of part of the research area.

## 6. Discussion and conclusions

In this Chapter, six cases were analysed (see Table 2 for a summary of the main observations, the four components of the quest are presented as one case) to assess the potential of goal-based farm modelling to enhance innovation processes (see Table 2 for a summary of the analysis). Two factors seem to be of key importance for understanding the impact of goal-based farm modelling in these six cases: 1. the role of the researcher; 2. conditions for goal-based learning. As for the first factor, a comparison of the quest, the Bulb Forum and the SHARES cases yielded two finding shedding light on the role of research. First, in both successful cases the researcher with modelling expertise had a legitimate and defined space –stretching over a certain period of time- within an ongoing project. In contrast, the participant observer in the quest was an outsider who entered other people's projects with her own agenda, at her own initiative, and with a relatively limited time horizon. The second finding relates to a comparison of the SHARES (case 6, Section 2.5.2) case and the quest. Both the SHARES and quest researcher worked supply-driven, i.e., they had one particular operational tool 'on offer'. However, the position of SHARES researcher, i.e., a legitimate and defined space to work, enabled her to wait longer for a stroke of luck than the quest researcher. To summarize, the two findings suggests that the position of a researcher in a likely niche may have significant implications for the employability of goal-based models. In retrospect, the whole idea of 'finding a niche' has proven to be a risky starting point. A more promising starting point might have been 'becoming involved in design' and then 'waiting for a niche to emerge'. Therefore, we hypothesize that the chances of capitalizing on modelling expertise are likely to be higher when researchers with such expertise are a logical and more or less permanent component of an ongoing trajectory than when the researcher comes from outside. As a logical result of this hypothesis, it cannot be excluded that an occasion to use a goal-based farm model would have arisen or cold even have been created in the quest. But for this to happen the quest researcher should have had a more established role in the BIOM and Farming with a future projects.

One more aspect to highlight in relation to the role of researchers in innovation trajectories is timeliness. A model can simply be ready for use too late, as the BLOEM case (case 1, Section 2.4.1) demonstrated. It implies that an appropriate model has to be timely operational as well whenever a researcher identifies an opportunity to use a model.

As to the second factor, i.e., conditions for goal-based learning, identification of similarities between the Bulb Forum (case 5, Section 2.5.1) and SHARES (case 6, Section 2.5.2) cases reveals important lessons. In both cases, pressure of a stakeholder creating a sense of urgency to make progress, evoked goal-inspired questions, i.e., the need to first understand the perspectives on problems before proceeding to the problems themselves. The SHARES case is especially illuminating in the sense that it demonstrates that monitoring- as well as goal-inspired questions can be formulated by the same group of people depending on contextual stimuli. Challenging of perspectives like occurred in cases 5 and 6 is referred to as ‘reframing’ in literature on negotiation processes (e.g., Putnam & Holmer, 1992; Kaufman & Smith, 1999). Aarts & Van Woerkum (2002) define reframing: “Reframing starts with the recognition of problems and interests of other people involved. In the process of reframing actors learn to understand the paradigms, metaphors, mindset or mental models that underpin how they operate. With this, one develops an awareness of one’s own thinking and its relationship to historically understandable views on one’s own interests. As a result, actors no longer take their frames of reference for granted. In this way, insight is gained on the relationship between one’s own problem and problems of others. In other words, problems are put into a new, broader perspective (or ‘frame’)”. The new, broader emerging perspective forms the basis for the search for more creative and more collective solutions (Aarts, 1998).

Thus, our research indicates that goal-based farm modelling has the potential to make a valuable contribution to reframing. Goal-based farm modelling appears to have this potential because it features two unique capabilities: (1) the methodology is design-oriented (i.e. it facilitates the distinction between objectives and agro-technical options) and (2) it provides methods to integrate quantitative knowledge. Clearly, goal-based modelling is not the only tool or method with the help of which reframing may be supported. Reframing requires that stakeholders somehow encounter – in a constructive manner – radically new horizons, perspectives or confrontational feedback. This may be aided by several means, varying from visiting a totally new environment, visualization techniques to the use of discussion techniques that are oriented to exploring the future (e.g., search conferences, Emery & Purser, 1996). Broadly speaking, those types of methods hinges on projections of a principally qualitative nature, a feature contrasting with those of goal based modelling as described above.

In addition, the findings support the hypothesis (Aarts & Van Woerkum, 2002) that reframing happens in situations of continuing, mutually felt dependency, i.e. dependencies that can not easily be broken off. However, as the quest demonstrated, reframing does not take place in situations where problems are discussed but do not need to become collectively owned to make progress. We conclude that the four niche criteria did not prove irrelevant but that the most important criterion was lacking: a situation in which reframing is likely to happen. Thus, a situation (i) of mutually felt dependency between stakeholders, (ii) in which there is sufficient pressure and urgency for stakeholders to explore new problem definitions and make progress.

In contrast to what is often easily claimed in publications (see Section 2.1), we have demonstrated that it is not trivial to find niches for the application of goal-based farm models. Researchers need to identify or perhaps create situations in which reframing is likely to happen and achieve an accepted position to bring in a model. The follow-up of this research aims to develop more detailed understanding of the role of goal-based modelling in reframing processes in order to further improve its capabilities to enhance such processes.

# 3

# Prototyping and farm system modelling – Partners on the road towards more sustainable farm systems?

**Abstract**

Farm system modelling and prototyping are two research methods proposed to enhance the process of developing sustainable farm systems. Farm system models provide means to formalize, expand and refine expert knowledge and to integrate this with scientific agro-ecological knowledge at the farm level. The prototyping methodology was developed for the design of more sustainable farm systems, either on experimental or commercial farms. The main features of prototyping are: 1. quantification of goals; 2. emphasis on multiple societal goals; 3. designing as an organizing principle; 4. iteration of system analysis, design and on-farm testing. Hypothetically, farm system modelling could enrich the prototyping methodology and vice versa. Taking a goal-oriented stance, a modelling exercise could reveal design options otherwise overlooked and extrapolation of prototyping results to other conditions and scenarios. The on-farm prototyping work could serve as a source of inspiration and information for farm system modelers. However, little cross-pollination between the modelling and prototyping efforts has occurred, even though the methodologies have been applied in parallel and in one country. Existing reports on prototyping projects merely present their methodological set-up and results, but lack description of the implementation of the methodology. We deemed insight into the implementation of prototyping essential to understand the discrepancy between theory and practice and to investigate the potential for cross-pollination between modelling and prototyping in the future. Three promising leads were identified to assess this potential, i.e. 1. Exploring goals of farm systems; 2. Exploring options for a change and improvement of farm systems; 3. Communication and extrapolation of project output. Analysis of more than two decades of Dutch prototyping research both on experimental and commercial farms indicated that prototyping on commercial farms is a highly localized process. Moreover, although the methodology manual suggests differently, goal formulation was not a distinctive phase of prototyping on commercial farms, so cross-pollination with farm system modelling could not occur (lead 1). As the timely operationalization and the localization of a farm system model demand considerable effort, contributions of farm model explorations to the localized change process on commercial farms (lead 2) seem impractical and unlikely.  For communication and extrapolation of prototyping output (lead 3), issue-specific (i.e. focus on a component of the system) models are increasingly used. For this purpose, we hypothesize that there may also be a role for farm system models.

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## 3.1 Introduction

Public-funded research is expected to contribute to the well-being of society. At the level of farm systems, this implies that agricultural research should enhance adaptability of farms to changing external factors. In the search for adequate research methodologies at farm level a multiplicity of approaches have been developed. From an instrumental point of view, three groups of methodologies can be distinguished: (1) computer modelling; (2) farm system experiments at experimental stations (e.g. Jordan et al., 1997; Jordan, 1998; Delate, 2002; Mueller et al., 2002; Helander & Delin, 2004); and (3) research with commercial farms ('on-farm research'). In the third group, a distinction can be made between research from a more detached or involved stance, here referred to as on-farm systems studies and action research (for background terminology see Alrøe & Kristensen, 2002). Note, in the literature the expressions 'farming systems research' (Collinson & Lightfoot, 2000) and 'farmer participatory research' (Okali et al., 1994) are frequently used instead of 'action research'. The trend towards undertaking more action research has been especially strong in developing countries. On-farm action research seemed to fit the concern for appropriate improvements for and empowerment of small-scale, illiterate and resource-poor farmers (Okali et al., 1994; Collinson, 2000).

In the more developed countries, questions about the multiple functions of agriculture in rural areas and the impacts of farming on the environment have left their mark on the development of systems research methodologies at farm level (Pacini et al., 2004; Gibon et al., 1999; MeyerAurich et al., 1998; Edwards et al., 1993). Compared to the preference for action research in developing countries, scientists in more developed countries have adhered rather to computer modelling (e.g. Gibon et al., 1999; Pacini et al., 2004), farming system experiments at experimental stations (e.g. Jordan et al., 1997; Jordan, 1998; Delate, 2002; Mueller et al., 2002; Helander & Delin, 2004) and on-farm systems studies (Drinkwater, 2002). Some of the few documented examples of action research in Europe are projects working with the 'prototyping' methodology (Vereijken, 1999). The main features of prototyping are: (1) Quantification of goals; (2) Emphasis on multiple societal goals; (3) Designing as an organizing principle; (4) Iteration of system analysis, design and on-farm testing. The methodology was implemented in a number of Dutch projects (Wijnands, 1992; Vereijken, 1997; Wijnands, 1997; Wijnands & Holwerda, 2003; Langeveld et al., 2005) and two EU-funded projects (Vereijken, 1999; De Haan & Garcia, 2002) on both experimental and commercial farms. On a smaller scale, the methodology was introduced in other sectors such as organic olive production (Kabourakis, 1996) and outside Europe (Stoorvogel et al., 2004b). At the end of the 1990s, ten years of

Table 1. The five steps of the prototyping methodology. Adapted from Vereijken (1997).

| | |
|---|---|
| 1. *Hierarchy of objectives* | To develop a hierarchy of objectives as a basis for a prototype in which the strategic shortcomings of current farming systems are replenished |
| 2. *Parameters and methods* | To transform the major objectives into multi-objective parameters and to quantify them. Subsequently, system technologies (Sumberg et al., 2003) are selected which are assumed to contribute to achievement of the objectives |
| 3. *Design of theoretical prototype and methods* | The selected system technologies are linked to the parameters on which they have an impact. In this way, the major and minor technologies and the (conflicting) conditions to the technologies become visible. On basis of this analysis, the technologies are further designed -in a logical order and guided by the set of conditions- resulting in a consistent package, a 'prototype' |
| 4. *Layout of prototype to test and improve* | Laying out the designed prototype on experimental or commercial farms to test and improve it in relation to the formulated objectives |
| 5. *Dissemination* | Disseminating the prototype by pilot groups (<15 farmers), regional networks and eventually by national networks |

proposals for conceptualization of the practical experiences culminated in a manual for prototyping arable farming systems (Table 1). In The Netherlands, development and implementation of the prototyping methodology on both experimental stations and commercial farms at the beginning of the 1990s have been the first steps in a series of action research prototyping projects. These projects shared the same overall goal: to develop and to introduce more sustainable farming systems in the agrarian community. Yet, the projects differed in set-up from one with ten intensively supervised farmers in a region to those with a national network of both intensively and extensively supervised groups, comprising more than 100 farmers. Although very complicated to properly assess, project evaluations suggest that management practices as well as the mind'set of the participants changed due to project activities (Van Weperen et al., 1995; Klein Swormink, 2003; Langeveld et al., 2005). This is the kind of output which can be regarded as successful for efforts to mobilize science and technology for sustainability (Cash et al., 2003). However, the project reports merely present *what* was done but not *how* it was done, i.e. it is not indicated how, and by who, objectives or alternative management options were identified, whether prototyping practice changed simultaneously with project set-up, etc.

Parallel to action- and experimental farm research, several farm system modelling studies were carried out in the Netherlands (Ten Berge et al., 2000). Hypothetically, action- and experimental farm research on one side and theoretical modelling on the other, could benefit from cross-pollination. Agricultural scientists, modelers specifically, have recently explored new ways to connect to social debates and farm management practice (Gibon et al., 1999; Edwards-Jones, 2001; Keating & McCown, 2001). Incorporation in prototyping projects would offer farm system modellers opportunity to 'connect'. On the other hand, the prototyping approach could benefit from modelling as well. Farm system models provide means to expand, refine and formalize expert knowledge (Ten Berge et al., 2000) and to integrate these and scientific agro-ecological (as defined by Dalgaard et al., 2003) knowledge at farm level. These model qualities could enable revealing options otherwise possibly overlooked and extrapolation of prototyping results to other conditions and scenarios.

Despite the promise, we observe that little cross-pollination between the modelling and prototyping efforts took place, even though the methodologies were applied in parallel and in one country. As stated above, existing reports on prototyping projects merely present their technical set-up and results but lack description of the implementation of the methodology. Therefore, to gain insight in how the prototyping methodology shaped action research and to investigate the potential for cross-pollination we need a better understanding of prototyping practice and especially the mobilization of agro-ecological knowledge herein. Hence, we formulated four research questions: (1) How was the prototyping methodology implemented in the series of Dutch action research projects? (2) How was agro-ecological knowledge mobilized to explore options for improvement and communicate project output? (3) Why was the methodology implemented in this way? (4) Why did hardly any cross-pollination between farm system modelling and prototyping happen?

After introducing the methodology in Section 3.2, Section 3.3 presents a number of analytical notions which guided the data presentation. In Section 3.4, almost three decades of Dutch experimental, farming system research inspired by the prototyping methodology is discussed. Subsequently, we return to the research questions and discuss the potential for mutual benefit of prototyping and farm system modelling in Section 3.5. In Section 3.6, we draw conclusions.

## 3.2 Methodology

The majority of the studied Dutch prototyping projects had ended when our research took place. Hence, the study had a reflective character. We could draw on the experiences of two of the authors of this Chapter. Wijnands has been actively involved in all projects discussed in this article. The first author has researched prototyping projects in the context of a research project over the past three years. For this research qualitative methods were applied: semi-structured interviews and study of internal and external project documentation. Also, the first author attended gatherings, such as project team meetings and bilateral encounters between project team members and farmers (so called kitchen table meetings). Informal conversations (i.e., unstructured interviews) were held with the participants during and after these activities to uncover their interpretations of what was going on.

## 3.3 Analytical framework

To address prototyping practice and at the same time elaborate on the potential for cross-pollination between this practice and farm system modelling, we identified two sets of structuring themes. From the first analysis of the prototyping project documentation and interviews we inferred four variables that shaped prototyping practice. These four variables guided the further analysis of prototyping practice:

- *Research strategy,* the perspective of the project initiator on innovation processes;
- *Policy environment,* influence of policy on the project;
- *Project network and role division,* project partners, who did what, relations between the partners; and
- *Project methods,* the main activities structuring the project process.

Coupling the formalizing and integrating capacities of farm system modelling to the prototyping methodology resulted in three leads for the possible role of farm models in mobilizing agro-ecological knowledge in prototyping processes. These three leads focused the exploration of the potential for cross-pollination of prototyping practice and farm system modelling (the steps refer to Table 1):

1. Exploration of objectives, including parameterization and quantification (step 1 and 2 of the prototyping methodology);
2. Exploration of options for improvement (step 3); and
3. Communication and extrapolation of project output (step 5).

Concerning lead 3 and step 5 of the prototyping methodology, we used a broader definition of what dissemination is. Not just farmers can be a target group but the government, other public organization and commercial firms as well. Besides, the dissemination phase can be targeted at management change directly, but also indirectly, e.g. through further research, policy explorations on basis of project results.

## 3.4 Prototyping in action

Almost three decades of prototyping practice is analysed, by discriminating a first phase with experimental farm research, a second phase with prototyping on commercial farms, and a third phase just starting up. The four variables formulated in Section 3.3 were used to cluster the data. However, if data belonging to two different variables were strongly intertwined, we sometimes chose not to separate. Hence, the clustering is not fully consistent.

### *3.4.1 Phase 1: Farm system experiments at experimental stations*

*Research strategy*

The first Dutch experiences with the prototyping approach originate from the early 1980s, when three arable farming systems –integrated[3], organic[4] and conventional– were laid out on an experimental farm at Nagele in the Flevopolders (Vereijken, 1989a,b). Later on, a number of other experimental farms in other Dutch regions and sectors started working with the prototyping methodology (Wijnands, 1997; Langeveld et al., 2005). The main reason for the initiative had been a call for an "entire farming

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[3] According to the newly established European working group on integrated arable farming systems (IAFS) integrated farming was trying to serve both economic and ecological aims "through substitution of expensive and potentially harmful inputs, especially fertilizers and pesticides, by both agricultural and ecological knowledge, labour and non-chemical husbandry techniques" and by "encouragement and conservation of flora and fauna in and around the fields […] as a major preventive measure against the outbreak of pests, weeds and diseases." (Vereijken & Royle, 1989, p. vi).

[4] About the choice to work on organic farming next to integrated farming, Vereijken (1994) explained: "[…] long-term IAFS are based more on ecological awareness and knowledge than short-term IAFS. Therefore, our prototypes of long-term IAFS are simply called EAFS (Ecological Arable Farming Systems), and short-term IAFS are referred to as IAFS. Organic systems can be considered a fore-runner of EAFS, but they have no quantified objectives in environment and nature/landscape and as a result, they need to be considerably improved to become acceptable to the majority of consumers."

system approach" (El Titi, 1992, 1989) in reaction to limited adoption of Integrated Pest Management by farmers (Vereijken, 1989a).

*Policy environment, project network and role division*

System research at experimental farms can not be run without stable and long term funding, e.g. to investigate a rotation scheme might take up to six years, depending on the length of the scheme. The Dutch Ministry of Agriculture, Nature and Fisheries (LNV) has been an essential partner in this sense. It has been the main sponsor of the prototyping research at experimental farms, though conditions for funding have changed. Till the end of the 1990s, the Ministry funded the owner of the experimental farms, Applied Plant Research (PPO). Internally, the money was distributed over the different projects. Hereafer, the Ministry funded projects directly on the basis of a proposal. Simultaneously, the Ministry became also more involved in the formulation of the project objectives. Besides, in the first years, it was mainly employees of Applied Plant Research doing the research on the experimental farms. In the 1990s, the experimental farms became part of the prototyping action research projects. Consequently, researchers from other organizations got involved in the experimental farm work as well.

*Project methods*

We use the research work at the Nagele experimental farm in The Netherlands (Wijnands & Dekking, 2002) to provide some illustrations of the implementation of the prototyping methodology for an organic farming system. Though not in a hierarchical order, five objectives were formulated for the system by the project team. We here further focus on the objective 'clean environment/nutrients' as an example to show the further elaboration of an objective. Five parameters accompanied by target values were linked to the nutrient objective (Table 2). Nutrient management in agriculture, especially nitrogen use, was highly debated in the Dutch policy arena in the 1990s. Hence, formulation of the nutrient objective, accompanying parameters and target values were to a great extent inspired by policy discussions about (im)possibilities. Earlier, when environmental policy was still in its infancy, researchers sought more inspiration from colleagues and professional literature according to respondents.

Researchers identified two main system technologies with the nutrient objective: 'multifunctional crop rotation' and 'ecological nutrient management'. These were not newly invented technologies or technologies not in use already. However, their purposive application to achieve quantified –and not just well-known economic, but also the new environment and nature related– target values was considered innovative.

Table 2. Objectives, parameters and target values for the prototyping research at Nagele experimental farm. Reproduced from Wijnands & Dekking (2002).

| Objective | Parameter | Dimension | Target value |
|---|---|---|---|
| Quality production | Quantity | - | 1 |
| | Quality | - | 1 |
| Clean environment; Nutrients | Nitrogen-min November | kg/ha (0-110 cm) | Clay 70; Sand 45 |
| | Nitrogen leaching | ppm $NO_3$ | <50 |
| | Nitrogen surplus | kg/ha | <100 |
| | Phosphate surplus | kg/ha | <20 |
| | $K_2O$ surplus | kg/ha | <40 |
| Clean environment; Pesticides | Air exposure risk index [a] | kg/ha | <0.7 |
| | Application active ingredients | kg/ha | As low as feasible |
| | Groundwater exposure risk index [a] | ppb | <0.5 |
| | Soil exposure risk index[a] | kg days/ha | <200 |
| | Aquatic environmental stress credits | % applications > 10 credits | 0 |
| | Soil life environmental stress credits | % applications > 100 credits | 0 |
| Sustainable management of soil and water | Pw[b] | Pw (0-30 cm) | 20-30 |
| | K-number[c] | K-number (0-30 cm) | Clay 18-29; Sand 11-19 |
| | Supply of effective organic matter | kg/ha | Equal to break down of effective organic matter |
| Farm Profit | Income per € 100 costs | € | >100 |
| | Hours hand weeding | Hours/ha | <20 |

[a] Indicator for emission risk of synthetic pesticides, herbicides and fungicides, calculated on basis of specific characteristics and applied quantity.

[b] Pw is a Dutch indicator for soil phosphate concentration, expressed as mg $P_2O_5$/l dry soil.

[c] Indicator for potassium concentration, expressed as mg $K_2O$/100 g dry soil.

Table 3. Characteristics of the crop rotation of the organic system at the Nagele experimental farm. Reproduced from Wijnands & Dekking (2002).

| Year | Crop | Family | Mow/ tuber, root, bulb crops | Nitrogen requirement* | Nitrogen transfer | Manure (solid) |
|---|---|---|---|---|---|---|
| 1 | Ware potato | Solanaceae | Tuber | ++ | + | Yes |
| 2 | Grass-clover | Poaceae/ leguminosae | Mow | + | +++ | No |
| 3 | Celeriac/ onion | Umbellifers/ liliaceae | Root/bulb | +++/++ | + | Yes/Yes |
| 4 | Wheat | Poaceae | Mow | +++ | ++ | Yes |
| 5 | Carrot | Umbellifers | Root | + | + | No |
| 6 | Pea | Leguminosae | Mow | + | ++ | No |

*+ = 0-50 kg N, ++ = 50-100 kg N, +++ = 100-150 kg N

Via yearly cycles of regular and extensive measurements, reflection and adaptation of the different system technologies, the farm system got a new orientation. The researchers' network and professional literature were sources of inspiration in this phase. For the multifunctional crop rotation this iterative design procedure resulted in a set of guidelines, such as:

- Alternate tuber/root/bulb with mowing crops;
- Make use of mineralization from previous crops or green manure;
- Grow green manure crops whenever possible.

Table 3 shows how the set of guidelines was operationalised at the Nagele experimental farm. Project results were presented in reports, researchers were frequently invited to give a talk to diverse audiences, and open days at the experimental farms were organized regularly.

### *Mobilization of agro-ecological knowledge*

If we single out the elements of the above analysis about the mobilization of agro-ecological knowledge and relate them to the three promising leads for cross-pollination (see Section 3.3) –(1) the identification of objectives, (2) options for improvement, and (3) the fate of project output– a few observations can be made. Objectives were defined by the involved researchers and indirectly, later more directly, influenced by the policy environment. Similarly, ideas for adaptations of the farm system emerged from discussions of researchers within their network and from professional literature. Though the prototyping methodology was unconventional, especially during the 1980s, the dissemination methods were not. They did not deviate from the usual communication strategies of Applied Plant Research, i.e., reports, talks and open days.

### *3.4.2 Phase 2:On-farm and action research*

*Research strategy, policy environment*

After a decade of research at the experimental farm in Nagele, Vereijken concluded that considerable progress in the direction of desired system performance had been made, however “[…] experimental farms will never be similar to commercial farms. Therefore, it is recommended to develop […] prototypes on pilot farms, where scale, design and management are representative of a viable agricultural enterprise” (Vereijken, 1994). At the same time, the Dutch government accepted two policy plans to restructure and sanitize the national agriculture. ‘Integrated’ production was considered a major tool to reduce the adverse effects of high pesticide and nutrient inputs (Wijnands & Vereijken, 1992). Against this background, two projects with commercial farms were initiated, an Integrated Arable Farming (Wijnands, 1992) and an Organic Arable and Open-field Vegetable Farming (Vereijken, 1997) project, hereafter referred to as the IAF and OAF projects. These two projects were followed by one more integrated (Langeveld et al., 2005) and two more organic farming projects, i.e., BIOM (‘organic agriculture innovation and conversion’) I and II (Wijnands & Holwerda, 2003) up to now. The integrated version, ‘Farming with a future’ (Fwf), was launched in the frame of additional nitrogen measures. The new policy mainly encompassed a reinforcement of the 1990 standards.

*Project network and role division and project methods*

In the OAF project, a relative small number of just ten farmers participated, concentrated in one region, and the extension service was not involved. The OAF project team believed that it was vital to concentrate all project resources in one region and make communication lines as short as possible in order to limit diversity in biophysical conditions and to allow testing the farm systems properly. The IAF and all later project teams followed another approach. Based on the ‘Nagele’ research results, researchers of Applied Plant Research (PPO) developed courses about the tested system technologies (the so-called ‘toolbox’) to train the extension officers who would become partners in the projects. New researchers received an internal training as well. Furthermore, for the IAF project, five regional groups of farms were composed to create diversity in soil, farm and management conditions. The later Farming with a

Table 4. The phase 2 projects.

| | Collaborators[a] | Duration |
|---|---|---|
| Integrated Arable Farming (IAF) | PPO, PRI, LEI, DLV, farmers (38) | 1989 – 1993 |
| Organic Arable and Open-field Vegetable Farming (OAF) | PRI, farmers (10) | 1991 – 1997 |
| BIOM I | PRI, PPO, DLV, farmers (54) | 1998 – 2002 |
| Farming with a Future (FwF) | PPO, PRI, LEI, DLV, farmers (33) | 2000 – 2003 |
| BIOM II | PPO, PRI, DLV, farmers (40) | 2002 – 2006 |

[a] PPO = Applied Plant Research, PRI = Plant Research International, LEI = Agricultural Economics Institute, both PRI and LEI are strategic research institutes, DLV = Extension Service, LNV = Ministry of Agriculture, Nature and Fisheries, EU = European Union.

future, BIOM I and II projects followed the IAF set up (for an overview of the partners in the different projects, see Table 4). The pros and cons of the OAF procedure versus the approach in the IAF and later projects were never evaluated. Hence, we are unable to pronounce upon the comparative fitness of these two approaches. The objectives of the different projects were similar to the ones listed in Table 2 for the Nagele experimental farm with one exception; BIOM II explicitly addressed the strengthening of organic market chains besides the more ‘conventional’ objectives. The inclusion of this new theme was a reaction to the importance the theme had gained in the communications in BIOM I.

Though the OAF project differed in set up from the others, in the execution phase all five projects functioned similarly. Every farm was put through an elaborate measuring and registration scheme during the project, reported in yearly farm evaluations. Researchers, extension officers and the farmers were each responsible for part of the scheme. The extension officer (read ‘researcher’ for the OAF project) visited the farms belonging to his regional group frequently, up to once every two weeks in the growing season. Main tools in the discussions were yearly nutrient management-, crop protection- and cropping plans. In these plans the toolbox was operationalized. It was particularly in the so-called ‘kitchen table’ meetings that usefulness of specific agro-ecological knowledge was probed. Researchers visited the farms to measure specific parameters such as the nitrate concentration in the drainage water at set times. This intensive farm performance monitoring and communication between extension officers, researchers and farmers was essential to interpret results in a credible way. Regional groups met regularly, facilitated by an extension officer. In summer, the participants made excursions to places of common interest and visited farms of members of the group. In winter, selected topics were highlighted in the meetings, such as nitrogen leaching or the management of a specific crop and the individual farm evaluations were interpreted by the group. The group meetings were organised to motivate the participants and to screen new management options. Usually, a farmer would not adopt all proposed system technologies in the first project year, he would rather make a selection from the ‘toolbox’. At a later stage, he might then start trying the other system technologies, e.g. because other members of his regional group were enthusiastic.

In phase 2, the project set up was assumed a major dissemination strategy, i.e. the participating farmers were supposed to share their experiences with their colleagues. In addition, courses on integrated and organic farming were offered to organizations that educate, train or advise farmers (extension service, private enterprises and agricultural schools or training centres) and farmers deliberating changeover to organic farming. Another strategy to create a broader support for integrated and organic farming was to extensively supervise farmers’ groups parallel to the intensively supervised groups. Furthermore, the Ministry of Agriculture, Nature and Fisheries did not engage with the contents till the end of the 1990s. However, the Ministry makes use of the project results to set its agenda since, according to respondents. Moreover, other researchers than those from PPO (e.g. PRI, see Table 4) made increasingly supplementary investigations zooming in on farm system components, often with the help of issue-specific model simulations, e.g. the relation between nitrate leaching and nitrate in groundwater. Partly, this work concerned policy explorations for the Ministry of Agriculture, Nature and Fisheries. For another part, the model work elaborated on observations made on the farms and its results affected future project activities.

### *Mobilization of agro-ecological knowledge*

Returning again to the three promising leads for cross-pollination between prototyping and farm system models (Section 3.3), a first observation is that few words are spent on the definition of project objectives in the analysis of the second phase. Although the prototyping manual (Section 3.1) suggests that the definition, parameterization and quantification are major phases in a prototyping process, covering 2 of the 5 steps of the methodology, in practice objective definition took place prior to the projects in a rather elusive way with input from experimental farm work, researchers networks and the policy environment. In reference to our second possible lead related to the exploration of options for improvement, we observe that –within the window of opportunities of the toolbox– occasions for identification of options were amply present during the whole course of the project, e.g. during kitchen table meetings and in regional group activities. These occasions were characterized by a diversity in settings and hence a variety of sources of inspiration such as quantitative measurements and farm visits. Our third lead dealt with the dissemination step of the prototyping manual. From the analysis of second phase it transpires that the project results were formulated and communicated in three distinctive ways: (1) Participating farmers were 'ambassadors'; (2) Project output was formulated in the form of farm management guidelines and communicated via reports, courses and farmers' groups external to the project; and (3) Project data were input for model explorations with the aim to better understand behaviour of particular system components or to support policy making.

### *3.4.3 Continuation: Phase 3*

After ten years of action research projects and even though the project evaluations were generally positive, the support for integrated and organic farming in the agricultural sector was judged insufficient by the Ministry of Agriculture, Nature and Fisheries as well as several representative organizations in the agricultural sector. Recently, projects have been started up following a new approach. Capitalizing on the extensive experience with the system technologies for integrated and organic farming, PPO researchers and extension officers now facilitate experimentation of farmers groups with (elements) of these system technologies. Measurements are only done in relation to the experimentation, not to monitor the complete farm system. A larger number of farmers participate but the collaboration is less intensive. Organizing the active engagement in the project of relations having a stake in farmers' management, such as fertilizer suppliers and authorities at the local and regional level, is a second major theme in the new approach. Because third phase projects have started only recently, it is not possible yet to analyse this phase any further. Apart from this so-called 'new approach' or 'third phase', entirely new visions, objectives and parameters have been formulated for a number of experimental farms, an initiative reminding of the first described prototyping phase in this Chapter (Section 3.4.1).

## 3.5 The evolution of prototyping and the potential for cross-pollination with farm system modelling

In Section 3.3, three promising leads in the prototyping methodology were identified for the integration of a farm system model. In Section 3.4, prototyping practice was pictured and the mobilization of agro-ecological knowledge analysed in relation to the three promising leads. Here, we reflect on the developments in prototyping practice over the years and the potential for cross-pollination of prototyping and model based farm system research.

### *3.5.1 Evolution of prototyping*

Figures 1 and 2 visualize what transpired as the main developments in prototyping practice over the years: a shift in project focus and in project stakeholders. The analysis of prototyping practice (Section 3.3) indicates that these developments were influenced by the project internal learning process as well as the policy environment. With respect to the latter factor, at the time the IAF and OAF projects were set up, ambitious environmental policy plans created a sense of urgency for the research, extension and farming communities to innovate *and* to innovate in the same direction, i.e. improving the environmental impact of farm management. The successors of the IAF and OAF projects were set up in the frame of additional measures to the earlier policy plans that did not create a similar sense of urgency. Consequently, in later projects, the strong focus on environmental aspects of farming decreased and socio-economic ambitions became more guiding in the work approach (Fig. 1) in reaction to communications in the earlier projects.

Figure 2 visualizes the increase in actively involved stakeholder groups. We hypothesize that this trend is not a coincidence, but at least partly the result of an internal learning process. One of the main pillars of this learning process has been the long-term involvement of a number of project team members and it has yielded three insights over the years. A first insight concerns the impact of the policy environment on project orientation, elaborated above. Secondly, the project team developed expertise in action research and integrated/organic farming. For the latter, the earlier research at the experimental farms proved an essential basis to cope with the complex of social and biophysical factors characterizing action research projects. The experimental farm work laid the agro-ecological foundation, operationalized in the toolbox, for the later action research projects. Both the extension officers and researchers built on this work with their project activities. Lastly, the project team was confronted with their (implicit) theories about the spread of project results within the farming community. The main dissemination methods, i.e., (1) the project participants as ambassadors and (2) written material, did not produce the expected dissemination. Building on this gradually evolving understanding, the project team started to involve a larger range of stakeholders to construct a more supportive (policy) environment. As a result of this initiative the project team took on additional roles, such as that of a

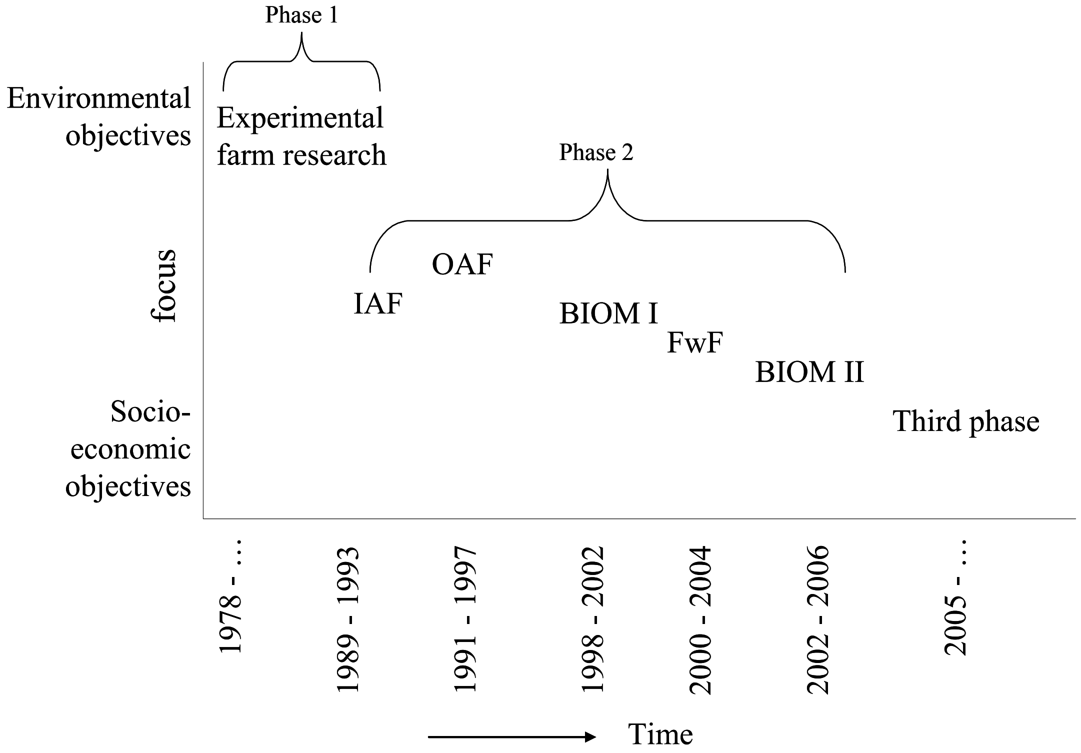

Figure 1. The focus on two categories of project objectives in the three phases of prototyping practice.

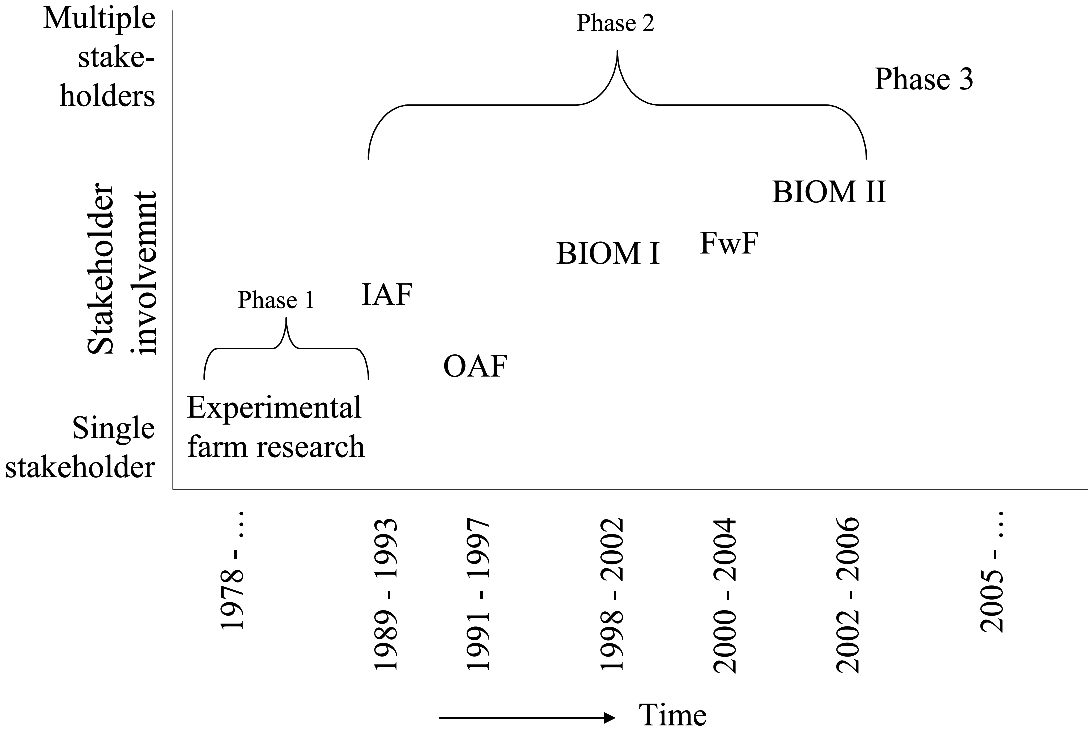

Figure 2. Stakeholder involvement in the three phases of prototyping practice.

network facilitator. To improve the diffusion of the tested system technologies, a radically different strategy was proposed in phase 3, i.e., familiarizing many farmers with (components of) the system technologies instead of aiming at quantitative goals with a relatively small group of farmers. Supposedly, the emerging expertise in the project team has been essential to cope with the growing number and diversity in collaboration styles.

### *3.5.2 Prototyping and modelling*

In Section 3.3, three promising leads for cross-pollination of modelling and prototyping were identified:

1. Exploration of objectives, including parameterisation and quantification;
2. Exploration of options for improvement; and
3. Communication and extrapolation of project output.

Sections 3.4.1 and 3.4.2 discuss how agro-ecological knowledge was mobilized to address these three themes in prototyping projects. Here, we explore the consequences for the potential for cross-pollination with farm system modelling. Note, in this exploration we assume that it is feasible to prepare a model timely, though this has proven a major hindrance in experiences to date (Chapter 1). From the analysis it transpires that the definition of project objectives (lead 1, Section 3.3) took place prior to the installation of the project organization. Besides, the set up (i.e. objectives and tested system technologies) and results of the work at the experimental farms (phase 1) had a significant influence on the objectives definition for the action research projects (phase 2). Thus, the formulation of objectives appears not to be a distinct activity within the prototyping action research projects themselves. Consequently, the potential for cross-pollination in relation to objective formulation in prototyping action research projects seems low. However, we did not find any indications that farm system modelling could not, in principle, play a role in the discussions about prototyping objectives for experimental farm research (phase 1).

Regarding the exploration of options for improvement (lead 2), the action research projects encompassed intensive and continuous communication between the project team and farmers about possible improvements, farm management activities and effects, often on-farm and supported by an extensive palette of tools, e.g. regular group and bilateral meetings, quantitative monitoring system and excursions. This approach resulted in a strongly localized research process. To be useful in this process, we hypothesize that a model has to be localized to the same degree. However, localization is not trivial for cropping system models such as APSIM (Carberry et al., 2002), let alone farm system models using parameters for many processes which are hard and very time consuming to quantify in a location-specific manner. Thus, though not impossible, it might well be impractical and perhaps not feasible to introduce a farm system model. In relation to the fate of project output (lead 3), issue-specific (i.e. focus on a component of the system) models were increasingly used in the projects. The prototyping project data were incorporated in model-based policy explorations, for instance with the purpose to elaborate the effect of diversity in nitrogen management for achieving (future) environmental policy targets. The application of issue-specific models could be due to its more advanced development in the past. Therefore, it might be a matter of time before farm system models are also mobilized for policy explorations in the slipstream of prototyping projects.

## 3.6. Conclusions

Analysis of more than two decades of Dutch prototyping research both on experimental and commercial farms indicated that prototyping on commercial farms is a highly localized process. Moreover, although the methodology manual suggests differently, goal formulation was not a distinctive phase of prototyping on commercial farms. Consequently, the chances that farm system modelling will be incorporated in the objective definition or testing phase of a prototyping project seem minimal. However, issue-specific (i.e. focus on a component of the system) models are increasingly used for policy explorations. We hypothesize that there may also be a role for farm system models for this purpose. With this type of models the diversity in farm management, which transpires from the prototyping work, can be formalized and then used to assess the effect of future environmental policy measures at the farm level.

# 4

# Computer models in action; Learning by doing in a Uruguayan on-farm research project

**Abstract**
Earlier work on the use of computer models outside the academic context demonstrated that these models can make a valuable contribution to learning. However, little empirical work has been done on how this learning comes about. A Uruguayan action research project provided the opportunity to empirically investigate the relations between model development, calibration, model presentation and model-induced learning. To address problems in vegetable productions systems in Uruguay at the farm level, farm modelling and action research were employed. A farm system model, called 'Farm Images', was developed. A modelling study with 'Farm Images' was concluded in the year before an action research project with commercial farmers was initiated. The modelling study was a main source of inspiration for the formulation of the project. The model developer became project coordinator and intended to use 'Farm Images' in the action research project as well. The learning experiences in the project indicate that the technologies incorporated in Farm Images were being tested in the project. However, both the project team and the involved farmers learned largely about, and not through Farm Images. They appreciated the capacities of the model, but the calibration and presentation of Farm Images in the project did barely affect their learning. Supposedly, the learning related to the use of Farm Images remained limited precisely because the project participants were already testing the ideas included in the model. Since Farm Images was an important source of inspiration for the formulation of the action research project, Farm Images had a considerable, however indirect, impact on learning in the project.

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Paper by B. Sterk, M.K. Van Ittersum, C. Leeuwis, G. Martin, S. Dogliotti; Submitted to Agronomy for Sustainable Development

## 4.1 Introduction

In the past 20 years, a number of research projects at the field level have been carried out in Uruguay to address problems in vegetable productions systems, such as reduction of soil erosion, physical and biological soil fertility improvement, irrigation techniques, measures to control weeds, pests and diseases, and breeding of varieties adapted to the local environment (Garcia and Clerici, 1996; Galvan et al., 1997; Garcia and Reyes, 1999; Docampo and Garcia, 1999; Zaccari and Sollier, 1999; Duran, 2000). The task of integrating the knowledge from this diverse range of research areas into improved and viable farming systems has been left in the hands of the farmers themselves.

Though the executed field level research seemingly offered solutions for the encountered problems in Uruguay, the Faculty of Agronomy of the university deemed the impact insufficient and pleaded for the integration of the different field level disciplines at farm level to support farmers more effectively. To this end, two research methodologies have been employed: goal-based modelling and action research. The first methodology may be defined as objective-oriented modelling for exploration of alternative, promising farm systems. Directed by the formulation of conflicting objectives (e.g., economic profit, minimal nitrogen leaching) and the potentials of a system, consequences are explored for farm lay-out and management. Multiple Goal Linear Programming (MGLP) is the most widely used integrated modelling approach in goal-based farm models. In the frame of a modelling project (Dogliotti, 2003), the MGLP model ‘Farm Images’ was developed to explore options for vegetable farm systems in Canelón Grande, a region in South Uruguay. Action research is a collaborative effort of experimentation and monitoring oriented towards change and carried by scientists and other stakeholders. Action research took place in a project with commercial farmers in South Uruguay from October 2004 onwards.

The modelling study was concluded in the year before the action research project started. Figure 1 provides an overview of the version of the developed MGLP model ‘Farm Images’ discussed in this Chapter (see Section 4 for further details). In the left part of the figure, up to and including ‘crop rotation management systems’, all available field level options regarding crop choice, animal production and crop management (e.g., green manure, irrigation) are combined and associated yields calculated. In the right part of the model, the consequences of every designed crop rotation management systems are quantified in terms of inputs and outputs (e.g. fertilizer application, nitrogen leaching) for a specific biophysical environment (i.e., slope, soil type). Thereafter, the most promising farm system in terms of the defined objective and boundary conditions is selected. Five objective functions were used:

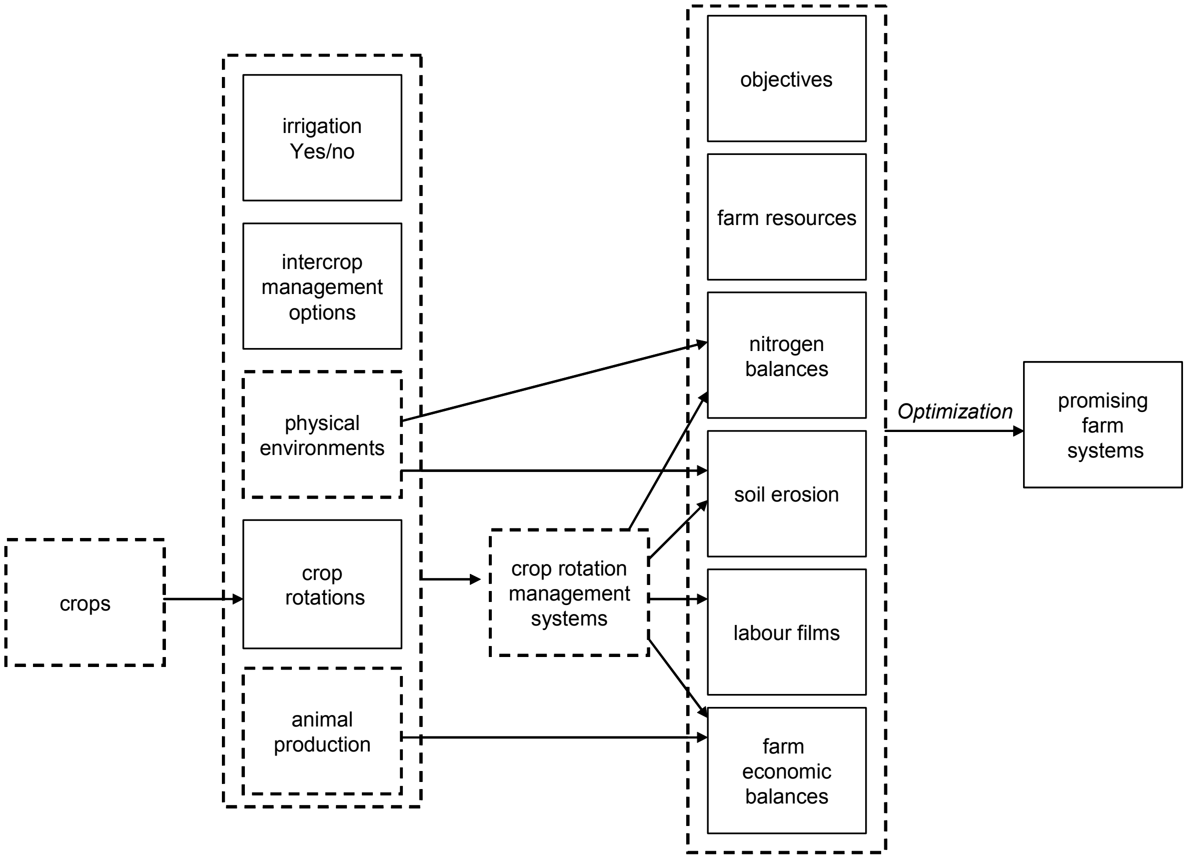

Figure 1. Outline of the version of Farm Images used in the action research project. Broken line block indicates input data for calculation procedure; Arrows indicate calculation procedure.

farm gross margin, family income, capital requirement, soil erosion and N surplus. One objective can be optimized per simulation. The others might be deployed as boundary conditions.

The developer of Farm Images became coordinator of the action research project. He intended to mobilize Farm Images to strengthen the action research project. Earlier work on the use of Multiple Goal Linear Programming models outside the academic context demonstrated that the quantification and integration of different disciplines to characterize a land use system and explore future options can make a valuable contribution to *learning*, both in the biophysical and social (i.e. motives, beliefs and interests) realm (Chapter 1). Here, the term ‘learning’ does not refer to learning in a classroom separated from daily work, but to learning in practice and through experiences. In literature, an extensive discussion has taken place about the fairly low use of computer models (cf. decision support systems, learning tools), highlighting issues such as relevance (Argent & Grayson, 2001; Keating & McCown, 2001; David, 2001) and transparency (Dahinden et al., 2000; Ewing et al., 2000) of models.

Table 1. Indicators for learning according to area and level (Van Mierlo et al., in press).

| Area of learning | Individual indicator |
|---|---|
| Aspirations and knowledge | Changes in problem definitions and perceived solutions regarding pre-existing goals<br>Changes in goals, values, norms, or perceived interests, going along with radically new problem definitions and search directions |
| Perception of own role and that of others | Increase in feelings of involvement, urgency and responsibility, or enhanced belief in own competencies and freedom of manoeuvre |
| Action | Changes in behavioural patterns of individuals or internal organizational adaptations |

Nevertheless, little empirical work has been done on how relevance comes about. Building on the afore-mentioned earlier work on the use of MGLP models, we perceive a model is relevant if learning occurs. The Uruguayan action research project provided an opportunity to empirically investigate the relations between model development, preparations for model use and model-induced learning with two potential user categories': the researchers and commercial farmers who participate in the project.

In the frame of a study about innovation, Van Mierlo et al. (in press) defined learning as a change in knowledge and understanding about the state or functioning of social, economic, biophysical or technological systems or perceptions regarding their own (and others') aspirations, capacities, opportunities, responsibilities, identities, duties, etc. On basis of this definition of learning, Van Mierlo et al. formulated indicators of learning. These indicators were used to label learning experiences in the Uruguayan action research project (Table 1). Four questions guided the research: How do (1) *development context*, (2) *calibration* and (3) *presentation* of Farm Images affect learning in the action research project in Canelón Grande?, and (4) How do the learning experiences in the project relate to the features of Farm Images? Concerning the development context (question 1), we perceive a model as the result of selections in the development process. These selections are contingent upon the social and technological context the model developer worked in (Wynne, 1984; Knorr-Cetina, 1981a). This Chapter investigates how the development context shaped Farm Images and the impact of this contextual contingency on Farm Images' contribution to learning. Question 2 -on calibration- refers to the steps that are taken to produce tailored model output and that consequently might influence the relevance of a model in a specific context (Argent & Grayson, 2001; Keating & McCown, 2001). The presentation (question 3) of Farm Images takes place at a certain stage in the project and has a specific format. Both these aspects might have an impact on learning (Chapter 1; Keating & McCown, 2001; Dahinden et al., 2000). Concerning question 4, learning in the project was also investigated independent of the model because there are indications that the nature of this 'learning in practice' is a major explaining factor for the relevance of a model in a specific context (Chapter 1; McCown & Parton, 2006). In Section 4.2, the research methodology is described. Sections 4.3, 4.4 and 4.5 report on the development, calibration and presentation of Farm Images. In Section 4.6, the results on learning experiences are presented. In Section 4.7, we answer the research questions and reflect on the applied research methods.

## 4.2. Methodology

The research methodology consisted of: (1) Historical analysis of model development; (2) Analysis of the Uruguayan action research project and the mobilization of Farm Images in the project; (3) presentation of model output.

To document the model development process, several semi-structured interviews with the model developer and his supervisors were held, and a content analysis of the research papers of the model developer was made. Moreover, one of the supervisors and the model developer are co-authors of this Chapter. Note, as mentioned in Section 4.1, besides co-author of the underlying Chapter, the model developer was the coordinator of the action research project as well.

The project analysis served three purposes: to facilitate calibration of Farm Images; to assess and explain learning experiences in the project, and; to develop an explanation for the contribution of model development and calibration to learning in the project. In the action research project, seven farmers and four project team members collaborated. The project team consisted of the project coordinator and three technical coordinators. From half way through the first project year (2005) till half way through the second year, one of the co-authors (hereafter referred to as 'calibrator') joined the project team to gather data about the project and to work on the model at several stages. Farm Images was calibrated and ran for three participating farms. Because they deemed it unfeasible to calibrate all eight farms in the project simultaneously, the model developer and calibrator selected four out of the eight farms. They selected the farms with production systems most resembling those studied for the model developers' modelling work. One of the four selected farmers left the project before the calibration procedure was finished because he did not feel comfortable with the project objectives. In this Chapter, the three remaining farms are pictured.

From the arrival of the calibrator onwards, the project was scanned for possibilities to fruitfully mobilize the model (i.e. a problem conceivably profiting from a quantitative study at the farm level). However, when it became apparent that such a possibility would not occur during the research period, the calibrator took the initiative to present simulation runs nevertheless; first to the project team and thereafter to the three farmers in question. At this stage, one of the technical coordinators had left the team. The three remaining project team members perceived the presentations of the model runs as a sort of midterm evaluation of their work because the presentations were given after the first, but before the second field year. Learning experiences were assessed both with the project team and the three involved farmers. In the case of the project team, the current performance of a farm was presented. Hereafter, the team members were invited to specify their plans with this specific farm on paper. Subsequently, the model-based scenarios were presented. Immediately after the presentation, the project team members were asked to write down their comments concerning the scenarios, and whether their initial ideas about the possible evolution of the farm had changed, and if so, why. On top, the project team members were interviewed in the following month to sound out their opinion about the model study. Subsequently, the calculated performance of the current system and the scenarios were presented to the farmer in question in a kitchen table session. After about two weeks, the impact of the presentation was evaluated with similar questions to the ones posed to the project team in the interviews.

In parallel to the calibration and presentation of the model, the calibrator observed dozens of project meetings, such as so-called kitchen table meetings of project team members with a farmer and meetings of the project team. Frequently, semi-structured interviews took place with participants during and directly after these meetings to uncover their interpretation of what had been going on. A reference of an actor to a change of mind or adapted practice in these encounters was labelled as a learning experience. The calibrator also had two scheduled semi-structured interviews with each of the seven farmers and four project team members, one before, and one after the presentations of model output. These interviews focused on assessing learning. The second round of interviews was used to crosscheck the analysis of the project-induced learning and was joined with the above-mentioned assessment of learning experiences through the presentations.

## 4.3 The development history of Farm Images

To appreciate the contextual contingent nature of Farm Images, we analysed how socio-technological forces shaped the model development. The starting points for this analysis were the intention to build a farm system optimization model, using Multiple Goal Linear Programming, and the intention to perform a scenario study for Canelón Grande with this model. From the analysis, three main driving forces transpired that influenced the model development: a strong academic interest of the supervisors in generating crop rotation proposals on basis of agronomic features of crops; the scientific heritage and agronomic background of both the thesis student and his supervisors. In this Section is described how the three forces were translated during model development.

### *4.3.1 The crop rotation generator*

The procedure 'ROTAT' in Farm Images combines crops from a predefined list to generate all possible rotations (Dogliotti et al., 2003). At the time of the start of Dogliotti's modelling research, the other partners in the project had been involved in the development of a number of land use optimization models. A recurring issue was the definition of crop rotations for modelling purposes. The crop rotation was regarded as a central feature of a farm system. The diversity in the selection of crop rotations determined the range of simulated farm system designs. The perceived problem was, that "the factorial number of combinations is commonly reduced to a feasible number of rotations by invoking 'expert knowledge', which introduces an undesirable element of arbitrariness" (Dogliotti et al., 2003). Filters were introduced to "represent expert knowledge in a quantitative and explicit way". The filters operationalized criteria, such as the maximum frequency of each crop in the rotation. ROTAT first combines crops from a predefined list to generate all possible rotations. Then, the filters eliminate the list of all possible rotations to a list of rotations that meet the formulated criteria. For the modelling study, ROTAT generated 7,447, 4,644 and 1,080 crop rotations for the three distinguished soil types in Canelón Grande (Dogliotti et al., 2004). Of the five modelling research years, one was spent on ROTAT.

### *4.3.2 The scientific heritage*

Of the nine procedures of Farm Images, only ROTAT was considered really innovative by the model developer and his supervisors. The others were adaptations or combinations of earlier scientific work. The necessary data originated from experiments at research stations in South Uruguay, a simulation model, and one of the Dutch supervisors. All these different data sources and the nine procedures came with a common, i.e. the internationally accepted scientific, unit system, which facilitated the linking of the databases and procedures in Farm Images.

### *4.3.3 The agronomic mark*

Of the nine procedures of Farm Images, two deal with other than agronomic features: The labour requirements calculator and the economic performance calculator. All procedures but ROTAT, have a 'serving' role, i.e., they do not produce alternatives but specify the characteristics of the alternatives generated by ROTAT. Consequently, the principally agronomic considerations built in in ROTAT have a relatively large influence on the window of opportunities that Farm Images encompasses. A proposed alternative can be unattractive in view of the defined objectives due to specific characteristics assigned to the alternative by the procedures. However, only ROTAT formulates the alternatives to be considered. Besides crop patterns of a rotation, five other management practices were incorporated in the model to explore options beyond the present performance of the farm systems of Canelón Grande:

- Inter-crop practices, such as fallow, green manure and forage crops and the application of animal manure;
- Mixed production, i.e. cattle fattening besides vegetable production. In the model, mixed production was operationalized through a mixed-production-specific labour film and the gross margin of cattle fattening, of which the latter depends on the quantity and quality of fodder crops in rotations;
- Mechanization level, high or low. The mechanization level does not have an impact on the crop yields;
- Irrigation of a field, yes or no; and
- Crop protection level, high or low.

Four of the six alternatives, i.e., crop rotation, inter-crop practices, irrigation and crop protection, are primarily agronomic measures. Therefore, the simulated diversity in performances of a farm system results for a larger part from the impact of agronomic management practices.

## 4.4 Calibration

After the completion of his modelling work in 2003, the model developer initiated an action research project in South Uruguay in 2004. The model study had suggested there was scope for improvement for vegetable farmers. These outcomes were presented to scientists, technical advisers, representatives of governmental agencies, the main Uruguayan farmers' union and to individual farmers. The presentations created the necessary support for an action research project. From 2004 onwards, a project team of four worked with individual, commercial farmers to evaluate technological alternatives that potentially enhance the sustainability of vegetable production systems. The model developer intended to use Farm Images in this project, but did not have a clear-cut plan at the start of the project. This Section reports how Farm Images was operationalized in the course of the project.

#### *4.4.1 ROTAT as a stand-alone tool*

The project team developed farm management proposals for each participating farmer. The core of these proposals was a rotation scheme. To construct this scheme, the model developer used ROTAT. He entered the preferences of the farmer, i.e. feasible crops and number of crops in the rotation, and added the other necessary data, such as cropping calendars. The preferences of the farmer were known from discussions with the farmer, the other data were expert knowledge from the project team. Subsequently, ROTAT generated between 10 and 20 possible crop rotations, instead of the more than 1,000 per soil type in the modelling study (see Section 4.3). The number of generated options was limited because the model developer usually entered the current crop selection of a farmer instead of a longer list including new crops as done in the modelling study. The model developer selected from the output a few rotations. For the selection, he did not run other modules of Farm Images to assess properties of the rotations, such as soil loss or gross margin, but relied on his own assessment capacity. After the selection, the model developer made farm management proposals, dressing the rotation with intercrops, a labour and a manuring schedule. The farm management proposals were discussed in the project team, one was selected, if necessary amended, and then presented to the involved farmer. The project team was aware that the model developer used ROTAT to select a rotation but they made no reference to it in the discussions about the farm management proposals. When asked about the use of ROTAT by the model developer, the three other team members indicated that they trusted him for this part of the work and that it did not influence the discussions about the farm management proposals.

#### *4.4.2 Calibration of Farm Images and results*

When the action research project ran for half a year, the calibrator joined the project to calibrate Farm Images for three farms in the project. In a first step, the database of Farm Images was filled up for the selected farms. The calibrator encountered two main problems during data collection: (1) Normally, the farmers did not keep a mental or written account of the farm's in- and outputs and therefore could not provide reliable data; (2) With the exploration of the future potential of a farm system, the assumption is that yields will increase with adapted management. Therefore, the model developer

**Farm Images' input tables**

| **Economic data** | **Biophysical data** | **Animal & Crop data** | **Field management data** | **Labour data** |
|---|---|---|---|---|
| *Mechanization costs* | *Soil types* | *Crop list* | *Cropping dates* | *Labour film of a crop* |
| *Seed prices* | Soil characteristics | *Weight of young and fattened animals* | *Nutrient management* | *Labour film of animal fattening* |
| Animal production costs | Production areas | Crop characteristics | Possible crop successions | *Labour availability* |
| Selling prices | Climate | Current & attainable yields | | |
| | | *Fattening period* | | |

Figure 2. Data requirements for calibration of Farm Images. In italics data for which a farmer was one of the information sources.

worked with attainable yield figures in his modelling research, i.e. the best yields in irrigated experiments on regional research stations. However, such figures were not available for all crops in the present project. Moreover, the yields from research stations were considerably higher than the yields of the farmers in the project. The project team assumed the research station yields would not be perceived conceivable by the participating farmers.

To start with the first problem. The calibrator used other sources of information than farm registrations, i.e., student surveys, literature and the project team, to adjust the database for a particular farm. The components 'fixed costs' and 'crop protection' were left out because there was not sufficient expertise available to provide and evaluate the necessary data. Figure 2 summarizes the collected data for each farm and the data sources. Literature, project measurements and the project team members were the data sources for categories such as soil characteristics and selling prices. For categories in italics, the input of the involved farmers was used as well as the three earlier mentioned data sources. Concerning the second problem, a 30-50% rise of the current yield was perceived attainable. The calibrator asked the project team members for farm, soil and water (irrigated/non-irrigated) management specific estimations. The estimations appeared to underestimate yields in at least one case; after one project year, the yields were about 20% higher than assumed attainable at one of the studied farms whereas the growing season was not considered exceptional.

With two of the three farm studies, a modelling problem emerged. We choose one of these two studies to exemplify scenario development and to present output of Farm Images. In Table 2, relevant characteristics of the farm are listed (Farm 1). The other two farms are included to put the figures in perspective. All three farm families had average yearly incomes below the national average, i.e. 5478 US$. $yr^{-1}$ for a family of 3.1 persons (INE, 2005). The horticultural area at Farm 1 occupied 1 to 1.3 ha. For the farm, two sets of scenarios were developed. A first set was based on the current crop list. In a second set, the green vegetables were removed and garlic was added to the list. The yields of green vegetables on the farm were low in comparison with the regional average due to the absence of irrigation on the farm. Moreover, the green vegetables scored unfavourable on the 'minimizing erosion' project objective. The two sets of scenarios (current crop list/green vegetables replaces by garlic) were combined with different upper bounds for the environmental boundary conditions 'nitrogen surplus' and 'erosion rate'. Exploration of alternative distributions of horticultural and pastoral area was part of the study as well. Farm Images, however appeared not able to optimize for two production systems on one soil type, though we had assumed this would be possible beforehand. Hence, varying shares of areas of horticulture and pasture were fixed manually as part of the scenario definition, resulting in 35

Table 2. Characteristics of the modelled farms. Farm 1 is discussed in Section 4.4.

| | Farm 1 | Farm 2 | Farm 3 |
|---|---|---|---|
| Arable area (ha) | 13.6 | 9.3 | 3.1 |
| Irrigable area (ha) | - | 2 | 0.1 |
| Slope of arable area (%) | 2 till 5 | 0.5 till 4 | 0.3 till 5 |
| Labour availability (h yr$^{-1}$) | 4200 | 6200 | 4900 |
| Mixed farming system | Yes | Yes | No |
| Proportion pasture (%) | 90 | 70 | - |
| Proportion *Allium* species in the horticultural area (%) | 39 | 51 | 66 |
| Contribution of *Allium* species the family income (%) | 15 | 56 | 80 |
| Animals fattened per year | 25 | 11 | 0 |
| Contribution of animal production to the family income (%) | 77 | 27 | - |
| *At whole farm level* | | | |
| Family size | 5 | 4 | 3 |
| Family income (US$ yr$^{-1}$) | 4136 | 6196 | 5013 |
| Capital requirements (US$ yr$^{-1}$) | 4728 | 5814 | 1939 |
| N surplus (kg ha$^{-1}$ yr$^{-1}$) | 36 | 53 | 53 |
| Erosion (tons ha$^{-1}$ yr$^{-1}$) | 4.0 | 10.2 | 31.4 |
| Labour requirements (h ha$^{-1}$) | 154 | 436 | 1331 |
| Labour productivity (US$ h$^{-1}$) | 1.98 | 1.55 | 1.23 |
| *For the horticultural area* | | | |
| Family income (US$ yr$^{-1}$) | 956 | 4906 | 5013 |
| Capital requirements (US$ yr$^{-1}$) | 411 | 3884 | 1939 |
| N surplus (kg ha$^{-1}$ yr$^{-1}$) | 134 | 125 | 53 |
| Erosion (tons ha$^{-1}$ yr$^{-1}$) | 13.1 | 30.4 | 31.4 |
| Labour requirements (h ha$^{-1}$) | 396 | 1345 | 1331 |
| Labour productivity (US$ h$^{-1}$) | 1.04 | 1.35 | 1.23 |

scenarios. Once all the simulation runs were performed, they were compared based on the share of crops in rotations. When differences lower than 20% for each crop in a rotation were observed between simulation runs, they were considered equivalent and one of them was selected as representative for the group. The performance of the six selected farm system designs and the current system are listed in Table 3. Family income and capital requirements of the current system were estimated (see above for

Table 3. Performance of six farm system designs and the current farm system.

| Scenario* | Family income (US$ $yr^{-1}$) | Labour Productivity (US$ $h^{-1}$) | Capital requirement (US$ $yr^{-1}$) | Erosion in Horticultural Area (tons $ha^{-1}$ $yr^{-1}$) | N surplus (kg $ha^{-1}$ $yr^{-1}$) Farm | Hort. area |
|---|---|---|---|---|---|---|
| Current | 4136 | 1.98 | 4728 | 13.1 | 36 | 134 |
| Classical2-R2 | 5360 | 2.19 | 5994 | 6.8 | 32 | 97 |
| Classical2.5-R0 | 6460 | 1.94 | 6192 | 14.7 | 48 | 203 |
| Classical4-R0 | 6574 | 2.00 | 6192 | 5.2 | 46 | 122 |
| Garlic2-R0 | 7172 | 2.06 | 6753 | 6.6 | 42 | 200 |
| Garlic2.5-R2 | 7008 | 2.18 | 6689 | 7.0 | 31 | 97 |
| Garlic4-R0 | 7844 | 2.16 | 6771 | 7.3 | 38 | 97 |

*Coding of scenarios: Classical2-R2 =Current crop list, 2 ha horticulture, N surplus < 100 kg $ha^{-1}$ $yr^{-1}$, erosion <10 tons. $ha^{-1}$ $yr^{-1}$; Classical 2.5-R0 = Current crop list, 2.5 ha horticulture; Classical4-R0 = Current crop list, 4 ha horticulture; Garlic2-R0 = Garlic on crop list, 2 ha horticulture; Garlic2.5-R2 = Garlic on crop list, 2.5 ha horticulture, N surplus < 100 kg kg $ha^{-1}$ $yr^{-1}$, erosion < 7 tons $ha^{-1}$ $yr^{-1}$; Garlic4-R0 = Garlic on crop list, 4 ha horticulture.

procedure), the other figures were calculated with Farm Images. All farm system designs generated higher family incomes compared to the current situation, with increases ranging from +30% to +90%. Part of the increase is explained by assumed higher crop yields than in the current system. Except for the “Classical2.5-R0” design, erosion was reduced by about 100% in the simulated systems. The nitrogen surplus varied from –28% to +51% in comparison with the current surplus. However, all surpluses were far below the maximum limit of 100 kg $ha^{-1}$ $yr^{-1}$, which was one of the project’s objectives. In Table 4, crop shares of the six selected rotations are presented. The vegetable area increased in all farm system designs. Except for ‘Classical2.50R0’, green vegetables were not selected. If available on the crop list, the rotation always contained garlic. Although garlic was a labour intensive crop, it generated the highest family income per hectare of the available crops. Even if produced on a small area, garlic provided a satisfying income and at the same time offered a window to erosion suppressing measures, such as more –labour extensive– pasture in the rotation. Though squash generated a relatively small gross margin, it had the highest labour productivity because of very low labour requirements, i.e. 15% of those of garlic. Therefore, squash, and tomato for industry, were selected to ‘fill the gaps’ between the highly profitable *Allium* species. The forage crops in the rotations compensated for the differences in pastoral areas. Hence, similar numbers of animals were fattened in all system designs.

Table 4. Production activities per year of the current farm system and the six farm system designs.

| Area per crop (ha) | Current | Classical 2-R2 | Classical 2.5-R0 | Classical 4-R0 | Garlic 2-R0 | Garlic 2.5-R2 | Garlic 4-R0 |
|---|---|---|---|---|---|---|---|
| Alfalfa/Pasture | 12.77 | 12.44 | 11.14 | 11.20 | 11.64 | 12.24 | 11.64 |
| Onion | 0.34 | 0.40 | 0.73 | 0.78 | 0.21 | - | 0.50 |
| Squash | 0.08 | 0.40 | 0.49 | 0.78 | 0.62 | 0.56 | 0.50 |
| Industry tomato | 0.12 | 0.40 | 0.73 | 0.78 | 0.62 | 0.28 | 0.50 |
| Green vegetables | 0.06 | - | 0.24 | - | - | - | - |
| Garlic | - | - | - | - | 0.41 | 0.56 | 0.50 |
| Potato | 0.12 | - | - | - | - | - | - |
| Maize | 0.03 | - | - | - | - | - | - |
| Sweet potato | 0.12 | - | - | - | - | - | - |
| Beef cattle | 25 | 30.7 | 29 | 28.7 | 30.7 | 31.3 | 30.1 |
| Produced Meat (kg) | 5261 | 6476 | 6107 | 6044 | 6461 | 6582 | 6345 |
| Total production area (ha) | 13.64 | 13.64 | 13.33 | 13.54 | 13.50 | 13.64 | 13.64 |
| Vegetable crops (ha) | 0.87 | 1.20 | 2.19 | 2.34 | 1.86 | 1.40 | 2.00 |

## 4.5 Presentation of model output and learning

The model calibrator presented the farm studies in tables (similar to Tables 3 and 4) and figures (such as Figure 3) to the project team. The model developer found that he had overlooked possible nitrogen surplus problems induced by suggested animal manure applications and proposed to start measuring the nitrate content of the drinking water on one specific farm. Another team member felt that the farm studies underpinned their hypotheses about promising adaptations and confirmed assumptions about processes not measured in the project, such as the erosion rate. The whole project team appreciated the overview of different aspects related to farm management the spider diagrams provided. The model developer gave more feedback on the contents of the presentation than the two other team members. Though several explanations can be hypothesized, one was explicitly mentioned in the interviews. One of the team members did not have a background in the more soil-related aspects of farm management and, therefore, had difficulties to interpret the presented figures.

For the farmers, a different presentation format was chosen. A booklet was compiled with six schemes summarizing the designs (Figure 4 shows an example of a scheme for the farm discussed in Section 4.4), explanation of the terminology and an

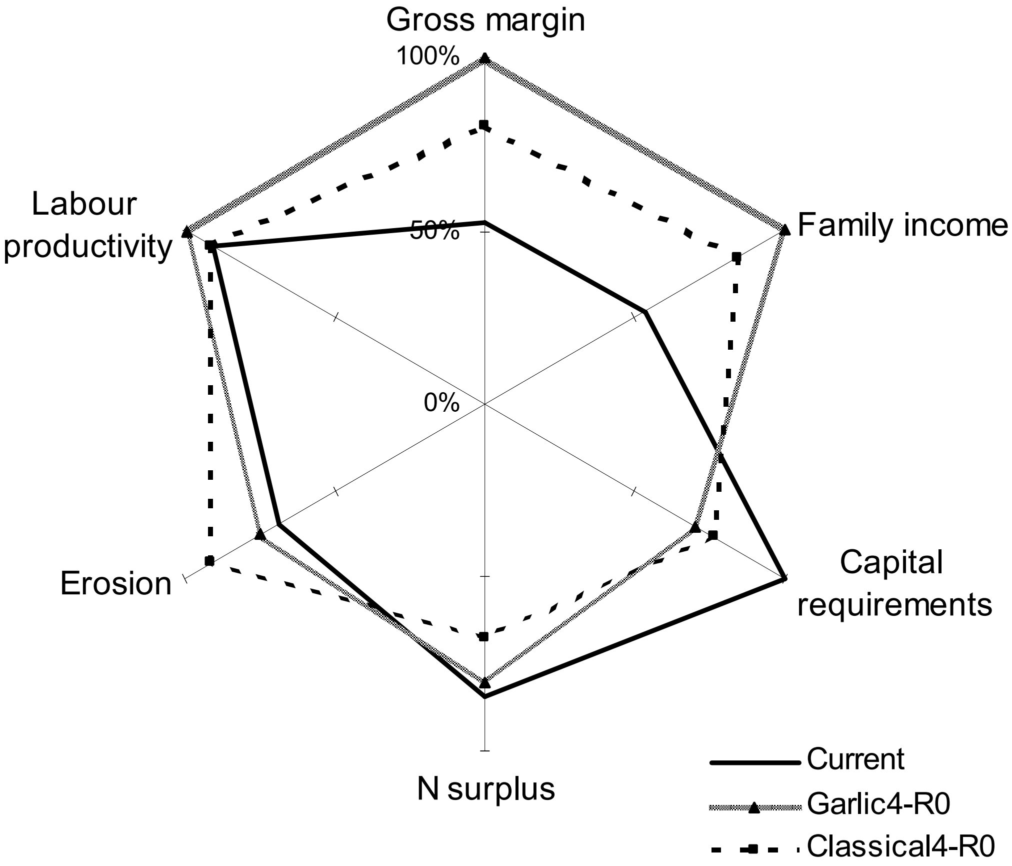

Figure 3. Spider diagram shows a comparison of farm system designs Classical4-R0, Garlic4-R0 and the current system for the farm discussed in Section 4.4. Values are expressed as percentage of the optimal value (optimal = 100%).

overview of the meaning the project team attached to selected indicators (see for example Figure 5). The model calibrator and one other team member visited the farmers one by one to introduce the booklet. Here, we also discuss their reactions one by one. The first farmer phrased no questions at the end of the presentation of the booklet. He said he had understood the main trends. Visiting the farm again two weeks later, the farmer told that he had been very busy and did not have a look at the booklet yet. Another appointment was made, one week before the calibrator would leave the project. At this last meeting, the visitors concluded that the farmer had difficulties with reading. This had not revealed before as he had never been asked to give feedback on written documents in the project and his wife did the input-output registration. Because it was too late to propose a new form of presentation and to organize another meeting with this farmer, he did not react on the farm system designs. After being introduced to the booklet, the second farmer indicated that he had understood all the elements. He underlined that "it is an entire thing as a problem with one indicator has

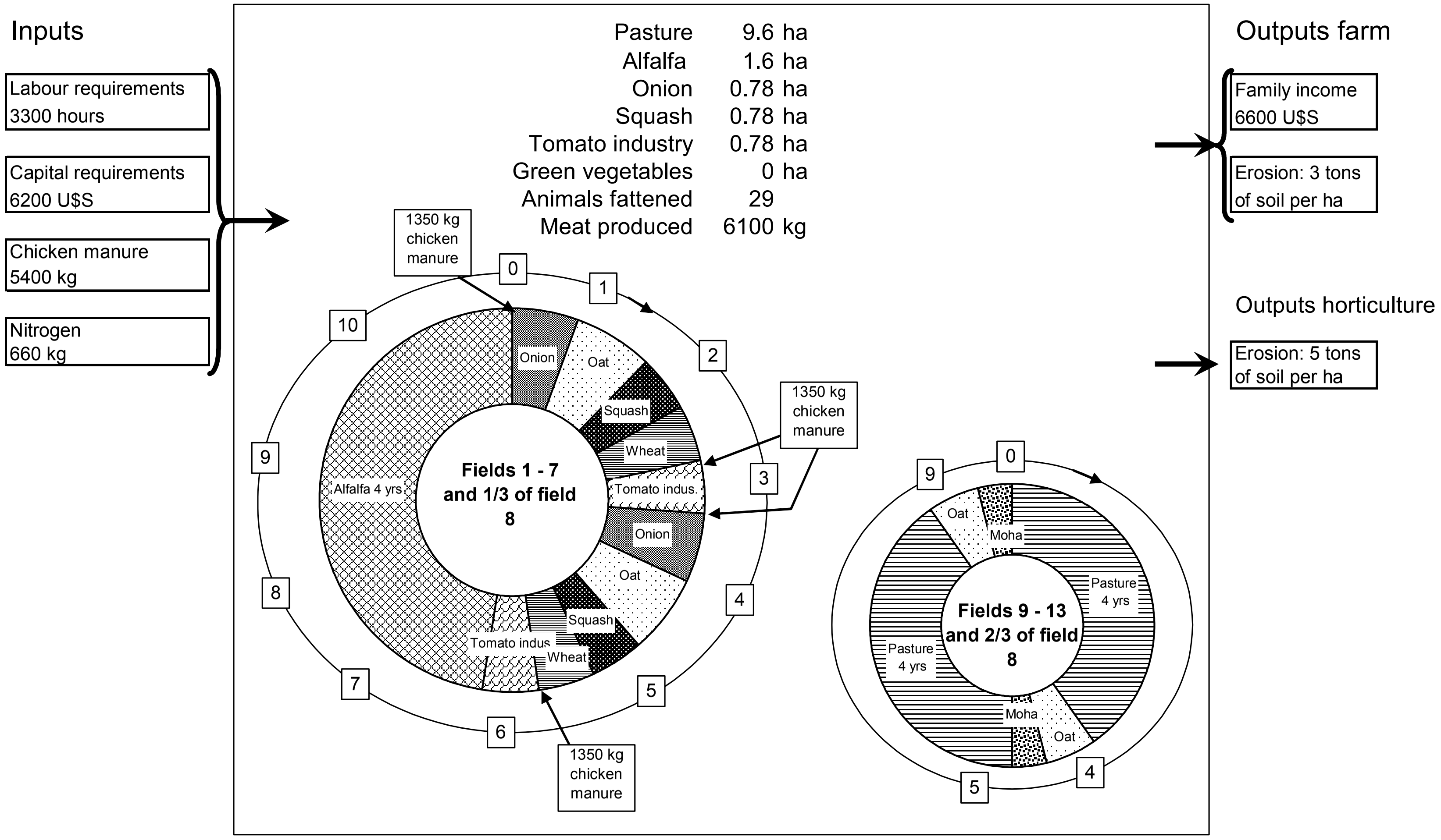

Figure 4. Visualization of farm system design Classical2.5-R0 for the farm discussed in Section 4.4.

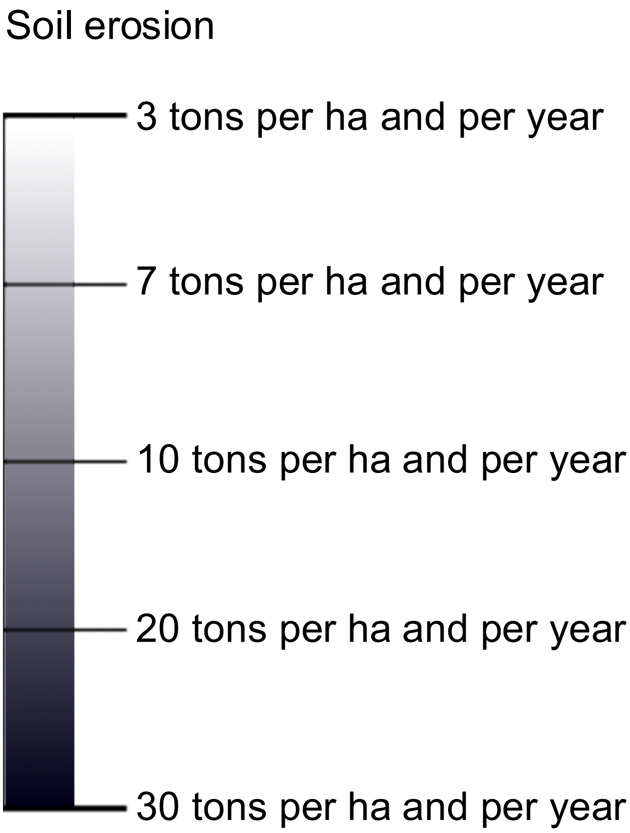

Figure 5. The indicator visualization.

consequences for the others." He appreciated the possibility to see combinations between indicators offering "something medium" on all the indicator visualizations. The farmer also mentioned that the proposed designs represented the ideal situation. The third farmer already monitored inputs and outputs for his own registration before the project asked him to do so. Therefore, he had a clear idea of his production results. Already during the presentation, he had questions about the risks related to the price and the relevance of the proposed crop distribution in case of price variations. At the visit after two weeks, the farmer remarked there were not so many differences when comparing the scenarios by pairs. Moreover, he contested the spatial organization that was associated with the farm system designs. The designs implied a subdivision of the existing fields into smaller plots and the construction of new paths and would thus have decreased the already limiting production area. A common observation about the impact of the presentation format on the farmers was that farmers both used, and appreciated the indicator visualizations to compare different farm system designs.

None of the project team members or visited farmers reacted negatively to the presentation of model output. Apart from the illiterate farmer, the farmers, as well as the technical coordinators learned what the model could do. The capacity of Farm

Images to provide an overview of different aspects related to farm management was generally appreciated. However, we did not observe any change in the farmers' perception or understanding of anything else apart from the model, nor in their actions in the project. Thus, the farmers learned *about,* but not *through* Farm Images. The project team had some more diverse learning experiences and learned not only about, but also through Farm Images. The project coordinator changed his perception of animal manure applications and the technical coordinators found confirmation for their assumptions and because of this became more confident.

## 4.6 Learning through the action research project

Main ingredients of the action research project were: farm management proposals (see Section 4.4.1); visits of project team members to the farmers to discuss the performance of the farm and to monitor and evaluate implemented adaptations; and some material support to reduce the risks associated with experimentation. The learning experiences mentioned by the farmers suggest that through the project, the farmers got acquainted with a diversity of animal production, crop- and field management technologies, such as new tillage techniques, a deliberately planned rotation, and the use of animal manure. The project team learnt about the feasibility of those technologies on a diverse range of commercial farms. Besides, both the project team and the farmers learnt from the collaboration about their own and others' capacities.

Table 5 and 6 summarize and categorize the above and in Section 4.5 described learning experiences of the project team and the three farmers pictured in Sections 4.4 and 4.5. Learning that could be related to the calibration and presentation of output from Farm Images is in italics. A number of the technologies the farmers and project team learn about, were also incorporated in Farm Images. However, the data provide no indications that the presentations of model output to the project team and farmers added to the learning that the project brought about.

## 4.7 Discussion

The Multiple Goal Linear Programming model 'Farm Images' was developed as part of modelling research that explored possibilities for farm systems in the region Canelón Grande in south Uruguay. In this Chapter, we presented a study of the operationalization of Farm Images in a different social and technological context, i.e., the exploration of possibilities for three individual farms in south Uruguay in the framework of an action research project. In the first Section, we posed four questions

Table 5. Learning among the project team members in the project. Learning experiences related to the operationalization of Farm Images are in italics.

| Area of learning | Technical coordinator 1 | Technical coordinator 2 | Project coordinator/model developer |
|---|---|---|---|
| Aspirations and knowledge | | Learnt about soil management, and to analyse at the farm system level | *-Reflected on his expectations about attainable goals and the proposed measures at the three modelled farms.* |
| | *Learnt what kind of analyses can be generated with Farm Images* | | *-Learnt what the calibration of Farm Images for an specific commercial farm might encompass* |
| | Learnt about the feasibility of alternative management practices, such as intercropping on commercial farms | | |
| Perception of own role and that of others | *Got more confidence in own power of judgement because farm studies confirmed assumptions* | | |
| | Became more involved in the project because they observed that the project approach produced positive results and the farmers started to show confidence in their capacities | | |
| Action | Increased the frequency of farm visits in the course of the first project year to improve the quality of the input-output registration and to discuss the farmers' planned activities more often | | |

Table 6. Learning among the three farmers presented with output from Farm Images. Learning experiences related to the presentation of model output are in italics.

| Area of learning | Farmer 1 | Farmer 2 | Farmer 3 |
|---|---|---|---|
| Aspirations and knowledge | Learnt about a number of alternative animal production, crop- and field management technologies | Learnt about a number of alternative animal production, crop- and field management technologies | -Learnt about a number of alternative crop- and field management technologies.<br>-Became aware of a lack of understanding about the impact of his management practices on soil processes |
| | | *Learnt what kind of outcomes can be generated with Farm Images* | |
| Perception of own role and that of others | Confidence in own technical skills increased | The project team was a trustworthy source of information | Involvement in the project increased because he observed that implemented changes produced positive results and his trust in project team grew<br>Confidence in own technical skills increased |
| Action | Adapted several crop- and field management practices<br>Discussed farming related plans with the project team | | |

addressing this change in context and its consequences for the contribution of a model to learning: How do (1) *development context*, (2) *calibration* and (3) *presentation* of Farm Images affect learning in the action research project in Canelón Grande?, and (4) How do the learning experiences in the project relate to the features of Farm Images? In this Section, these four questions are answered.

From the analysis of the *development* of Farm Images transpired three main contextual forces: a strong interest of the collaborators in generating rotation proposals in a transparent way; the agronomic background of all collaborators, and; the scientific heritage. The materializations of those three forces in the model were ROTAT, a rotation generator, a list of predominantly agronomic management alternatives and a model for the larger part evolving from earlier scientific work. The *calibration* process appeared far more laborious than expected by the model developer/project coordinator. The involved farmers were not able to provide necessary farm-specific data, Farm Images could not optimize two production systems on one soil type, and one farmer left the project. The *presentations* of model output were positively evaluated both by the project team and the involved farmers.

Section 4.6 lists learning experiences of the project team and the three farmers involved in the calibration. Expect for the farmer not able to read and the model developer/project coordinator, all others got acquainted with Farm Images. The project team learnt through the model, the farmers did not. In proportion to the time investment in calibration and preparation for the presentations, learning seems fairly limited. All participants were positive about the presentations of model output. Why did they then primarily learn about, and not through Farm Images? During and after his modelling research, the model developer/project coordinator developed and presented his ideas for an action research project, i.e. to evaluate selected technologies on commercial farms for their impact on farm sustainability. These ideas built on his work with Farm Images. The learning experiences collected in Section 4.6 indicate that the technologies incorporated in Farm Images were being tested in the project. Because the project members were already experimenting with the technologies incorporated in Farm Images, supposedly, learning through Farm Images remained limited. Consequently, we cannot exclude the possibility that Farm Images would have had a larger impact had the real life experimentation not been in place. Moreover, since Farm Images clearly was a source of inspiration for the formulation of the action research project, Farm Images had a considerable, however indirect, impact on learning in the project.

# 5

# Land use models in complex societal problem solving; Plug and play or networking?

**Abstract**

Land use systems research addresses issues, such as agricultural policy making, land use planning and integral water management that often involve multiple stakeholders. Several potential roles for land use models in multi- stakeholder situations have been identified, such as: a heuristic role, improving understanding; a symbolic role, putting an issue on the political agenda; and a relational role, creating a community. This Chapter addresses the question which kind of arrangements, conditions, model qualities, or other factors harness land use modelling to perform those roles. Thereto, a conceptual framework of the interactions betweens scientist, model, and societal stakeholders was developed. Subsequently, this framework was instrumental to analysing three case studies of linking land use modelling to problem solving in a multi-stakeholder context. The conceptual framework suggests that a land use model can only perform a role in problem solving when it is enrolled in the interactions by one or more of the stakeholders. It then gets a different status because it becomes part of the interactions, is contextualized and its role is being defined. Thus, the framework puts forward this network building of scientists, societal stakeholders, *and* the land use model during model development and application as a main explaining factor for the roles computer models get to perform. The comparative analysis of the case studies suggests that land use models were accepted both for their characteristic system research features, i.e., the study of interactions between components and the integrative capacity, and through 'work on the network'. In all three cases, substantial investments were made to enrol and contextualize the land use model in question and maintain relations with relevant stakeholders. The studied land use models performed heuristic roles in combination with at least one other role. In two cases, the model had a symbolic role in addition to its heuristic role. Also in two cases a relational role was found, i.e., the model fostered network building around the land use issue at stake. This is a role of land use models, which has rarely been highlighted in literature to date. However, we deem it a highly relevant issue for further research while the linking of social and ecological systems and the capacities of communities to manage natural resources in a sustainable way are major issues in natural resource management research these days.

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## 5.1 Introduction

The potential of computer-based models as a source of advice for tackling management problems was well established with the concept of the decision support system or DSS (Sage, 1991, in McIntosh et al., 2007). This potential was also recognized within the land use systems research community. As a result, a large number of computer-based models and tools have been produced over the past decade with the aim of providing support to land use policy and management (e.g., Van Keulen, 2007; Rossing et al., 2007; Argent, 2004; Oxley et al., 2004 ). A number of studies of effective mobilization of scientific computer models were reported for a diverse range of users, such as farmers and policy makers (e.g., Zadoks, 1989; Carberry et al., 2002; ISNAR, 2004, p 41-48; Meinke et al., 2006). Here, we adhere to the definition of effectiveness of Cash et al. (2003): "[…] impacts on how issues are defined and framed, and on which options for dealing with issues are considered, rather than only in terms of what actions are taken to address environmental problems." All those reported effective efforts of mobilizing scientific computer models involved two actors, a scientific and a societal stakeholder (group). However, land use systems research addresses issues, such as agricultural policy making, land use planning and integral water management that often involve *multiple* stakeholders. There are far less reports of effective use of tools in those situations involving multiple stakeholders. One of the few examples concerns the political debate about climate change. Shackley (1997) concluded that climate models were instrumental in establishing the issue of climate change on national and international policy agendas.

Several potential roles for models in multi-stakeholder situations have been identified, such as: a heuristic role, improving understanding; a symbolic role, putting an issue on the political agenda; and a relational role, creating a community (Shackley & Wynne, 1995; Van Daalen et al., 2002; McIntosh et al., 2005). Shackley (1997) suggests that computer models can have these roles because models are "efficient ways of reducing complexity through synthesizing and integrating knowledge, and hence of generating and legitimating a commonly held story line, e.g., beliefs about the causes and effects of a phenomenon, about the possible ameliorative actions and also about the allocation of responsibility for the issue". These story lines serve as a sort of 'social glue', helping to hold together a range of actors, with divergent goals and interests (Hajer, 1995). With this analysis, Shackley provides an answer to why in particular computer models are suited for those roles. However, the few reported examples of effective use of a tool in a multi-stakeholder context do not provide the theoretical and/or empirical material to understand *how* computer models get to perform their heuristic, symbolic and relational roles (cf. Van Daalen et al., 2002;

Oxley et al., 2004; McIntosh et al., 2005). Therefore, the aim of the work reported here is to build critical understanding regarding which kind of arrangements, conditions, model qualities, or other factors harness land use modelling to perform heuristic, symbolic and relational roles in multi-stakeholder contexts. Thereto, a conceptual framework of the interactions betweens scientist, model, and societal stakeholders is developed (Section 5.2). Subsequently, this framework is used to analyse a number of case studies of linking land use modelling to problem solving in a multi-stakeholder context (Section 5.4). The land use models in question have all been described in peer-reviewed journals. The case study methodology is introduced in Section 5.3. Our discussion (Section 5.5) is meant to be suggestive rather than conclusive, providing a partial analysis of the cases at hand, as well as outlining an approach to future case studies.

## 5.2 A conceptual framework of the interactions between scientist, model, and societal stakeholders towards solving a problem

The variety in computer-based models and tools has generated lively debate in recent years about the appropriateness of specific models, and the question which type of model provides ‘the best tool for the job’ (e.g., Matthies et al., 2007). Earlier publications have discussed ‘critical success factors’, such as the representation of uncertainties in computer models, the need for proper timing, the ease of use of graphical user interfaces and transparency (e.g. Saloranta et al., 2003; Oxley et al., 2004; Mysiak et al., 2005). However, as argued in Section 5.1, those analyses provide few clues on *how* model development and application are to be arranged. We found that the sociology of science offers a useful basis to address this ‘how’ question, i.e., to link model development and application related features, such as possible research arrangements, conditions and model qualities to the roles a land use model gets to perform. Sociologists of science argue that opinions about a model merge from a complex interplay of scientific, social, institutional, policy and material factors. Concerns about, for instance, transparency are not the cause of disputes about models, nor just its effect, but rather an integral part of decisions and practices which change over time and space (Shackley, 1997; Van Daalen et al., 2002). What is the ‘best tool for the job’ eventually is decided in interaction. In this Section, we use those and other insights from the sociology of science to develop a conceptual framework to understand how models become effective in a multi-stakeholder context.

### *5.2.1 Actor Network Theory*

Societal problem solving in a multi-stakeholder context, in the remainder of this

Chapter referred to as ‘complex’ problem solving”, is about coping with different backgrounds, interests and opportunities, and with sometimes completely different perspectives of both problems and solutions. These perspectives imply specific interpretations of realities and the responses to these, constructed by the actors involved, according to their backgrounds and interests (Weick, 1995; Koppenjan & Klijn, 2004). Conflicts of interest are likely to emerge wherever actors strive for meaningful change (Leeuwis, 2000). In such cases, problem solving requires negotiation as well as social learning. Here, social learning is about the recognition of mutual dependencies between the actors that are involved in the problem at stake (Bouwen & Taillieu, 2004). Social learning and negotiation imply interactions between actors. To understand the roles of computer models in such context, actor network theorists argue, that the computer model, as a non-human entity, should not be excluded from the analysis of those interactions beforehand (e.g. Callon, 1986; Latour, 1987). Actor Network Theory looks at the state of affairs in an action arena as the effect of interactions amongst human and *non-human* entities. A key element of this approach is that the patterns of interactions or ‘actor networks’ are composed not only of people, but also of machines, animals, money and so on because artefacts and natural phenomena have an influence on how human beings behave in a given context. A machine may perform certain tasks and hence ‘act’ in a particular way, and at the same time it structures human behaviour. That is, people must also act in particular ways if they want the technology to work. In the frame of our search for better understanding of how land use models become used, Actor Network Theory is relevant for another reason as well. Actor Network Theory explicitly addresses the process of incorporation of an entity in a network (Callon, 1987). Thus, the question of how an entity, such as a computer model, becomes accepted by the other actors. In Actor Network Theory, the strategies and methods to build and maintain a network, are referred to as methods for ’translation’. Translation can be described as a multifaceted interaction in which actors (1) construct common definitions and meanings, (2) define and distribute roles, and (3) enrol each other as well as new people and things in the pursuit of individual and collective objectives (Callon, 1986). Consequently, objectives as well as the strategies to achieve them are not fixed in the network, but are continuously re-ordered as new people and things enter the arena.

### *5.2.2 Contextualization of scientific knowledge*

This Chapter discusses the roles of land use models that were initially developed as research tools. In this sense, those land use models differ from, for instance, a chess computer. However, even though these models are science-based, they are not value-free. Similar to the input of other actors, scientists’ questions, concerns and conclusions are not neutral (see e.g. Latour, 1987; Knorr-Cetina, 1981). Working in science, usually the experience of a researcher becomes ‘objectified’ by being transformed into peer-reviewed publications. In this transformation process, the researcher approaches the stance of an “ideal” observer so that this “objective experience” in principle, can be shared with and criticized by any member of the scientific community. When science plays a role in the world it studies, however, the claim of objectivity accompanying this procedure of ‘objectifying’ within the scientific community appears often problematic (Carolan, 2006). What is perceived as objective within the scientific system does not need to be perceived as such outside this system because, similar to other social systems, power and interests play an influential role in science. Therefore, Alrøe & Kristensen (2002) proposed to redefine scientific objectivity; “[…] not the conventional, un-reflected objectivity, which excludes the intentional and value-laden aspects of science, but a reflexive objectivity that includes these aspects and exposes their role.”

In a complex problem solving context, however, the scientific perspective does not only need explication of underlying values and aspirations, but frequently also needs the fitting to a social and biophysical context as well as interpretation in relation to other knowledge sources such as rules of thumb, or the experiences of other actors, to become effective knowledge (Eshuis & Stuiver, 2005; Carolan, 2006; Cash et al., 2006). In the remainder of the Chapter the combination of explication of values and aspirations, fitting to context and interpretation of model work in relation to other knowledge sources is referred to as ‘contextualization’. Shackley’s (1997) analysis of why computer models are enrolled in policy processes, illustrates the relevance of contextualization. He found that scientists and policy makers were involved in continually adjusting their expressed or implied expectations, requirements, opportunities and constraints during the construction of a computer model. The end result was a product of mediation (including accommodation with ‘reality’, through the scientists’ perceptions of natural resistances). He concluded that this product of mediation appeared an important means through which coalitions began to take shape. If the model had not been mediated, or, in other words, contextualized, it is likely that research would not have contributed to the shaping of coalitions.

### *5.2.3 A conceptual framework*

Figure 1 is an attempt to capture the actors and interactions discussed above. The problematic context is nested in a biophysical and socio-economic context. A *science model* can only perform a role in complex problem solving when it is enrolled in the interactions by one or more of the stakeholders. It then gets a different status because it becomes part of the interactions, is contextualized and its role is being defined.

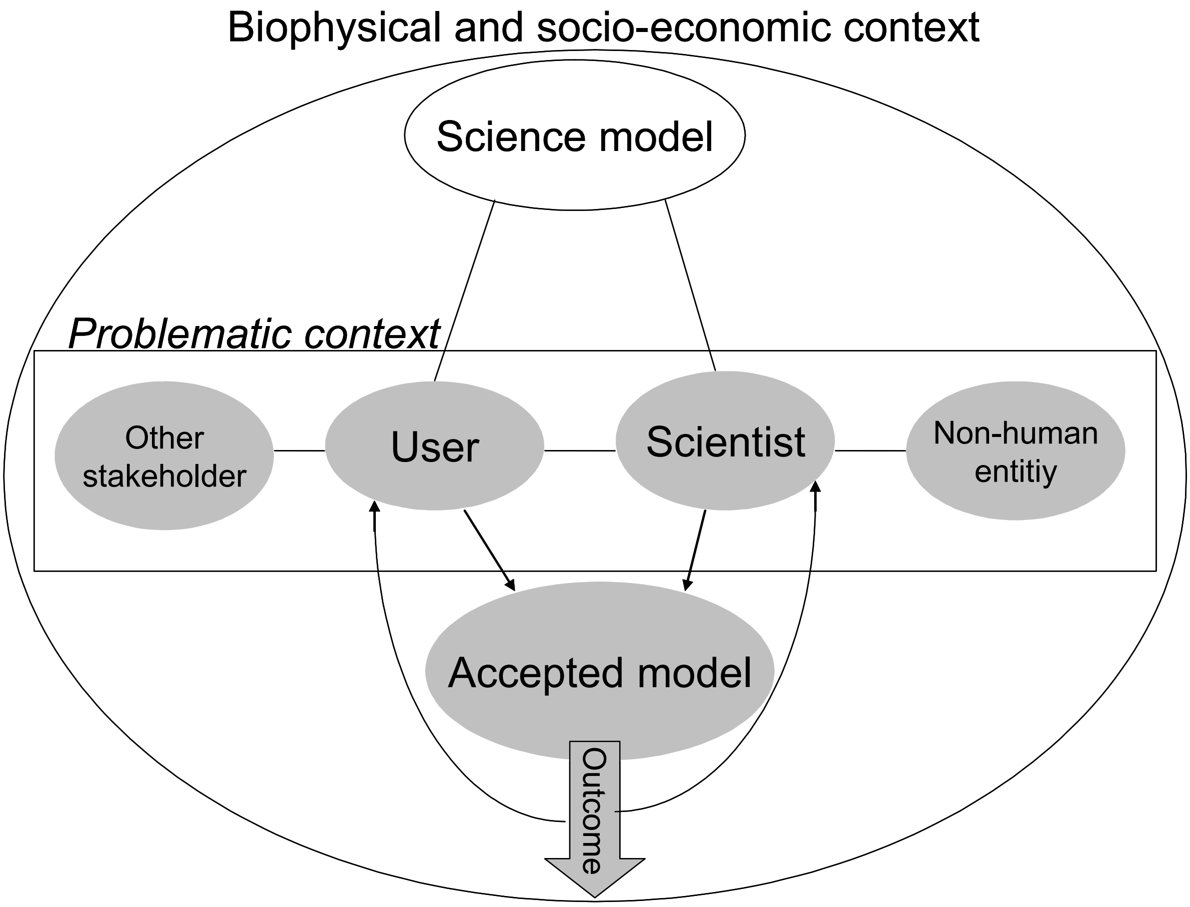

Figure 1. Visualization of the interactions between human actors, land use model and other non-human entities.

Therefore, the computer model enrolled in the interactions is labelled *accepted model*. The *non-human entity* refers to possible other non-human features than the model, such as the meeting place, that are part of the interactions. The scientific stakeholders are referred to as *scientists* and the non-scientific actors as (societal) stakeholders. Societal stakeholders are people affected by the land use problem in question. Pertaining to the contribution of a computer model, two groups can be distinguished within the societal stakeholders category: *users* and *other stakeholders*. Users are a person, group, or corporate entity who have an interest in the problem and introduce the output of model simulations in the problem-related interactions. Other stakeholders also have an interest in the problem solving process at hand but do not bring in model output.

The conceptual framework in this Section was developed to address the question how computer models come to contribute to complex problem solving and get specific roles. We used the conceptual framework to elaborate this main question in three sub questions to further investigate the issue in three case studies:

- What role(s) did the model play in the course of the interactions?
- How did the model become part of the interactions in the network?
- Which model qualities contributed to the accepted role(s) of the model?

The first two questions relate to the conceptualization of effective model application as presented in this Section, i.e., a land use model becomes part of the interactions in a network, is contextualized and gets a role. The last question is about what precisely land use models add to the translation methods of a network, i.e. the methods and strategies to build and maintain a network. The results are presented in Section 5.4.

## 5.3 Case study methodology

The three studied models are referred to as GOAL, EURURALIS and TOA. Through literature and oral hints, three cases were identified. In all three cases, researchers from Wageningen University and Research Centre were involved. The case studies were constructed from data of semi-structured interviews, official and internal reports, grey literature and journal articles. There were no opportunities to observe interactions as two cases took place in the beginning of the 1990s, and in the third case, a meeting of users and stakeholders was postponed till a couple of months after our research period. In total, 13 persons were interviewed (i.e. GOAL 4, EURURALIS 5, TOA 4) nine out of the 13 more than once, three responded through e-mail, the oral interviews lasted on average one hour each time. The respondents of the respective cases represented the different actor groups involved in the problem at stake, i.e., modellers, users, and other stakeholders. Section 5.4 was thereafter checked for factual mistakes by the respondents. We would have preferred to question more persons, but non-response was high, in particular of the ‘other stakeholder’ category. However, we feel that the three case-studies together still provide enough material to develop suggestions and hypotheses about how to effectively harness land use modelling for problem solving in multi-stakeholder contexts.

Obviously, to research how a land use model came to play a role in complex problem solving, the model needed to have had some kind of impact. Impact was defined as noticeable reactions outside the scientific networks. It was not the purpose of the reported research to prove or evaluate the reach of impact in the case studies. Therefore, if none of the respondents objected to a claimed impact and we did not find any clues in literature invalidating the claim, it became a starting point for the case study work. The three possible roles of land use models, i.e., heuristic, symbolic and relational, were made operational to create a further basis for the data analysis. Explicit reference to learning as well as reports of new insights, a change in mindset or a reorientation in topics of discussion were labelled ‘heuristic’. A ‘symbolic’ role encompasses contributions to putting an issue on the agenda as well as a change in perception, e.g. of the urgency, or relevant aspects, of an already entered point on the agenda. A computer model had a relational role when the data suggested that the model enhanced network building and co-ordination.

## 5.4 Case studies

Each of the three models is briefly introduced, after which its impact and the three formulated questions (see Section 5.2.3) are addressed. The main findings are summarized in Table 1.

### *5.4.1 GOAL and The Netherlands Scientific Council for Government Policy*

The linear optimization model GOAL (General Optimal Allocation of Land use, Rabbinge & Van Latesteijn, 1992; Van Latesteijn, 1995) links the technical possibilities for land-based agriculture to a diverse range of socio-economic, agricultural productivity and environmental policy goals to calculate a number of land use alternatives for the European Union (EU). Through assigning a different priority to each of the policy goals a certain policy view can be represented, e.g. free market and free trade, or regional development. The technical possibilities for land-based agriculture in the EU were quantified by combining agronomic information on the relation between crop properties and production potentials, information on soil properties and historical observations of the weather. Those quantified technical possibilities were confronted with quantified and prioritized policy goals regarding the performance of the agricultural system.

*Impact and model qualities*

GOAL was developed to provide the data for the study “Ground for Choices” (WRR, 1992) of the Netherlands Scientific Council for Government Policy. This Council advises the government –sometimes at the government’s request, but frequently unasked– on issues facing society which are or could become the subject of government policy. In principle, the Council is free to study any issue the government deals with, or should deal with. Ground for Choices evoked an unusual number of reactions for a Scientific Council study according to respondents. The senior scientists of the study were invited hundreds of times to present the modelling results at political, policy and scientific meetings worldwide. The results were debated in the Dutch written press (more than 50 items in the first month after presentation) and on radio. The presentation of the study report was a news item on television. The

Netherlands Scientific Council for Government Policy and respondents claimed that the Dutch government and agricultural and nature conservation organisations became convinced of the need of further consideration of the options to integrate environmental, nature and forest objectives with agricultural objectives in response to Ground for Choices. In the years after publication of the study, the focus shifted from 'agricultural' to developing 'rural' policy. Furthermore, one of the senior scientists was invited to advise the Ministry of Agriculture, Nature Conservation and Food Quality on strategic policy and vision development.

### *Building a network*

How did the output of GOAL become noticed? A Council member initiated the study because he questioned a number of claims in the debate about the reform of the EU agricultural policy. The results were presented at a time that the discussion about the reform of the EU was heated Furthermore, Dutch policy and policy-oriented research institutes, as well as European and foreign national institutes in Europe were purposefully approached for data and feedback on results to foster credibility and visibility from the start of the project. The leaders of the Dutch political parties in the national parliament were each informed about the outcomes of the study before the official presentation; preliminary results were presented at a meeting of the ministers of agriculture of the EU member states in The Netherlands. Also, Dutch nature conservation and agricultural organizations were introduced to the modelling work. All those efforts to communicate about the project were facilitated through the contacts of the Netherlands Scientific Council member. He was member of the council of a Dutch agricultural organisation that both represented the interests of the sector in politics and had the responsibility to execute agriculture-related public policies ('Landbouwschap'), and a large national nature conservation organization ('Natuurmonumenten'). Moreover, he had been politically active in different public organs for two decades already.

### *Which roles*

The above listed impacts of the work with GOAL suggest that GOAL contributed to understanding (heuristic role) and adaptation of the agricultural policy agenda (symbolic role). Respondents and the Netherlands Scientific Council for Government Policy claim that the relations between differing issues proposed in GOAL, such as high-input agriculture and nature conservation convinced the government and societal stakeholder groups of the relevance of a debate about a rural area policy in order to address not only agriculture but also other land uses. Thus, GOAL contributed to the reframing of the issue in terms of a rural, rather than a purely agricultural development question. We hypothesize that GOAL had heuristic and symbolic roles because: (1) the study was published at an appropriate point in time, i.e. the EU agricultural policy reforms were intensively debated at the time outcomes were presented. Because of those debates, people were perceptive to a new contribution; (2) From the start the project team invested in contextualization and communication of their work to the target groups, facilitated by the contacts of the project leader; (3) GOAL related differing issues that were previously debated in isolation. Subsequently, it could suggest new spaces for manoeuvre because of the integration of those differing issues. We did not find any indications that GOAL fostered community-development (i.e. a relational role).

### *5.4.2 EURURALIS and the European network of directors of rural area*

EURURALIS (Westhoek et al., 2006; Verburg et al., 2006) assesses the effects on landscape of plausible changes at the European level in political and socio-economic conditions. To this end, EURURALIS assesses scenarios of plausible changes as defined by globalisation drivers and the control of governments of societal developments. EURURALIS is a chain of models. A macro-economic model first calculates the economic consequences of a certain scenario for the agricultural system. The output of the macro-economic model is fed into an integrated assessment model to calculate yields, the demand for land, feed efficiency rates and environmental indicators. A subsequent model allocates land to different land uses.

*Impact*

In 2002, Wageningen UR and the Netherlands Environmental Agency were asked by the Dutch Ministry of Agriculture, Nature and Food Quality to develop an, at least partly quantitative, discussion support tool. In 2007, the ministry funded a third version of the tool 'EURURALIS'. In parallel with the development of EURURALIS a network of directors of rural area of agricultural ministries of the European Union (EU) member states was built. According to a respondent of the ministry, it is likely that this newly established network stops to exist if the EURURALIS modelling work would not be part of the network anymore.

*Building a network, and model qualities*

In first instance, EURURALIS was not meant to become enrolled in the EU-wide directors  rural area network. The development of the tool was commissioned in reaction to an interpellation about the vision of the Minister on the development of the Dutch rural area. Two of the collaborators in the Ground for Choices study (see 5.4.1) had entered in governing bodies. They hooked on the interpellation to initiate a follow-

Table 1. Answers to the three research questions (Section 5.2) per case study.

| | **GOAL** | **EURURALIS** | **TOA** |
|---|---|---|---|
| **Roles** | heuristic, symbolic | heuristic, relational | heuristic, relational, symbolic |
| **Building of a network** | initiated and maintained by modellers<br>communication was explicit component of project management<br>priveleged position of project leader<br>contextualization was a major activity in the network | model enrolled and representativity maintained by rural area team of Ministry<br>model development is used as reason for interactions in network | initiated and maintained by research-intervention project team.<br>network composed of broad range of stakeholders, i.e., different disciplinary backgrounds, and farming-, intervention- or research-oriented.<br>work on TOA was part of larger project, comprising a range of research and intervention activities<br>contextualization was a major activity in the network |
| **Qualities of model** | relates differing issues<br>explores space for manoeuvre | encapsulates different views on future developments | exploration of management and technical alternatives<br>relates differing issues |

up of the Ground for Choices study. EURURALIS was intended for a meeting of the Ministers of Agriculture from the EU member states. This initiative did not keep up. However, the project was then adopted by the rural area team of the ministry to contribute to a meeting of the directors 'rural area' from the different EU member states. The Dutch director wished to create a European network of national policy makers, similar to the already existing networks around water and nature conservation, to address the future of the rural areas and to develop an EU rural policy agenda. Those existing networks evolved around EU policy instruments, such as the Water Framework and the Habitat directive. A similar tangible occasion lacked in the case of the rural area. The team felt that EURURALIS could fill this gap. EURURALIS was installed on laptops for the directors rural area of EU member states to explore model output during a two-day meeting. According to the respondents, the directors rural area especially appreciated the possibility to employ the EURURALIS tool as a card index and the visualization of output in land use maps because these features helped the users to get an overview of the diversity in developments and interdependencies in the rural area at both national and European level. The Dutch rural area team asked for a second version of the model. The progress of EURURALIS 2.0 was regularly discussed with the Dutch policymakers, in an international policy advisory board and in subsequent meetings of the EU rural area network. Though the second version has not been delivered yet, the rural area team of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality already commissioned a third version and plans to visit network participants in the different countries to discuss EURURALIS on a bilateral basis.

*Which roles*

With the second version still to be presented and a third version commissioned, chances are likely that EURURALIS roles will be negotiated in the future. At the moment, respondents explicitly refer to its community-creating role, i.e. without the model, the directors rural area network would fall apart. Furthermore, its heuristic role was acknowledged, i.e., EURURALIS helped the users to develop an idea of relevant aspects and interdependencies at both national and European level. The Dutch rural area team foresees a symbolic (putting issues on the agenda) role for EURURALIS. Their purpose with investing in the network is to develop an widely approved agenda on EU rural area policy. To this end, the second and third version of EURURALIS will allow the user to implement policy instruments under all four scenarios to assess their impact. The above presented data suggest that EURURALIS has heuristic and relational roles because: (1) EURURALIS provides flexibility in the sense that it offers four elaborations (i.e., four scenarios) of the same question "what are plausible changes in land use?" and can therefore accommodate diverse perceptions. This flexibility suits the explorative stage the network is presently in. The actors in the network do not need to agree on what exactly entails rural area development to communicate about model outcomes; (2) The rural area team of the Dutch Ministry of Agriculture, Nature Conservation and Food Quality employed presentations of output of EURURALIS to structure network meetings, and will use EURURALIS as an occasion to visit European colleagues. The team has purposefully enrolled EURURALIS as a means to establish a network and initiate a discussion on rural area policy at the European level.

### *5.4.3 TOA and potato production in Ecuador*

TOA (Tradoff Analysis Model, Crissman et al., 1998; Stoorvogel et al, 2004a) is a modelling framework to integrate disciplinary data and models for trade-off analysis. TOA was developed to examine pesticide impacts on agricultural production, human health, and the environment in the highly commercial potato growing province of Carchi, Ecuador. For a trade-off analysis, an inventory is made of possible sustainability indicators of a particular system, whereafter a selection is made. Hypotheses are formulated regarding the relationships between these indicators, so called 'trade-off curves', and policy or technology interventions that might shift the curves. The subsequent needed analysis to quantify the trade-off curves uses spatially explicit econometric simulation models linked to spatially referred biophysical simulation models.

#### *Impact*

The policy debate on pesticides in Ecuador in the 1980s was largely driven by environmental groups claiming that pesticides were having significant environmental impacts. Scientists who worked on the impacts of pesticide use in Ecuador, claim that the output of TOA contributed to the shift in attention from environmental towards human health impacts of pesticide use. As a result, a committee composed of directors from the national agricultural research institute, the Ministry of Education, and the Ministry of Health drafted a `Declaration for life, environment and production in Carchi' to call for action at the provincial level in 1999. In 2001, a similar call was made by a committee of national stakeholders. According to involved scientists, video and other visual images of the fluorescent tracers of pesticides on individuals' body surfaces as well as in the home, were particularly useful to create a sense of urgency. Subsequently, TOA created a basis for discussing alternatives, e.g. TOA outcomes suggested that both IPM and applicator safety measures improved economic returns as well as health outcomes.

### *Building a network and model qualities*

How did TOA become enrolled in this power play? An international group of researchers developed TOA to explore the tradeoffs between economic, environmental and health indicators in Carchi, Ecuador. To develop specific components of TOA, the researchers worked with stakeholders in the study area. Stakeholder meetings were held to identify key sustainability indicators and their tradeoffs, and relevant policy and technology scenarios. A two-year survey was conducted for 187 fields of 40 farmers, with approximately monthly visits to each farmer to obtain data about management practices on each field they managed. According to one of the international researchers, the extensive contacts of the International Potato Research Institute (CIP) and the national agricultural research institute in the area facilitated these research activities considerably. The modelling work took place in the context of a larger research-intervention project that included amongst others health studies of the neurological impacts of pesticide exposure on farmers and their families, sociological studies of farmers practices related to pesticide use and educational programmes. In the frame of this larger research-intervention project, a few times per year local and provincial stakeholders and the researchers were convened to discuss research results. One of the major provincial-wide stakeholder meetings attracted one hundred and five representatives from the government, industry, development organizations, communities and the media.

### *Which roles*

The work on TOA was part of a larger research-intervention project. Moreover, it integrated data and insights from other activities within the framework of this larger project. Nevertheless, it appeared possible to analyse TOA's (partial) contributions and induce its roles from this analysis. The data suggest that TOA improved understanding (heuristic role) and fostered network building (relational role). Moreover, similar to GOAL (Section 5.4.1) TOA influenced the framing of the problem of intensive pesticide application practices in Carchi that had already entered the agenda (symbolic function). To start with the heuristic and symbolic roles, video and other visual research methods were complementary to the integrative capacity of TOA. The empirical work had an awareness-raising effect while the modelling work demonstrated until then unknown relations between health and productivity and herewith created space for alternatives. In reference to the relational role of TOA, a respondent from a NGO working on empowerment in Carchi noted: "For me, the data collection and modelling activities were most useful when they involved diverse stakeholders early on in the process, and as such contributed to new relationships and changing perceptions and senses of responsibilities. At the end of the day, the relationships and emergent networks of actors seem to make greater contributions than the raw data and its extrapolations.” Why did TOA have these roles? Although it is particularly hard in this case to unravel the relationships and interactions because of the manifold related and in parallel occurring research and intervention activities, our hypothesis is that it were: the regular interactions between all involved actors due to model contextualization activities and meetings organized in the frame of the research-intervention project, in combination with the necessary involvement of a large diversity of stakeholders to provide input for model development.

## 5.5 Discussion and conclusions

Land use modelling addresses issues related to agricultural policy making, land use planning and integral water management, in this Chapter referred to as complex problems because those issues often concern multiple stakeholders with divergent objectives, and perspectives. Computer models were found to perform heuristic (improving understanding), symbolic (putting the issue on the political agenda) and relational (creating a community) roles in complex problem solving (Shackley, 1997). The conceptual framework presented in Section 5.2 puts forward contextualization of the model and network building of scientists, societal stakeholders, *and* the land use model during model development and application as main explaining factors for the roles computer models get to perform. From the conceptual framework, three questions were derived to further investigate in three case studies how models get roles in complex problem contexts. Those questions were: (1) What role(s) did the model play in the course of the interactions? (2) How did the model become part of the interactions in the network? (3) Which model qualities contributed to the accepted role(s) of the model? In this Section, these three questions are addressed from an integrative perspective.

Concerning the first question, what stands out is that all three studied models had a heuristic role and that it were characteristic system research features, i.e., the study of interactions between components, and the integrative capacity , that were mentioned in relation to this role (question 3). Though data of three partial cases is far too limited to draw any generic conclusions, on basis of earlier investigations of model use (Chapters 1 and 6) and these three cases, we would suggest that other features typically associated with the use of land use models, such as the representation of uncertainties in computer models, the ease of use of graphical user interfaces, and transparency (e.g. Saloranta et al., 2003; Oxley et al., 2004; Mysiak et al., 2005) are model qualities that are not key to the heuristic capacity of land use models but rather are facilitating in a particular network setting of scientists, societal stakeholders, and the land use model.

Furthermore, though in all three cases the computer model had a heuristic role it always came with in combination with at least one other role. This other role(s) was more directly connected with the social ambitions that were present in a specific case-study. In two cases (GOAL and TOA), the land use model had a symbolic role. Also in two cases (TOA and EURURALIS), modelling work fostered network building around the land use issue at stake (relational role). This is a role of land use models that has rarely been highlighted in literature to date. However, we deem it a highly relevant issue for further research while the linking of social and ecological systems and the capacities of communities to manage natural resources in a sustainable way are major issues in natural resource management research these days (see e.g. Fabricius et al., 2007; Reynolds et al., 2007).

Concerning questions 2 and 3, a comparative analysis of the three case studies (Table 1) suggests that land use models were accepted for their particular qualities, the characteristic system research features as discussed above, network building, and contextualization. The presented case studies show that the land use models were not accepted in a network by chance. In all three cases, substantial investments were made to enrol and contextualize the land use model concerned and maintain relations with relevant stakeholders. Furthermore, it was not one specific actor (group) that made these investments. In the TOA and GOAL cases, it were scientists who took the initiative to enrol a model in the network. In the EURURALIS, the user was the instigator. Considering the presented conceptual elaborations and the empirical observations, it is plausible that both network building and contextualization are crucial for effective model use in a multi-stakeholder context.

This Chapter set off to investigate how models get to perform certain roles in a complex problem solving context. The developed conceptual framework (Section 5.2) drew the attention to the importance of contextualization of a model and the social interactions surrounding land use model development and application. The analysis of the three case studies (Section 5.3) confirmed that network building and contextualization are important explanatory factors, as well as characteristic system modelling qualities, i.e., the study of interactions between components, and an integrative capacity. Furthermore, the data analysis revealed that in complex societal problem solving, land use models perform heuristic roles in combination with at least one other role. In view of the presented innovative findings, we consider the proposed conceptual framework helpful to the understanding of model development and application in multi-stakeholder contexts.

# 6

# The interface between land use system research and policy: Multiple arrangements and leverages

**Abstract**

In recent years, pressure has been applied to agricultural research organizations to become more pro-active in engaging with policymakers, assuming that such engagement leads to more impact. It has been argued that the management of land, whether at the field, farm or regional scale, can benefit from computer-based systems analysis. This Chapter formed part of the preparations for and is one of the outputs of a workshop on modelling support in policy decision-making that took place in July 2007 in The Netherlands. In 26 semi-structured interviews that were made in Australia and The Netherlands in preparation of the workshop and the workshop itself 11 cases of policy-oriented modelling research were investigated. In this Chapter, two steps are made to assess appropriate approaches towards policy-oriented modelling work. First, the concept ‘boundary arrangement’ was made operational for our field of interest, i.e. computer-based systems analysis of rural development, with emphasis on the use of land for agricultural production and other environmental services. Five ideal-typical boundary arrangements are discerned: ‘Civil mandate’; ‘Trickle out’; ‘Janus Face’; ‘Critical participant’; and ‘Knowledge broker’. This ideal-typical classification of boundary arrangements makes explicit the institutional space in which modellers function. In a second step, a number of critical leverage points is identified in policy-oriented modelling research and related to the five boundary arrangements. The six points are: reputation of research institute and/or scientists; raising and balancing expectations; communication about and investment in the scientific basis of the modelling work; participation in model development; heterogeneous and extensive social network in policy sphere; institute mandate that secures availability of stepping stones, such as persons who invest in a heterogeneous and extensive network in the policy sphere and see opportunity to use modelling work developed in a more science sphere oriented context. For those of us functioning in a rather science sphere oriented environment, similar to the above listed ‘Trickle out’ arrangement, the reported work suggests that there are more options than the frequently proposed ‘more participation’ for increasing the probability that policy-oriented work is used. These include establishing contacts with research groups or institutes that are in a position to function as ‘stepping stones’, or to let a member of the group develop a social network in the policy sphere.

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## 6.1. Introduction

Over the past 30 years, there has been a consistent rationale to justify much of the research undertaken in the field of land use systems analysis. Such rationale proposes that decision-makers, whether farmers, policymakers, or other stakeholders, struggle with the complexity and uncertainty inherent in land use and would welcome support in deciding what to do. Consequently, it is argued that the management of land, whether at the field, farm or regional scale, could benefit from computer-based system analysis (Herrero et al., 1999; Bernet et al., 2001; McCown et al., 2002; Santé & Crecente, 2006; Van Ittersum et al., 2007;Van Keulen, 2007).

In recent years, pressure has been mounting on agricultural research organizations to become more pro-active in engaging with policymakers, assuming that such engagement leads to greater impact (CGIAR Science Council, 2006). We are aware of one effort to reflect on the use of computer-based system analysis in public administration (McIntosh et al., in press). Consequently, while researchers are under pressure to become more pro-active in engaging with policymakers, there is little basis on which to determine appropriate strategies for model application in the policy sphere. Against this background, in this Chapter two steps are made to assess appropriate approaches towards policy-oriented modelling work on agricultural production and other environmental services of land.

The first step is a better understanding of the positioning of a modeller vis-à-vis (envisaged) users in the policy sphere and its implications for the utilization of a model. Worldwide, the collective experience at developing science models to address issues of rural development, with emphasis on the use of land for agricultural production and other environmental services is extensive. A review of the literature suggests that the use of this modelling work outside science –especially in the policy arena– has been a disappointment to many developers and a source of considerable reflection (McCown, 2002a,b; Parker et al., 2002; Walker, 2002; Van Keulen, 2007; Rossing et al., 2007; McIntosh et al., in press). However, we found a different image when we dug deeper, into the unpublished stories. Most countries have agencies with mandates to sit between the science and policy spheres. In those agencies, a range of models is mobilized to perform policy-oriented analyses, including research models that have a production-ecological basis. Generally, the usefulness of modelling work is not questioned in those agencies. In this Chapter, we suggest how those two differing images and perceptions on the mobilization of computer-based research models in the policy arena may be analysed, using the positioning of a modeller vis-à-vis (envisaged) users as an explanatory variable.

In a second step, the positioning of a modeller vis-à-vis (envisaged) users is coupled to effective strategies for model development and application. In literature, a diversity of methods and criteria has been discussed, such as participation of stakeholders/envisaged users in model development (e.g. Parker et al., 2002; Walker, 2002; Jakeman et al., 2006; Van Paassen et al., 2007; McIntosh et al., in press). In the frame of an assessment of effective methodologies for agricultural research in general, Sumberg et al. (2003) concluded that "[…] there is no magic or universal formula for successful product development, just as there is no single best approach to end-user involvement in the development process." The premise of this Chapter is that this same 'no-one-cure-for-all' conclusion applies to participation of stakeholders or any other potential leverage point, and that positioning of a modeller vis-à-vis (envisaged) users offers a useful entry point to assess an appropriate modelling research strategy in a given context. The term leverage point' covers means, conditions and methods that foster use of modelling work and are not given, and thus may be part of a strategy to increase the chances that a model is used.

The research methodology is discussed in Section 6.2. This Chapter is based on the experiences of the authors, numerous interviews and a workshop. Therefore, the data consisted of a rich variety of anecdotal stories. The sociological concept 'Boundary arrangement' was the main building block of the analytical framework to identify the different forms that the positioning of a modeller can take vis-à-vis (envisaged) users (Section 6.3). Five boundary arrangements in the field of modelling agricultural production and/or other environmental services are identified in Section 6.4. Subsequently, we investigated critical leverage points in relation to those five boundary arrangements (Section 6.5). Section 6.6 gives the discussion of the results and a research outlook.

## 6.2 Methodology

This Chapter formed part of the preparations for and is one of the outputs of a workshop on modelling support in policy decision-making that took place in July 2007 in The Netherlands. We used material from the preparations and the workshop to feed into this Chapter. For the preparations, 26 semi-structured interviews were held in Australia and The Netherlands. The average length of an interview was one hour. The respondents had a background in modelling or policy sciences, worked at a university or an agency with a mandate to sit between science and policy, and had been involved in work on the science-policy interface or had experience with the use of computer models in a policy context. Many of the respondents participated in the workshop as well. The presentations and discussions in the workshop were structured around impact, and effective model development and application. References to the modelling

Table 1. Names, main features and references of the modelling research cases.

|  | Name model or research project | Subject of research, initiator | Main references |
|---|---|---|---|
| 1 | GOAL (General Optimal Allocation of Land Use) | Science-initiated investigation to explore consequences of various options for rural policy for land use in Europe. | Van Latesteijn, 1995; Rabbinge & Van Latesteijn, 1992 |
| 2 | Eururalis | National Department-commissioned scenario study of the future of Europe’s rural areas and the role of possible policy instruments. | Westhoek et al., 2006; Verburg et al., 2006 |
| 3 | TOA (TradeOff Analysis) | Science-initiated investigation of the environmental and human health effects of pesticide use and the process of tillage erosion for the potato-pasture production system in the Ecuadorian Andes. | Stoorvogel et al., 2004; Crissman et al., 1998 |
| 4 | Bulb on the move | An association of bulb growers and environmentalists approached a science shop with the question how environmentally friendly bulb production might be combined with economically viable farming. One of the purposes was to inform national policies on biocide use in the sector. The science shop brought the association in contact with modellers. | Rossing et al., 1997 |
| 5 | Sysnet (Systems Network) | Science-initiated programme to identify land use options at the sub-national scale to support agricultural and environmental policy formulation in South and South-East Asia. | Roetter et al., 2005; Van Ittersum et al., 2004 |

Table 1. Continued.

| | | | |
|---|---|---|---|
| 6 | IRMLA (Integrated Resource Management and Land use Analysis) | Science-initiated programme with the purpose to link land use analyses at household and regional scale to support resource use analysis and planning at four sites in Asia. | Roetter et al., 2007 |
| 7 | LARCH (Landscape ecological Analysis and Rules for the Configuration of Habitat) | Science-initiated development of a decision system tool to assess sustainability (for individual species) and spatial cohesion (aggregating results of more species) of landscapes. | Verboom et al., 2001 |
| 8 | SEAMLESS (System for Environmental and Agricultural Modelling; Linking European Science and Society) | Project initiated in the frame of funding from the European Union for policy-oriented research on predefined themes. In the project a computerized framework is developed for ex-ante assessment of new agricultural and environmental policies in the European Union. | Van Ittersum et al., in press |
| 9 | FORSPACE (FORestry dynamics in SPAtially Changing Environments) | Landowners and the provincial government asked to investigate the effects of large grazers on forest development in contiguous areas with differing management objectives, i.e. nature development and wood production. | Kramer et al., 2006 |
| 10 | European and Dutch ambitions regarding nitrate emissions from agriculture | Policymakers at the national level asked to assess permissible manure and fertilizer use in the Netherlands in order to comply with the Nitrate Directive target. | Schröder et al., 2007 |
| 11 | LandscapeIMAGES (Interactive Multi-goal AGricultural landscape Generation and Evaluation System) | Science-initiated spatially-explicit exploration of options for multifunctional agriculture in landscapes to inform land use planning. | Groot et al., 2007 |

work that constituted the basis of the reported enquiry are listed in Table 1. We did not consider cases of which the modelling research was not published in a peer-reviewed journal. For the analytical work presented in Section 6.3, all material was used. In Section 6.4, the results are only based on cases for which some kind of impact of the modelling research was reported. Impact was defined as noticeable reactions in the policy sphere. In ongoing cases, those 'noticeable reactions' also covered activities of the envisaged users that indicated commitment, such as active involvement during and in between meetings, or interest of others than the principal in the modelling work. It was not the purpose of the reported research to prove or evaluate the reach of impact in the cases. Therefore, if none of the informants (i.e., interview respondents and/or workshop participants) objected to a claimed impact, the case became subject of analysis. The results presented in Sections 6.3 and 6.4 were verified by several of the informants. Those persons are listed in the acknowledgements.

## 6.3 Boundary arrangements between science and policy

The science-policy interface in general has been researched extensively (Guston, 2001). The concept 'boundary work' has been central in analysing the impact of scientific knowledge in the policy sphere (e.g., Cash et al., 2003). The term 'boundary work' refers to social practices to maintain the science-policy interface, such as frequent and two-way communication, developing rules of conduct and establishing criteria for decision-making. Hoppe (2005) recently proposed the related term 'boundary arrangement' to describe how actors conceive of the division of labour between science and policy, and thus perform specific boundary work. Boundary arrangements are not fixed. They are negotiated and frequently renegotiated between actors over time. Multiple boundary arrangements can be found in one research institute and even with one researcher. Hoppe distinguishes eight arrangements, on basis of two variables: 'relative primacy' and 'logic of social function'. The first variable refers to relative primacy of science or policy in terms of control and authority. The logic of social function variable highlights presupposed convergent or divergent relational logic among scientists and policymakers. We used those two variables to identify the distinctive boundary arrangements in our field of interest, i.e., modelling agricultural production and/or other environmental services of land. To analyse the data, the variables were made operational as follows:

*Relative primacy*, the positioning of a case depends on who is perceived to initiate research activities and to formulate objectives and questions. The two extremes are then science-driven and policy-steered.

*Logic of social function,* at the divergent end science and politics are considered two incompatible ways of life, whose relational logic is Either/Or. Explicit references to the independent and objective status of scientific knowledge indicate such divergent logic for instance. Convergent logic encompasses arguments and actions to integrate scientific knowledge development with policy work.

The analysis of the, mainly oral, reports of the development and (potential) use of science models addressing production and/or other environmental functions of land led to five distinctive ideal type arrangements presented in Section 6.4. The ideal type method is helpful for broadly positioning experiences of modellers in the fluid and fuzzy space of countless possible science policy arrangements. An ideal type is constructed from characteristics and elements of a collection of cases that are common with regard to specific features of interest. Hence, the ideal type is not meant to correspond to all of the characteristics of any one particular case. It is not meant to refer to perfect things, moral ideals nor to statistical averages but rather to stress certain elements common to the cases belonging to the field of interest. Sketching the ideal types of science-policy boundary arrangements involving modelling work, we conceptually set aside the real indistinctness and ambiguity, and imagined a ‘pure’ case in which the relevant features are distinct and unambiguous. The result is a boundary arrangement type that in all likelihood does not exactly depict any of its existing instances. The five arrangements together encompass the space of possibly actually existing arrangements. For further analysis of the collected cases, the ideal type boundary arrangements constituted the framework to loosely group collected experiences of modellers resembling a particular ideal type arrangement. Subsequently, for each group of experiences critical leverage points were identified in the model development and application trajectory.

## 6.4 Five science-policy boundary arrangements in the field of computer-based land use system analysis

In this Section, first the five ideal type boundary arrangements are singled out. In Figure 1, the distinguished boundary arrangements are positioned in relation to two axes, representing the primacy and relational logic. Figure 2 gives a symbolic image of the different arrangements.

In the first arrangement, science operates within its own sphere, aiming at the creation of knowledge and tools, whilst policy operates in another sphere. Policy is in control: “political leaders and their administrative staffs articulate knowledge questions and assign detailed research projects to scientists-*as-engineers*” (Hoppe, 2005). This ideal type is referred to as the ‘Civil mandate’ arrangement. For us, the

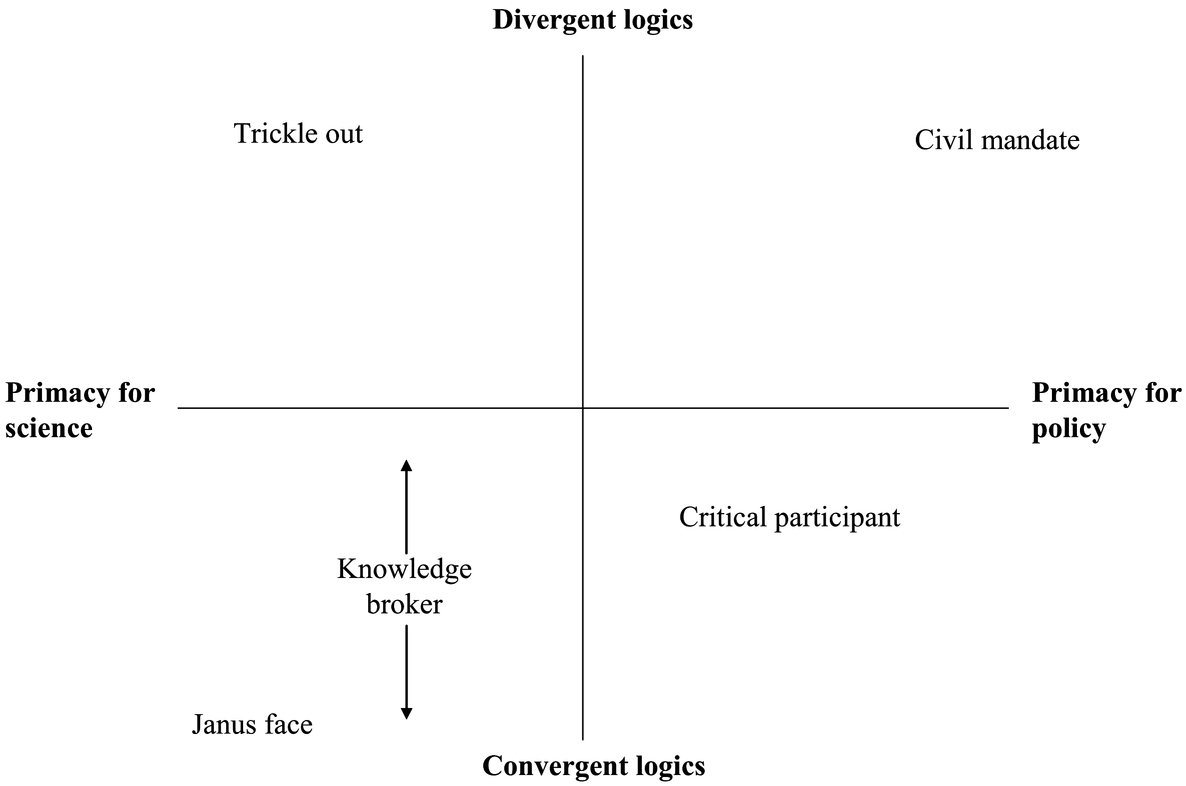

Figure 1. Positioning of five science-policy boundary arrangements involving policy-oriented modelling work on agricultural production and other environmental services of land in relation to relative primacy in terms of control and authority and logic of social function.

term 'Civil mandate' connotes a clear, consistent and explicit task distribution between the two spheres of respectively policy/politics and modellers.

The second ideal type 'Trickle out' represents the view of model development initiated in the science sphere with science-argued expectations of uptake, as typified by Roetter et al. (2005) "current land use policies in general inadequately take into consideration multiple objectives and the increased complexity of current resource management decisions. … In such situations, effective systems analysis tools are required to … contribut(e) to a more transparent policy-making process". In the 'Trickle out' arrangement, relative to the investment in tool and methodology development, little effort is placed in fostering uptake or evaluating impacts as noted in cases reviewed by Rossing et al. (2007). 'Civil mandate' and 'Trickle out' are modes of operation that largely maintain a divergent relational logic between the science and policy spheres.

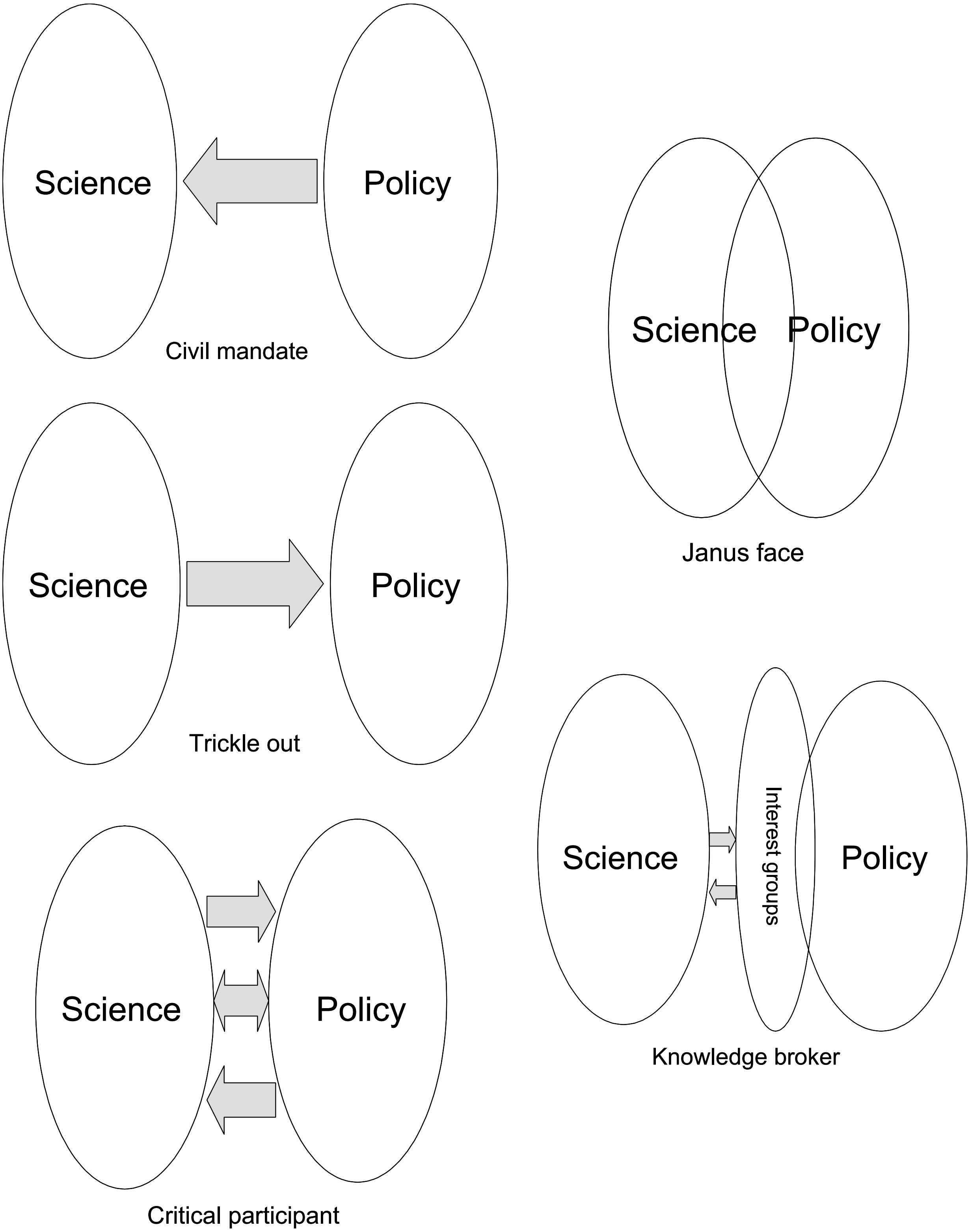

Figure 2. Visualization of five boundary arrangements of science and policy involving policy-oriented modelling work on agricultural production and other environmental services of land. The arrows indicate which sphere is perceived to have primacy over initiation of research and formulation of objectives and question.

This third arrangement is named ‘Janus Face’ because of the concurrent functioning in the policy and science sphere. Scientists can become embroiled within the political sphere. Those scientists do not simply engage with politicians, they work to become part of the political establishment and in doing so are able to have science heard in political debates. To maintain credibility as a scientist, primacy of the science sphere is perceived essential.

In the ‘Critical participant’ arrangement, science-graduates are funded to do policy-oriented work on land use related issues. This fourth ideal type is very similar to the first ‘Civil mandate’ type, except for the fact that the objectives of the work are not commissioned by the government but are formulated in the science sphere. Furthermore, in contrast to ‘Civil mandate’ and ‘Trickle out’, both the third and fourth arrangement ‘Janus Face’ and ‘Critical participant’ are situated more to the convergent end of the relational logic variable. In the case of ‘Janus Face’ this is obvious. For ‘Critical participant’, the argument goes that the policy sphere gives science the freedom to reflect on the whole decision-making process, i.e., both goals and means, hence the label ‘Critical participant’. To allow this for policymakers, and for the scientists to perceive this as feasible, a convergent relational logic is basic.

The fifth arrangement mirrors the situation that scientists engage with interest groups. The other way around, interest groups can also invite science to work with them. In a multi-stakeholder context, policy may be represented, but is not necessarily directly engaging with science. The primacy is more with the science than with the policy sphere. However, in contrast to the ‘Trickle out’ arrangement, considerable efforts are made to transfer scientific knowledge. In terms of the conceived position of scientific knowledge in the fifth arrangement, there are two alternatives: scholars found that computer models were mobilized as efficient ways of reducing complexity through synthesizing and integrating knowledge, and hence jointly shape a political discourse around a central analogy (Shackley, 1997). Hoppe (2005) situates this mobilization of scientific knowledge more at the divergent end of the relational logic axis. We argue that it depends on the degree of social learning involved, i.e., learning about other actors perspectives, values, theories and aspirations and recognition of mutual dependencies between the actors that are involved in the problem at stake (signified by the double-sided arrow in Figure 1). Synthesizing and integrating knowledge can remain superficial. However, social learning can also involve reframing, leading to alternative solutions and integrative negotiations (Aarts & Van Woerkum, 2002). Which of the two pathways is taken depends on the conceived relational logic as well as on contingent circumstances connected to the policy process, such as the experienced interdependency and trust among those involved (idem). Therefore, those two pathways are represented by one boundary arrangement. This ideal type is labelled 'Knowledge broker' to signify the possible other users of policy-oriented modelling research, apart from policymakers.

## 6.5 Assessing critical leverage points in view of boundary arrangements

In the previous Section, the focus was on the positioning of a modeller vis-à-vis (envisaged) users in the policy sphere and its implications for the utilization of a model. The five distinguished ideal-typical boundary arrangements present a framework to position oneself as a modeller in the space of possible boundary arrangements. In this Section, as a second step the five ideal-typical boundary arrangements are related to effective means, conditions and methods to foster model use. From the interview and workshop data on cases where a model had impact (cases 1, 2, 3, 4, 7, 9, 10, Table 1) six critical leverage points were distilled and categorized according to their relevance for the boundary arrangements (Table 2). Furthermore, the leverage points were classified according to three stages in the modelling process: continuously; before; and during. 'Continuously' indicates that the point is relevant before, during and after a modelling project. Though we use empirical data to illustrate the critical leverage points, and related the points to the distinguished ideal types, we would like to emphasize that this does not imply that a specific case corresponds to a particular ideal type. A case has characteristics that resemble an ideal type, but an ideal type is a simplification of reality and therefore cannot be used to label a whole case.

*Reputation of research institute and/or scientists* A good reputation is especially relevant when for instance a principal from the policy sphere does not intend to evaluate the research methodology or other issues related to the commissioned research, but rather is interested in the results. Thus, expectations of the research quality are based on reputation of a researcher rather than on communication about the research concerned. This reputation may be, but is not necessarily, assessed on basis of publications in peer reviewed journals. Schröder (pers. comm., case 10, Table 1) experienced that policymakers may ask for explanation of the modelling work nevertheless, not with the purpose to check the methodology, but to be able to defend it towards colleagues in the policy sphere.

*Raising and balancing expectations* entails continuous clarification and negotiation of the type of outcomes that may be expected. In SEAMLESS (case 8, Table 1) it was noticed that expectation management may function as a kind of marketing strategy. It raises interest from potential users, it balances expectations and it allows for dovetailing of the modelling work with those interested. Even though numerous

Table 2. Connections between critical leverage points for model use in the policy sphere and boundary arrangements. Critical leverage points are classified according to their relevance continuously, before or during model development.

| Continuously | Before | During | Critical leverage point | Arrangement type: Civil mandate | Trickle down | Janus Face | Critical participant | Knowledge broker |
|---|---|---|---|---|---|---|---|---|
| | ░ | | Reputation of research institute and/or scientists | ■ | | ■ | | ■ |
| | ░ | ░ | Raising and balancing expectations | ■ | | | ■ | ■ |
| ░ | | ░ | Communication about and investment in the scientific basis of the modelling work | | | | ■ | |
| | | ░ | Participation in model development | | | | | ■ |
| ░ | | | Heterogeneous and extensive social network in policy domain | | | ■ | ■ | |
| ░ | | | Institute mandate that secures availability of stepping stones | | ■ | | | |

informants referred to raising and balancing expectations as a critical leverage point, it remained a rather elusive process. We consider this a relevant subject for further study.

*Communication about and investment in the scientific basis of the modelling work* This leverage point applies in situations where there is no direct relation between supply and demand, for instance, when funds are made available for policy-oriented research and these funds are not labelled to address specific questions but rather in terms of themes. In such contexts, modelling results are more likely to be used when the research methodology is explicitly addressed in the communication between scientists and potential users. 'Communication about and investment in the scientific basis of the modelling work' is not a leverage point when a group or researcher is perceived to function in a 'Trickle out' resembling arrangement, i.e. clearly targeting the science sphere. In such cases, it is far less likely that the scientific quality becomes an issue of discussion because the modelling work is already assessed solid science. Communication about the research methodology is frequently combined with purposeful investment in the scientific basis. The GOAL case elucidates this point. The GOAL model (case 1, Table 1) was developed in the frame of a policy-oriented, science-initiated research project of The Netherlands Scientific Council for Government Policy. The GOAL model was developed to address land use issues in the European Union against the background of the Common Agricultural Policy (CAP). The involved scientists frequently communicated and discussed their assumptions, questions and data with the envisaged users in The Netherlands. Moreover, they chose to verify their work with research and administrative bodies within the European Union and to invest in publications in peer-reviewed journals and presentations at scientific meetings.

*Participation in model development* The above introduced expectation management is part of participation in model development. Participation in model development may also encompass: involvement of users in the formulation of the starting points of modelling work; assistance in data collection; regular communication about the progress; and responsibility of all involved actors for the communication of the modelling work. Participation in model development that encompasses more than 'raising and balancing expectations' is opportune when the modelling work takes place in a context where several stakeholders work on an issue of public concern, as in the TOA and the 'Bulb on the move' cases (cases 3 and 4, Table 1). In a multi-stakeholder context the mediation of different perceptions of the problem and possible solutions and the integration of multiple knowledge sources becomes opportune. Thus, in most other boundary arrangements 'raising and balancing expectations' suffices, but in a multi-stakeholder context it does not. Research priorities and the ambitions and possibilities to contribute for instance to the clarification of arguments and values and/or to mediate in parallel to the research task, shape the participation trajectory. The TOA (case 3) and 'Bulb on the move' (case 4) cases present examples of how participatory trajectory can get shaped dependent on the nature of the perceived problem. In the TOA case, the area-specific problem definition needed clarification, therefore the researchers considered it necessary to work with recent data from the area concerned. Consequently, experiments and measurements were performed in the area where the users of the modelling research lived to feed the TOA model. In contrast, in the 'Bulb on the move' case, the data for the modelling research came from experimental stations and scientific literature. In the Bulb on the move case, science was invited to mediate in a conflict between representatives of commercial bulb growers and environmentalists about farm management. The scientists proposed to explore future options. For such explorations, it was more appropriate to use data from experimental stations and literature than to do measurements.

*Heterogeneous and extensive social network in policy sphere* A network is two-way traffic. The contacts inform the modelling work. On the other hand, the contacts are also entry points to 'market' research. A heterogeneous and extensive network in the policy sphere is a critical leverage point in situations where science aims to support policy-making but does not respond to concrete questions. The LARCH case (case 7), below presented in more detail, is an example where the network both informed the modelling work and later on was effectively used to promote the model both in relevant departments and agencies with a mandate to mediate between the science and policy sphere.

*Institute mandate that secures availability of stepping stones* When science functions relatively isolated from influences from the policy sphere, a 'stepping stone' in the same research group or institute is helpful. This 'stepping stone' is the closer involvement of other researchers or managers in the group or institute within the policy sphere, for instance in arrangements resembling the ideal types 'Civil mandate', 'Janus Face' or 'Critical participant'. Those researchers/managers invest in a heterogeneous and extensive network in the policy sphere, pick up on policy issues or do commissioned research, and see opportunity to integrate modelling work developed in contexts resembling arrangement 'Trickle out'. In the 'Bulb on the move' case (case 4, Table 1), a so-called Science Shop, which was affiliated with the university, brought scientists from the university together with two interest groups with a question. Science shops are organizations created as mediators between citizen groups (trade unions, pressure groups, non-profit organizations, etc.) and research institutions (universities, independent research facilities). LARCH is an example of the synergy of multiple arrangements in one research group. LARCH (case 7, Table 1) integrated research that was inspired by a Dutch nature conservation plan, the ‘Ecological Main Structure’. The set-up of this earlier research resembled the ‘Trickle out’ arrangement in that it was science-initiated and the work was published in peer-reviewed journals. Comparatively little effort was made to communicate the work to other possible user groups. However, the research group that did this research had a broad mandate, including more supply- as well as demand-driven policy-oriented research. Consequently, the group had contacts in the policy sphere and with agencies with a mandate to mediate between the science and policy sphere. Fed by this network of contacts, the group identified a niche for their research that was initially science-oriented.

## 6.6 Discussion

The purpose of the efforts presented in this paper was to provide some grips for assessing appropriate strategies for policy-oriented modelling work. To this end, the concept ‘boundary arrangement’ was made operational for our field of interest, computer-based systems analysis of agricultural production and other environmental services of land. Five ideal-typical boundary arrangements were discerned: ‘Civil mandate’; ‘Trickle out’; ‘Janus Face’; ‘Critical participant’; and ‘Knowledge broker’. Those ideal types are theoretical constructs to which none of the particular cases exactly corresponds, but they stress certain elements of interest that are common to the cases belonging to the field of interest. The ideal typical classification of boundary arrangements made explicit the institutional space in which modellers function. This space enables certain activities, and at the same time constraints other initiatives, dependent on who is perceived to initiate research activities and to formulate objectives, and whether it is considered appropriate to integrate scientific knowledge development with policy work. ‘Janus Face’ is an exception because it is the only arrangement that is not the outcome of the interaction between personal agency and institutional space, but rather of personal agency alone. Subsequently, a number of critical leverage points in policy-oriented modelling research were identified and related to the five boundary arrangements. We conceive of two applications of this research for modellers who are interested in the use of their work in the policy sphere. First, the boundary arrangement classification helps to interpret experiences of others and to assess the salience of lessons and suggestions for their own context. Secondly, the combination of the boundary arrangement perspective and critical leverage points presents a basis to design an institutional pathway for fostering impact of modelling research. Some of the authors of this Chapter normally work in a 'Trickle out' resembling context. The analysis in this Chapter suggests that there are more options than the frequently proposed 'more participation' for increasing the probability that their policy-oriented work is used, such as establishing contacts with research groups or institutes that are in a position to function as 'stepping stones', or hiring somebody to develop a social network in the policy sphere and move towards the 'Critical participant' arrangement.

None of the identified critical leverage points (Section 6.5), i.e., 'reputation of research institute and/or scientists', 'raising and balancing expectations', 'communication about and investment in the scientific basis of the modelling work', 'participation in model development', 'heterogeneous and extensive social network in policy sphere', 'institute mandate that secures availability of stepping stones', pertains directly to model qualities. This observation confirms the hypothesis (Chapter 5) that features typically associated with the use of land use models, such as the representation of uncertainties in computer models, the ease of use of graphical user interfaces, and transparency (e.g. Saloranta et al., 2003; Oxley et al., 2004; Mysiak et al., 2005) are model qualities that are not key to the use of models but rather are facilitating in a particular arrangement of scientists and societal users.

In this Chapter, we addressed the question of appropriate approaches towards policy-oriented modelling work on agricultural production and other environmental services from an institutional perspective. The question of effective research strategies has repeatedly been approached from a different perspective as well, i.e., the contrast between structured vs. unstructured problems. Problems are grouped according to the perceived relative certainty about relevant knowledge and the perceived relative consensus on relevant norms and values (Funtowicz & Ravetz, 1993; Hoppe 1989, in Hisschemöller & Hoppe, 2001). This leads to a division with on the one end of the spectrum unstructured problems and on the other end structured problems. The latter are to be solved by standardized techniques and procedures. The problem is clearly defined and policy making responsibility is in the hands of one actor group. If a problem is unstructured, technical methods for problem solving appear inadequate. Several strategies have been proposed to cope with unstructured problems such as: a high level of public participation and inclusion of heterogeneous sources of knowledge; confrontation of different viewpoints and learning about each others' frames; first problem finding, and thereafter problem solving (Hisschemöller & Hoppe, 2001; Aarts & Van Woerkum, 2002). Those strategies are similar to critical leverage points identified for cases associated with the 'Critical participant' and 'Knowledge broker' boundary arrangements. This observation suggests that unstructured problems and arrangements resembling ‘Critical participant’ and ‘Knowledge broker’ are strongly related.

This Chapter is about the use of models in the policy sphere, without further definition of what this use could, or should entail. A logical next step is to address *effective* use, i.e., possible and desired impacts and appropriate modelling strategies. A number of project reports self-nominated learning as the mode of impact for their computer models (Walker et al., 2001; Roetter et al., 2005; Verboom et al., 2007). Referring to learning in the context of policymaking, we are not talking about compulsory classroom situations, but about adults confronted with changing circumstances and problems that require negotiations. “The learning is less of a goal in itself, is often more voluntary, and is immediately connected with diverse human interests and changes in professional practice” (Leeuwis, 2004, p. 149). Even if we agree that this is the kind of impact to expect, it still remains rather intangible how to measure this type of impact. In the evaluation of development-oriented and innovation programs, a similar question emerged earlier. In reaction, one of the authors of this Chapter (Leeuwis) works on the idea of reflexive process monitoring with the triple purpose of: learning to enhance the process under study; accountability to participants and other stakeholders; and scientific development. Activities that suit this triple purpose are: to assess or observe in specific cases whether there is (coherent) change in terms of people’s perceptions, actions and practices and whether such change is relevant from theoretical, stakeholder and policy perspectives; look for linkages to the modelling work in stories or actions of those involved; ask stakeholders to characterise the relative importance/influence and quality of model-related interventions; and discuss with stakeholders ways along which model-related interventions may be enhanced. In this manner, one may be able to create a ‘rich picture’ or ‘thick description’ of a change process. We think that this might be a fruitful approach, especially because of the triple purpose that includes scientific development. It may make modellers more willing to involve in documenting a process while it takes place. This documentation again may lead to more published, suitable data to learn about the use of science models.

# 7

# General discussion

## 7.1 Introduction

It was the premise of a learning enhancing effect of science-based land use models that formed the backbone of this thesis work. What we found were indeed proofs of learning through modelling. The learning took the form of a new perspective on a land use system, frequently in combination with a better understanding of the position of other stakeholders, resulting in adapted problem definitions, a changed solution space and/or the formation of new coalitions to tackle a particular land use related problem. The question "*How, and for what reasons does land use modelling enhance learning in the context of societal problem solving?*" guided our research efforts in three differing social contexts: farm management; multi-stakeholder; and public policy successively. The Plant Production Systems Group of Wageningen University had available a number of operational goal-based farm system models that had been developed in collaboration with other groups of Wageningen University & Research Centre. These operational models were the starting point for the empirical work reported in Chapters 2, 3 and 4. In those Chapters, a design approach was followed in the sense that we were looking for a suitable opportunity to introduce a (goal-based) farm system model in an ongoing change process. In all three Chapters, the change process concerned collaborations of researchers and commercial farmers to test system technologies on-farm, such as manure strategies and innovative crop rotations. Subsequently, Chapter 5 addressed the positioning of a land use model when several stakeholders are involved. In Chapter 6, the modeller-policy interface was the focal point of an analysis of appropriate approaches towards policy-oriented modelling work.

The ultimate aim of this thesis was to develop grips for those who wish to pursue the use of science-based land use models to contribute to societal problem solving. In the next few pages, we integrate the insights from the separate Chapters and induce several of such grips.

## 7.2 Understanding social contexts and problem solving processes

The research started with a basic idea of the contribution of modelling to societal problem solving, i.e. to enhance the learning that is connected with human interests and changes in professional practice. In literature, 'critical success factors' were suggested, such as the representation of uncertainties in computer models, the need for proper timing, the ease of use of graphical user interfaces and transparency (e.g. Saloranta et al., 2003; Oxley et al., 2004; Mysiak et al., 2005; Van Delden et al., 2007). The subject was approached from two main different methodological angles, i.e., search for a suitable opportunity to introduce a land use model, and comparative case study analysis. Models were found to contribute not only to improving understanding (heuristic role), but also to agenda-setting (symbolic role) and the creation of communities (relational role). Time and again it appeared not so much ‘critical success factors’ that proved helpful to understand the contribution of modelling to societal change, but rather features of a social context and/or problem solving process in place, such as actors ‘ aspirations, intentions, and perceptions of their own abilities, social and institutional relations. Illustrations from this thesis of social contexts are the practice of action research inspired by the prototyping methodology (Vereijken, 1997; Chapter 3), a modeller who feeds his system analytical knowledge to an action research project with commercial farmers (Chapter 4), or the modeller-policy interface (Chapter 6). Terms such as ‘experienced interdependency’ (Chapter 2), ‘network building’ (Chapters 5, 6) and ‘model contextualization’ (idem) were introduced to explain model use in problem solving processes. The experienced interdependency in a problem solving process was associated with the contributions of goal-based models to learning. Network building of modellers, potential users and stakeholders and contextualization of modelling work were found to foster model acceptance and use in a multi-stakeholder context. Contextualization encompasses the explication of underlying values and aspirations, fitting to a social and biophysical context and interpretation in relation to other knowledge sources such as rules of thumb, or the experiences of other actors. Consequently, instead of rather static and distinct factors, this thesis work suggests that we need to anticipate the relatively fluid and fuzzy features of social contexts and problem solving processes to harness land use modelling for societal learning.

## 7.3 The facilitating role of stepping stones

In Chapter 6, the term ‘stepping stone’ was introduced to acknowledge the relevance of certain policy-science arrangements in the vicinity of modelling research when this particular research is not commissioned or invited. The ‘stepping stone’ in Chapter 6 was the closer involvement of other researchers/managers of the research group or institute within the policy sphere. Those persons perform commissioned research, or pick up on policy issues, and see opportunity to integrate modelling work developed in relative isolation from those policy issues and commissioned research. In hindsight, stepping stones that connect actors and co-ordinate information form a red thread in the thesis work. In Chapter 2, we concluded that it was probably rather naïve to presume that a researcher without affiliations or obligations to potential users could find a niche for a model within the limited time frame of about a year. Chances of capitalizing on modelling expertise were hypothesized to be higher when researchers with such expertise are a logical and more or less permanent component of an ongoing trajectory than when the researchers come from outside to purposefully search for a niche. In hindsight, what we intended with our search for a niche was creating a stepping stone by means of the involved researcher. In the reported cases of actual model use, stepping stones came in diverse human and non-human forms: a researcher who was a logical and permanent component of an ongoing trajectory (Chapters 2, 6); an intermediary organization such as a science shop (Chapters 2, 6); an intervention-oriented project in which the modelling work was embedded (Chapter 5); a researcher active in the policy domain (Chapter 5); a mandate in an institute to execute policy-oriented research (Chapter 6).

The idea of a 'stepping stone' is close to what 'boundary work' encompasses, i.e., social practices to maintain the interface between science and other societal actors. However, boundary work is about what happens when the interface is established while this thesis predominantly covered the earlier stage of establishing connections. Therefore, we deem it opportune to introduce here the term 'stepping stone' to highlight the hallway to boundary work. Our analysis suggests that in principle any institution, organizational arrangement or person can become a stepping stone. However, for possible subsequent boundary work, accountability to both sides of the interface proves crucial (Guston, 2001; Cash et al., 2003).

In relation to the issue of connecting actors and co-ordinating information, we concluded that network building was highly relevant in problem solving that involved a number of stakeholders in Chapter 5. A comparative analysis of all chapters reveals that network building by modellers does not necessarily have to encompass the envisaged users of the modelling work. It can also concern a person, activity or organizational unit that may function as stepping stone, like for instance in the SHARES case (Chapter 2). In that particular case, the modelling team asked an outsider, i.e., a researcher active in rural development projects, to explore the possibilities for the use of the SHARES model in rural development processes.

## 7.4 How modelling work is organized that enhances change-oriented learning

Chapters 5 and 6 explicitly addressed the question how modelling work may be organized and embedded in a particular context. However, the issue of effective arrangement of modelling research is touched in all chapters. Taking stock of the whole thesis, here we elaborate further on one intensively debated aspect of the arrangement of modelling research, i.e., the participation of stakeholders/envisaged users in model development. (e.g., Parker et al., 2002; Walker, 2002; Jakeman et al., 2006; McIntosh et al., in press). The argument goes that more participation would increase relevance and commitment of the involved stakeholders and consequently leads to greater impact of modelling outside science. In the thesis, all multi-stakeholder cases where a land use model contributed to change-oriented learning exhibited some degree of participation in model development, ranging from a few meetings to discuss the problem definition and research questions, inform about the progress and tune the research again with the envisaged users, to collaborative data collection of modellers and stakeholders. The observed consistent employment of participatory modelling suggests that it is a viable approach, but the implementation varies.

Participation of stakeholders/envisaged users in modelling may be considered part of a strategy to do science with the explicit purpose to produce knowledge that is perceived to be salient, legitimate and credible knowledge by relevant stakeholders outside science. As especially in Chapter 6 is demonstrated, the nature of such a strategy is dependent on the particular user-modeller boundary arrangement that is adhered to at a specific moment in time. Chapter 6 was specifically about the policy domain. However, such arrangements can be recognized with other user groups as well (cf. Cash et al., 2003). In view of the different and variable boundary arrangements and associated strategies, we propose to start thinking about the set-up of participation in modelling research in terms of its functions. After such a definition of its functions in a particular context, one can then select appropriate means to shape the participation, such as interviews, regular stakeholder meetings or collaborative data collection. In this thesis, two main functions of participation came to the fore: the contextualization of scientific knowledge and community-building. Contextualization refers to the fitting of a scientific perspective to a social and biophysical context, and its interpretation in relation to other knowledge sources such as rules of thumb, or the experiences of other actors. Community-building is about the organizing of actors around the land use issue at stake. Note, in Section 7.2 the seemingly similar process ‘network building’ was discussed. However, in this thesis, ‘network building’ is a means for creating a context where computer models can contribute to societal learning. The ‘network’ concerns a relatively heterogeneous collection of persons or groups. Community-building is a possible result of network building and concerns a relatively homogeneous group of people.

We are interested in model-enhanced learning towards societal problem solving. Contextualization and community-building do not automatically lead to the necessary commitment for problem solving (cf. Akkermans & Vennix, 1997). In Chapter 5, we found that considerable investments were made in network building in cases where a model had societal impact. Based on this finding, we hypothesize that the combination of contextualization *and* network building is crucial for model-enhanced learning in societal problem solving that involves multiple stakeholders.

## 7.5 Outlook

As already memorized in Section 7.2, the thesis research began with the basic concept ‘learning’ to arrive at a collection of related approaches and concepts that proved relevant to the investigation of how, and for what reasons, land use models add to societal change. With this collection of approaches and concepts, we feel that a sound basis has been established for future research on the development and application of land use modelling for contributing to societal learning. However, most of the reported work necessarily had an explorative character because of the lack of suitable data for, e.g., a more quantitative analysis of a number of comparable cases to test hypotheses about impact, or a discursive analysis of interactions before, during and after the presentation of modelling results to look into the relations between model features and the roles models get to perform in more detail. Therefore, some sort of documentation of the model development and application process by those involved, in the form of reflexive monitoring (see Chapter 6) for instance, would greatly enhance the basis for future research.

In this Chapter, rather abstract terms such as ‘stepping stones’, ‘social contexts’, and ‘network building’ were used to highlight the major lessons learned from the thesis research. What do the findings imply for those who wish to pursue the use of science-based land use models to contribute to societal problem solving? First of all, the thesis work demonstrates that the contributions of land use models to societal problem solving represent ‘a window of opportunities’. The contributions are not limited to *learning* about a land use system, but are more diverse and extend to learning about the views, norms and values of other actors, *mediation* of conflicts between stakeholders, and *community-building* when the organization of stakeholders is desirable for coping with a problem. Furthermore, our research suggests that in designing a modelling strategy, equal attention needs to be paid to the requirements for model development, *and* the embedding of the work in a given/intended societal context. Depending on the background of the research team, such modelling strategy may encompass: arranging stepping stones, e.g., to let a team member establish and maintain a social network of possible users, or to establish contacts with persons/organizations that can become stepping stones. At the more executive level, suitable activities are: an exploration of possible and desired roles (i.e., heuristic, symbolic, relational) of the model in the given or intended societal context and to assess appropriate methods to shape participation in model development in line with the envisioned roles.

# References

Aarts, M.N.C., 1998. Een kwestie van natuur: Een studie naar de aard en het verloop van communicatie over natuur en natuurbeleid. PhD thesis, Wageningen University, The Netherlands.

Aarts, N., Van Woerkum, C., 2002. Dealing with uncertainty in solving complex problems. In: Leeuwis, C., Pyburn, R. (Eds.), Wheelbarrows full of frogs. Social learning in rural resource management. Koninklijke Van Gorcum BV, The Netherlands, pp. 421-436.

Akkermans, H.A., Vennix, J.A.M., 1997. Clients' opinions on group model-building: An exploratory study. System Dynamics Review 13, 3-31.

Alrøe, H.F., Kristensen, E.S., 2002. Towards a systemic research methodology in agriculture: Rethinking the role of values in science. Agriculture and Human Values 19, 3-23.

Altieri, M.A., 1995. Agroecology. The Science of Sustainable Agriculture. Westview Press, Boulder, CO.

Argent, R.M., 2004. An overview of model integration for environmental application - components, frameworks and semantics. Environmental Modelling & Software 19, 219-234.

Argent, R.M., Grayson, R.B., 2001. Design of information systems for environmental managers: An example using interface prototyping. Environmental Modelling and Software 16, 433-438.

Bernet, T., Ortiz, O., Estrada, R.D., Quiroz, R., Swinton, S.M., 2001. Tailoring agricultural extension to different production contexts: A user-friendly farm household model to improve decision-making for participatory research. Agricultural Systems 69, 183-198.

Bouwen, R., Taillieu, T., 2004. Multi-party collaboration as a social learning for interdependence: Developing relational knowing for sustainable resource management. Journal of Community and Applied Social Psychology 14, 137-153.

Callon, M., 1986. The sociology of an actor-network: The case of the electric vehicle. In: Callon, M., Law, J., Rip, A. (Eds.), Mapping the dynamics of science and technology. MacMillan, London, p. 19.

Callon, M., 1987. Society in the making: The study of technology as a tool for sociological analysis. In: Bijker, W.E., Hughes, T.P., Pinch, T. (Eds.), The social construction of technological systems; New directions in the sociology and History of Technology. MIT Press. pp. 83-106.

Carberry, P.S., Hochman, Z., McCown, R.L., Dalgliesh, N.P., Foale, M.A., Poulton, P.L., Hargreaves, J.N.G., Hargreaves, D.M.G., Cawthray, S., Hillcoat, N., Robertson, M.J., 2002. The FARMSCAPE approach to decision support: Farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. Agricultural Systems 74, 141-177.

Carolan, M.S., 2006. Science, expertise, and the democratization of the decision-making process. Society and Natural Resources 19, 661-668.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences of the USA 100, 8086-8091.

Cash, D.W., Borck, J.C., Patt, A.G., 2006. Countering the loading-dock approach to linking science and decision making. Science, Technology and Human Values 31, 465-494.

Castélan-Ortega, O.A., Fawcett, R.H., Arriaga-Jordán, C., Herrero, M., 2003. A decision support system for smallholder *campesino* maize-cattle production systems of the Toluca Valley in Central Mexico. Part I – Integrating biological and socio-economic models in a holistic system. Agricultural Systems 75, 1-21.

CGIAR Science Council, 2006. Impact assessment of policy-oriented research in the CGIAR: A scoping study report. Science Council Secretariat, Rome, Italy.

Collinson, M., 2000. Understanding farmers and their farming. In: Collinson, M. (Ed.), A history of farming systems research. Food and Agriculture Organization of the United Nations and CABI Publishing, pp. 1-4.

Collinson, M., Lightfoot, C., 2000. The future of farming systems research. In: Collinson, M. (Ed.), A history of farming systems research. Food and Agriculture Organization of the United Nations and CABI Publishing, pp. 391-420.

Cox, P.G., 1996. Some issues in the design of agricultural decision support systems. Agricultural Systems 52, 355-381.

Crissman, C.C., Antle, J.M., Capalbo, S.M. (Eds.), 1998. Economic, environmental and health tradeoffs in agriculture: Pesticides and the sustainability of Andean potato production. Kluwer Academic Publishers, Boston.

Dahinden, U., Querol, C., Jäger, J., Nilsson, M., 2000. Exploring the use of computer models in participatory integrated assessment – experiences and recommendations for further steps. Integrated Assessment 1, 253-266.

Dalgaard, T., Hutchings, N.J., Porter, J.R., 2003. Agroecology, scaling and interdisciplinarity. Agriculture, Ecosystems and Environment 100, 39-51.

David, A., 2001. Models implementation: A state of the art. European Journal of Operational Research 134, 459-480.

De Haan, J.J., Garcia Diaz, A. (Eds.), 2002. Manual on prototyping methodology and multifunctional crop rotation. VEGINECO project report no. 2, Applied Plant Research BV, Wageningen, The Netherlands.

DeFries, R., Hansen, A. Turner, B.L., Reid, R., Liu, J., 2007. Land use change around protected areas: Management to balance human needs and ecological functions. Ecological Applications 17, 1031-1038.

Delate, K., 2002. Using agroecological approach to farming systems research. HortTechnology 12, 345-354.

De Wit, 1978. Simulation of assimilation, respiration and transpiration of crops. Simulation Monographs, Wiley, New York, USA.

Do Campo, R., García, C., 1999. Sistemas de cultivos para producción hortícola sostenible en la región sur. In: Seminario de Investigación Apicada. PRENADER Proyecto no. 35, Montevideo, Uruguay.

Dogliotti, S., 2003. Exploring options for sustainable development of vegetable farms in South Uruguay. PhD thesis, Wageningen University, The Netherlands.

Dogliotti, S., Rossing, W.A.H., Van Ittersum, M.K., 2003. ROTAT, a tool for systematically generating crop rotations. European Journal of Agronomy 19, 239-250.

Dogliotti, S., Rossing, W.A.H., Van Ittersum, M.K., 2004. Systematic design and evaluation of crop rotations enhancing soil conservation, soil fertility and farm income: A case study for vegetable farms in South Uruguay. Agricultural Systems 80, 277-302.

Dogliotti, S., Van Ittersum, M.K., Rossing, W.A.H., 2005. Exploring options for sustainable development at farm scale: A case study for vegetable farms in south Uruguay. Agricultural Systems 29-51.

Drinkwater, L.E., 2002. Cropping systems research: Reconsidering agricultural experimental approaches. HortTechnology 12, 355-361.

Duran, J., 2000. An alternative model for soil systematisation. Agrociencia 4, 111-123.

Edwards, C.A., Grove, T.L., Harwood, R.R., Pierce Colfer, C.J., 1993. The role of agroecology and integrated farming systems in agricultural sustainability. Agriculture, Ecosystems and Environment 46, 99-121.

Edwards-Jones, G., 2001. Should we engage in farmer-participatory research in the UK? Outlook on Agriculture 30, 129-136.

El Titi, A., 1989. Farming systems research at Lautenbach, Oedheim, FR Germany. In: Vereijken, P., Royle, D.J. (Eds.), Current status of integrated farming systems research in western Europe. Working group “integrated arable farming systems”, WPRS Bulletin, pp. 21-36.

El Titi, A., 1992. Integrated farming: an ecological farming approach in European agriculture. Outlook on Agriculture 21, 33-39.

Emery, M., Purser, R., 1996. The search conference: A powerful method for planned organisational change and community action. Jossey Bass Publisher, San Francisco.

Eshuis, J., Stuiver, M., 2005. Learning in context through conflict and alignment: Farmers and scientists in search of sustainable agriculture. Agriculture and Human Values 22, 137-148.

Ewing, S.A., Grayson, R.B., Argent, R.M., 2000. Science, citizens and catchments: decision support for catchment planning in Australia. Society and Natural Resources 13, 44-459.

Fabricius, C., Folke, C., Cundill, G., Schultz, L., 2007. Powerless spectators, coping actors, and adaptive co-managers: A synthesis of the role of communities in ecosystem management. Ecology and Society 12, article 29.

Falconer, K., Hodge, I., 2000. Using economic incentives for pesticide usage reductions: Responsiveness to input taxation and agricultural systems. Agricultural Systems 63, 175-194.

FAO, 1976. A framework for land evaluation. FAO Soils Bulletin 32, Rome.

Funtowicz, S.A., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25, 739-755.

Galván, G., González, H., Vilaró, F., 2005. Estado actual de la investigación de poblaciones locales de hortalizas en Uruguay y su utilización en el mejoramiento. Agrociencia 9, 115-122.

García, F., Clerici, C., 1996. The use of the RUSLE model in Uruguay. Annals of the XIII Congreso Latinoamericano de la Ciencia del Suelo, August 4-8, Aguas de Lindoia, Brasil.

García, M., Reyes, C., 1999. Estudio de sistemas productivos hortícolas en el largo plazo teniendo como base el manejo de suelos. PRENADER Proyecto no. 35, Montevideo, Uruguay.

Gibon, A., Sibbald, A.R., Flamant, J.C., Lhoste, P., Revilla, R., Rubino, R., Sørensen, J.T., 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. Livestock Production Science 61, 121-137.

Groot, J.C.J., Rossing, W.A.H., Jellema, A., Stobbelaar, D.J., Renting, H., Van Ittersum, M.K., 2007. Exploring multi-scale trade-offs between nature conservation, agricultural profits and landscape quality—A methodology to support discussions on land-use perspectives. Agriculture, Ecosystems and Environment 120, 58-69.

Guijt, I., Proost, J., 2002. Monitoring for social learning. Insights from Brazilian NGOs and Dutch farmer study groups. In: Leeuwis, C., Pyburn, R. (Eds.) Wheelbarrows full of frogs. Social learning in rural resource management. Koninklijke van Gorcum, The Netherlands, pp. 215-232.

Guston, D.H., 2001. Boundary organizations in environmental policy and science: An introduction. Science, Technology and Human Values 26, 399-408.

Hajer, M., 1995. The politics of environmental discourse: Ecological modernization and the policy process. Oxford, Oxford University Press.

Hansen, J.W., 1996. Is agricultural sustainability a useful concept? Agricultural Systems 50, 117-143.

Helander, C.A., Delin, K., 2004. Evaluation of farming systems according to valuation indices developed within a European network on integrated and ecological arable farming systems. European Journal of Agronomy 21, 53-67.

Hengsdijk, H., Van Ittersum, M.K., 2002. A goal-oriented approach to identify and engineer land use systems. Agricultural Systems 71, 231-247.

Herrero, M., Fawcett, R.H., Dent, J.B., 1999. Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agricultural Systems 62, 169-188.

Hisschemöller, M., Hoppe, R., 2001. Coping with intractable controversies: The case for problem structuring in policy design and analysis. In: Hisschemöller, M., Hoppe, R., Dunn, W.N., Ravetz, J.R. (Eds.), Knowledge, power, and participation in environmental policy analysis. Policy Studies Review Annual, Volume 12, 47-71.

Hoppe, R., 1989. Het Beleidsprobleem geproblematiseerd: Over beleid ontwerpen en probleemvorming. Coutinho, Muiderberg.

Hoppe, R., 2005. Rethinking the science-policy nexus: From knowledge utilization and science technology studies to types of boundary arrangements. Poiesis & Praxis 3, 199-215.

International Service for National Agricultural Research (ISNAR), 2004. Method in our madness: Making sense of ecoregional research with modelling tools and processes. The Hague, The Netherlands.

Ison, R.L., Maiteny, P.T., Carr, S., 1997. Systems methodologies for sustainable natural resources research and development. Agricultural Systems 55, 257-272.

Jakeman, A.J., Letcher, R.A., Norton, J.P., 2006. Ten iterative steps in development and evaluation of environmental models. Environmental Modelling and Software 21, 602-614.

Jansen, D.M., Buijze, S.T., Boogaard, H.L., 1999. Ex-ante assessment of costs for reducing nitrate leaching from agriculture-dominated regions. Environmental Modelling and Software 14, 549-565.

Jansma, J.E., Rossing, W.A.H., De Ruijter, F.J., Schans, J., 1994. De bol aan de rol. Verkenning van ontwikkelingsrichtingen voor duurzame bloembollenteelt. Wetenschapswinkel rapport 103, Agricultural University Wageningen.

Jordan, V.W.L., 1998. The development of integrated arable production systems to meet potential economic and environmental requirements. Outlook on Agriculture

27, 145-151.

Jordan, V.W.L., Hucheon, J.A., Donaldson, G.V., Farmer, D.P., 1997. Research into and development of integrated farming systems for less-intensive arable crop production: Experimental progress (1989-1994) and commercial implementation. Agriculture, Ecosystems and Environment 64, 141-148.

Kabourakis, E., 1996. Prototyping and dissemination of ecological olive production systems: A methodology for designing and a first step towards validation and dissemination of prototype Ecological Olive Productions Systems (EOPS) in Crete. PhD thesis, Wageningen University, The Netherlands.

Kaufman, S., Smith, J., 1999. Framing and reframing in land use change conflicts. Journal of Architectural and Planning Research 16, 164-180.

Keating, B.A., McCown, R.L., 2001. Advances in farming systems analysis and intervention. Agricultural Systems 70, 421-443.

Klein Swormink, B.W., 2003. Communicatie. In: Wijnands, F.G., Holwerda, J. (Eds.), Op weg naar goede biologische praktijk: Resultaten en ervaringen uit BIOM. Applied Plant Research, Lelystad, The Netherlands, pp. 23-38.

Knorr-Cetina, K.D., 1981a. The manufacture of knowledge; An essay on the Constructivist and Contextual Nature of Science. Pergamon Press.

Knorr-Cetina, K., 1981b. The scientist as a practical reasoner: Introduction to a constructivist and contextual theory of knowledge. Chapter 1 in: The manufacture of knowledge: An essay on the constructivist nature of science. Permagon Press, Oxford, p. 1.

Kolb, D.A., 1984. Experiential learning: Experience as the source of learning and development. Prentice-Hall, Englewood Cliffs.

Koppenjan, J.M.F., Klijn, E.H., 2004. Managing uncertainties in networks; A network approach to problem solving and decision-making. Routledge, London.

Kramer, K., Groot Bruinderink, G.W.T.A., Prins, H.H.T., 2006. Spatial interactions between ungulate herbivory and forest management. Forest Ecology and Management 226, 238-247.

Langeveld, J.W.A., Uithol, P.W.J., Kroonen-Backbier, B., Van den Akker, H., 2003. Calculating environmental indicators for individual farms and fields: The case of potato cultivation in The Netherlands. Www.fao.or/agrippa, 8 August.

Langeveld, J.W.A., Van Keulen, H., De Haan, J.J., Kroonen-Backbier, B.M.A., Oenema, J., 2005. The nucleus and pilot farm research approach: Experiences from The Netherlands. Agricultural Systems 84, 227-252.

Latour, B., 1987. Science in action: how to follow scientists and engineers through society. Harvard University Press, Cambridge.

Leeuwis, C., 1993. Of computers, myths and modelling. The social construction of diversity, knowledge, information, and communication technologies in Dutch horticulture and agricultural extension. PhD thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Leeuwis, C., 2000. Reconceptualizing participation for sustainable rural development: Towards a negotiation approach. Development and Change 31, 931-959.

Leeuwis, C., 2004. Communication for rural innovation; Rethinking agricultural extension. Blackwell Science, Oxford, UK.

Lütz, M., Bastian, O., 2002. Implementation of landscape planning and nature conservation in the agricultural landscape: A case study from Saxony. Agriculture, Ecosystems and Environment 92, 159-170.

Maat, H., 2001. Science cultivating practice. A history of agricultural science in the Netherlands and its colonies. PhD thesis, Wageningen University, Wageningen, The Netherlands.

Matthews, R.B., 2002. Models as tools in research. In: Matthews, R.B., Stephens, W. (Eds.), Crop-soil simulation Models: Applications in developing countries. CABI Publishing, Wallingford, Oxon, UK.

Matthies, M., Giupponi, C., Ostendorf, B., 2007. Environmental decision support systems: Current issues, methods and tools. Environmental Modelling and Software 22, 123-127.

Mayer, S.I, Van Daalen, C.E., Bots, P.W.G., 2004. Perspectives on policy analyses: a framework for understanding and design. International Journal of Technology, Policy and Management 4, 169-191.

McCown, R.L., 2002a. Locating agricultural decision support systems in the troubled past and socio-technical complexity of ‘models for management’. Agricultural Systems 74, 11-25.

McCown, R.L., 2002b. Changing systems for supporting farmers’ decisions: Problems, paradigms, and prospects. Agricultural Systems 74, 179-220.

McCown, R.L., Hochman, Z., Carberry, P.S. (Editors), 2002. Learnings from 25 Years of agricultural DSS: Case histories of efforts to harness simulation models for farm work. Agricultural Systems 74, 1-220.

McCown, R.L., Parton, K.A., 2006. Learning from the historical failure of farm management models to aid management practice. Part 2. Three systems approaches. Australian Journal of Agricultural Research 57, 157-172.

McIntosh, B.S., Jeffrey, P., Lemon, M., Winder, N., 2005. On the design of computer-based models for integrated environmental science. Environmental Management 35, 741-752.

McIntosh, B.S., Seaton, R.A.F., Jeffrey, P., 2007. Tools to think with? Towards understanding the use of computer-based support tools in policy relevant research.

Environmental Modelling and Software 22, 640-648.

McIntosh, B.S., Giupponi, C., Voinov, A., Smith, C., Matthews, K.B., Monticino, M., Kolkman, M.J., et al., in press. Bridging the gaps between design and use: developing tools to support environmental management and policy. In: Jakeman, A.J., Voinov, A., Rizzoli, A.E., Chen, S. (Eds.), State of the art and Futures in Environmental Modelling and Software.

Meinke, H., Nelson, R., Kokic, P., Stone, R., Selvaraju, R., Baethgen, W., 2006. Actionable climate knowledge: from analysis to synthesis.Climate Research 33, 101-110.

MeyerAurich, A., Zander, P., Werner, A., Roth, R., 1998. Developing agricultural land use strategies appropriate to nature conservation goals and environmental protection. Landscape and Urban Planning 41, 119-127.

Michelsen, J., 2001. Recent development and political acceptance of organic farming in Europe. Sociologia Ruralis 41, 3-20.

Mueller, J.P., Barbercheck, M.E., Bell, M., Brownie, C., Creamer, N.G., Hitt, A., Hu, S., King, L., Linker, H.M., Louws, F.J., Marlow, S., Marra, M., Raczkowski, C.W., Susko, D.J., Wagger, M.G., 2002. Development and implementation of a long-term agricultural systems study: Challenges and opportunities. HortTechnology 12, 362-368.

Mysiak, J., Giupponi, C. Rosato, P., 2005. Towards the development of a decision support system for water resource management. Environmental Modelling and Software 20, 203-214

Nicholson, C.F., Lee, D.R., Boisvert R.N., Blake, R.W., Urbina, I., 1994. An optimization model of the dual-purpose cattle production system in the humid lowlands of Venezuela. Agricultural Systems 46, 311-334.

Okali, C., Sumberg, J., Farrington, J. 1994. Farmer participatory research; Rhetoric and reality. Intermediate Technology Publications on behalf of the Overseas Development Institute.

Oxley, T., McIntosh, B.S., Winder, N., Mulligan, M., Engelen, G., 2004. Integrated modelling and decision support tools: A Mediterranean example. Environmental Modelling and Software 19, 999-1010.

Pacini, C., Wossink, A., Giesen, G., Huirne, R., 2004. Ecolgical-economic modelling to support multi-objective policy making: A farming systems approach implemented for Tuscany. Agriculture, Ecosystems and Environment 102, 349-364.

Pannell, D.J., 2007. Linking research to policy. http://cyllene.uwa.edu.au/~dpannell/pd/pd0095.htm, consulted in June 2007.

Parker, P., Letcher, R., Jakeman, A. , Beck, M.B., Harris, G., Argent, R.M., Hare, M., et al., 2002. Progress in integrated assessment and modelling. Environmental, Modelling and Software 17, 209-217.

PhD proposal, 2002. Towards a next generation of explorative farm models – enhancing their capabilities in strategic innovation processes. Chairs Plant Production Systems and Communication & Innovation Studies, Wageningen University.

Putnam, L.L., Holmer, M., 1992. Framing, reframing, and issue development. In: Putnam, L.L., Roloff, M.E. (Eds.), Communication and Negotiation. Sage Annual Reviews of Communication Research Volume 20, Sage Publications, Newbury Park, California, pp. 128-155.

Rabbinge, R., Van Latesteijn, H.C., 1992. Long-term options for land use in the European Community. Agricultural Systems 40, 195-210.

Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P.J., Downing, T.E., et al., 2007. Global desertification: Building a science for dryland development. Science 316, 847-851.

Rigby, D., Cáceres, D., 2001. Organic farming and the sustainability of agricultural systems. Agricultural Systems 68, 21-40.

Roetter, R.P., Van den Berg, M.M., Laborte, A.G., Hengsdijk, H., Wolf, J., Van Ittersum, M.K., Van Keulen, H., Agustin, E.O., Son, T.T., Lai, N.X., Guanghuo, W., 2005. Combining farm and regional level modelling for integrated resource management in East and South-east Asia. Environmental Modelling and Software 22, 149-157.

Rossing, W.H.A., Jansma, J.E., De Ruijter, F.J., Schans, J., 1997. Operationalizing sustainability: Exploring options for environmentally friendlier flower bulb production systems. European Journal of Plant Pathology 103, 217-234.

Rossing, W.A.H., Van Ittersum, M.K., Ten Berge, H.F.M., Leeuwis, C., 1999. Designing land use options and policies. Fostering co-operation between Kasparov and Deep Blue? In: Leeuwis, C. (ed.), Integral design: Innovation in agriculture and resource management. Mansholt Studies 15, Wageningen, The Netherlands, pp. 49-72.

Rossing, W.A.H., Zander, P., Josien, E., Groot, J.C.J., Meyer, B.C., Knierim, A., 2007. Integrative modelling approaches for analysis of impact of multifunctional agriculture: A review for France, Germany and The Netherlands. Agriculture, Ecosystems and Environment 120, 41-57.

Sage, A.P., 1991. Decision Support Systems Engineering. John Wiley and Sons Inc., London.

Saloranta, T.M., Kämäri, J., Rekolainen, S., Malve, O., 2003. Benchmark criteria: A tool for selecting appropriate models in the field of water management. Environmental Management 32, 322-333.

Santé, I., Crecente, R., 2006. LUSE, a decision support system for exploration of rural land use allocation: Application to the Terra Chá district of Galicia (N.W. Spain). Agricultural Systems 94, 341-356.

Schröder, J.J., Scholefield, D., Cabral, F., Hofman, G., 2004. The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. Environmental Science and Policy 7, 15-23.

Schröder, J.J., Aarts, H.F.M., Van Middelkoop, J.C., Schils, R.L.M., Velthof, G.L, Fraters, B., Willems, W.J., 2007. Permissible manure and fertilizer use in dairy farming systems on sandy soils in The Netherlands to comply with the nitrates directive target. European Journal of Agronomy 27, 102-114.

Shackley, S., 1997. Trust in models? The mediating and transformative role of computer models in environmental discourse. In: Redclift, M., Woodgate, G. (Eds.), International handbook of environmental sociology. Edward Elgar Publishing Limited, UK, pp. 237-260.

Shackley, S., Wynne, B., 1995. Global climate change: The mutual construction of an emergent science-policy domain. Science and Public Policy 22, 218-230.

Shepherd, M., Chambers, B., 2007. Managing nitrogen on the farm: the devil is in the detail. Journal of the Science of Food and Agriculture 87, 558-568.

Stoorvogel, J.J., Antle, J.M., Crissman, C.C., 2004a. Trade-off analysis in the Northern Andes to study the dynamics in agricultural land use. Journal of Environmental Management 72, 23-33.

Stoorvogel, J.J., Bouma, J., Orlich, R.A., 2004b. Participatory research for systems analysis: Prototyping for a Costa Rican banana plantation. Agronomy Journal 96, 323-336.

Sukkel, W., Brinks, H., Venhorst, B., Klein Swormink, B., 2003. BIOM 'uitgerekend biologisch!. Projectplan 2002-2006, PPO, The Netherlands.

Sumberg. J., Okali, C., Reece, D., 2003. Agricultural research in the face of diversity, local knowledge and the participation imperative: theoretical considerations. Agricultural Systems 76, 739-753.

Ten Berge, H.F.M., Van Ittersum, M.K., Rossing, W.A.H., Van de Ven, G.W.J., Schans, J., Van de Sanden, P.A.C.M., 2000. Farming options for The Netherlands explored by multi-objective modelling. European Journal of Agronomy 13, 263-277.

Van Daalen, C.E., Dresen, L., Janssen, M. A., 2002. The roles of computer models in the environmental policy life cycle. Environmental Science and Policy 5, 221-231.

Van de Ven, G.W.J., Rossing, W.A.H., Van Ittersum, M.K., Boekhoud, H., Van Evert, F.K., Van de Sanden, P.A.C..M., Mauritz, R.F., 2002. Farm Explorer: Designing sustainable arable farming systems. Book of Proceedings, VIIth Congress of the

European Society for Agronomy, Cordoba, Spain, 15-18 July, 2002, pp. 587-588.

Van de Ven, G.W.J., De Ridder N., Van Keulen, H., Van Ittersum, M.K., 2003. Concepts in production ecology for analysis and design of animal and plant–animal production systems. Agricultural Systems 76, 507-525.

Van Delden, H., Luja, P., Engelen, G., 2007. Integration of multi-scale dynamic spatial models of socio-economic and physical proceses for river basin management. Environmental Modelling and Software 22, 223-238.

Van Ittersum, M.K., Rabbinge, R., 1997. Concepts in production ecology for analysis and quantification of agricultural input-output combinations. Field Crops Research 52, 197-208.

Van Ittersum, M.K., Rabbinge, R., Van Latesteijn, H.C., 1998. Exploratory land use studies and their role in strategic policy making. Agricultural Systems 58, 309-330.

Van Ittersum, M.K., Leffelaar, P.A., Van Keulen, H., Kropff, M.J., Bastiaans, L., Goudriaan, J., 2003. On approaches and applications of the Wageningen crop models. European Journal of Agronomy 18, 201-234.

Van Ittersum, M.K., Roetter, R.P., Van Keulen, H., De Ridder, N., Hoanh, C.T., Laborte, A.G., Aggarwal, P.K., Ismail, A.B., Tawang, A., 2004. A systems network (SysNet) approach for interactively evaluating strategic land use options at sub-national scale in South and South-east Asia. Land Use Policy 21, 101-113.

Van Ittersum, M.K., Ewert, F., Heckelei, T., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., et al., 2007. Integrated assessment of agricultural and environmental policies – a modular framework for the European Union (SEAMLESS). Agricultural Systems (in press).

Van Keulen, H., 2007. Quantitative analyses of natural resource management options at different scales. Agricultural Systems 94, 768-783.

Van Latesteijn, H.C., 1995. Assessment of future options for land use in the European Community. Ecological Engineering 4, 211-222.

Van Mierlo, B., Leeuwis, C., Smits, R., Klein Woolthuis, R., in press. Innovation systems and social learning: Linking the meso and the micro level. Research Policy.

Van Paassen, A., 2004. Bridging the gap: Computer model enhanced learning about natural resource management in Burkina Faso. Tropical Resource Management Papers 49, Wageningen University and Research centre, Wageningen, The Netherlands.

Van Paassen, A., Roetter, R.P., Van Keulen, H., Hoanh, C.T., 2007. Can computer models stimulate learning about sustainable land use? Experience with LUPAS in the humid (sub-)tropics of Asia. Agricultural Systems 94, 874-887.

Van Weperen, W., Röling, N., Van Bon, K., Mur, P., 1995. Introductie geïntegreerde akkerbouw: Het veranderingsproces. Communication & Innovation Studies, Wageningen University, The Netherlands.

Verboom, J., Foppen, R., Chardon, P., Opdam, P., Luttikhuizen, P., 2001. Introducing the key patch approach for habitat networks with persistent populations: An example for marshland birds. Biological Conservation 100, 89-101.

Verboom, J., Alkemade, R., Klijn, J., Metzger, M.J., Reijnen, R., 2007. Combining biodiversity modeling with political and economic development scenarios for 25 EU countries. Ecological Economics 62, 267-276.

Verburg, P.H., Schulp, C.J.E., Witte, N., Veldkamp, A., 2006. Downscaling of land use change scenarios to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment 114, 39-56.

Vereijken, P., Edwards, C., El Titi, A., 1986. Study group management of arable farming systems for integrated crop protection. SROP bulletin, IUBS, Wageningen, The Netherlands.

Vereijken, P., 1989a. From integrated control to integrated farming, an experimental approach. Agriculture, Ecosystems and Environment 26, 37-43.

Vereijken, P., 1989b. Research on integrated arable farming and organic mixed farming in the Netherlands. In: Vereijken, P., Royle, D.J. (Eds.), Current status of integrated farming systems research in western Europe. Working group “Integrated arable farming systems”, WPRS bulletin, pp. 41-50.

Vereijken, P., Royle, D.J., 1989. Objectives of integrated farming systems. In: Vereijken, P., Royle, D.J. (Eds.), Current status of integrated farming systems research in western Europe. Working group “integrated arable farming systems”, WPRS bulletin. Pp. vi.

Vereijken, P., 1992. A methodic way to more sustainable farming systems. Netherlands Journal of Agricultural Science 40, 209-223.

Vereijken, P., 1994. 1. Designing prototypes. Progress reports of research networks on integrated and ecological arable farming systems for EU and associated countries (concerted action AIR 3 – CT 920755). AB-DLO, Wageningen, The Netherlands, p. 86.

Vereijken, P., 1997. A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. European Journal of Agronomy 7, 235-250.

Vereijken, P., 1999. Manual for prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. AB-DLO, Wageningen, The Netherlands.

Veysset, P., Bebin, D., Lherm, M., 2005. Adaptation to Agenda 2000 (CAP reform) and optimisation of the farming system of French suckler cattle farms in the Charolais area: a model-based study. Agricultural Systems 83, 179-202.

Walker, D.H., 2002. Decision support, learning and rural resource management. Agricultural Systems 73, 113-127.

Walker, D.H., Cowell S.G., Johnson, A.K.L., 2001. Integrating research results into decision making about natural resource management at a catchment scale. Agricultural Systems 69, 85-98.

Weick, K.E., 1995. Sensemaking in organizations. London, Sage.

Westhoek, H.J., Van den Berg, M., Bakkes, J.A., 2006. Scenario development to explore the future of Europe's rural areas. Agriculture, Ecosystems and Environment 114, 7-20.

Wijnands, F.G., Dekking, A.J.G., 2002. Biologische akkerbouw; centrale zeeklei. Praktijkonderzoek Plant & Omgeving BV, The Netherlands.

Wijnands, F.G., De Haan, J.J., Sukkel, W., 2002a. Methodology for prototyping integrated and organic farming systems. In: De Haan, J.J., Garcia Diaz, A. (Eds.), Manual on prototyping methodology and multifunctional crop rotation. Applied Plant Research BV, The Netherlands, pp. 8-16.

Wijnands, F.G., Van Leeuwen-Haagsma, W.K., Van Koesveld, F., 2002b. Op weg naar een goede biologische praktijk; ervaringen en resultaten uit het BIOM-project. In: Wijnands, F.G., Schröder, J.J., Sukkel, W., Booij, R. (Eds.) Biologisch bedrijf onder de loep. Biologische akkerbouw en vollegrondsgroenteteelt in perspectief. Praktijkonderzoek Plant & Omgeving B.V., The Netherlands, pp. 17-42.

Wijnands, F.G., Holwerda, J. (eds.), 2003. Op weg naar goede biologische praktijk; Resultaten en ervaringen uit BIOM. Applied Plant Research, Lelystad, The Netherlands.

Wijnands, F.G., Vereijken, P., 1992. Region-wise development of prototypes of integrated arable farming and outdoor horticulture. Netherlands Journal of Agricultural Science 40, 225-238.

Wijnands, F.G., 1992. Evaluation and introduction of integrated arable farming in practice. Netherlands Journal of Agricultural Science 40, 239-249.

Wijnands, F.G., 1997. Integrated crop protection and environment exposure to pesticides: methods to reduce use and imact of pesticides in arable farming. European Journal of Agronomy 7, 251-260.

WRR, 1992. Ground for choices: four perspectives for the rural areas in the European Community. SDU publishers, The Netherlands.

Wynne, B., 1984. The institutional context of science, models, and policy: The IIASA Energy Study. Policy Sciences 17, 277-320.

Zadoks, J.C., 1989. EPIPRE, A computer-based decision support system for pest and disease control in wheat: Its development and implementation in Europe. In: Leonard, K.J., Fry, W.E. (Eds.), Plant Disease Epidemiology, Vol 2: Genetics, Resistance, and Management. McGaw-Hill, New York.

Zander, P., Kächele, H., 1999. Modelling multiple objectives of land use for sustainable development. Agricultural Systems 59, 311-325.

# Summary

Scientists have repeatedly argued that the management of land, whether at the field, farm or regional scale, can benefit from computer-based land use system analysis. As a result, a large number of computer-based models and tools have been developed over the past decades with the aim of providing support to policy and management. At first, modellers referred to the potential decision-support function of their product. The shift from ‘decision support system’ to ‘learning tool’ reflected a change in conceptualization of how decisions come about. Regular decision-making became regarded as “the final outcome of longer lasting learning processes with varying degrees of deliberateness and consciousness”. This learning takes place in the context of a professional practice and is immediately connected with diverse human values.

Though there is still optimism about the potential of land use modelling to contribute to societal problem solving, a number of scholars perceive the impact as too limited. Others, reporting model use outside the scientific sphere, do not explicitly analyse this use for its impact, and the reasons for this impact. Against this background, this thesis investigates the contribution of land use models to learning for societal problem solving. This concerns then the learning of farm managers and/or land use planners at local, regional, national or international level, to solve a land use related problem, such as: the conservation of a diverse range of ecosystem services simultaneously, including biodiversity and the provision of food and fibre, or undesired emission of nutrients from farms. The key question that the study seeks to answer is: How, when, and for what reasons does land use modelling enhance learning in the context of societal problem solving? The aim is to develop guidelines for those who wish to pursue the use of science-based land use models to contribute to societal problem solving.

The research question is geared towards gaining an in-depth understanding of the learning practices of social actors in model-supported change trajectories. A research tradition that allows a contextual analysis of social dynamics and interrelations is the case-study approach. For our purpose, it meant the close following (or reconstruction) of events and interactions in and around a selected change process, using qualitative research methods, such as participant observation, in-depth interviewing, qualitative literature analysis.

The Plant Production Systems Group of Wageningen University had available a number of operational goal-based farm system models that had been developed in collaboration with other groups of Wageningen University & Research Centre. Goal-based land use models may be defined as objective-oriented tools for exploration of

alternative, promising land use systems. The available and operational goal-based farm system models were the starting point of the empirical work in the first phase of this research. In Chapter 2, the learning practices in Dutch research projects where researchers, extension officers and farmers collaborate to develop and test more sustainable farming practices form the core of the analytical work to find a niche for goal-based farm system models. We demonstrate that it is not trivial to find niches for the application of goal-based farm system models. Model outcomes appeared not to match questions of farm managers that emerged while monitoring and learning from their own and other farmers' practices. However, our research also indicates that whole-farm design modelling possesses the capabilities to make a valuable contribution to reframing. Reframing is the phenomenon that people feel an urge to discuss and reconsider current objectives and perspectives on a problem. Reframing might take place in a situation (i) of mutually felt dependency between stakeholders, (ii) in which there is sufficient pressure and urgency for stakeholders to explore new problem definitions and make progress. Furthermore, our research suggests that the way the researcher enters a likely niche to introduce a model and/or his or her position in this niche may have significant implications for the potential of models to enhance a change process. Therefore, we hypothesize that the chances of capitalizing on modelling expertise are likely to be higher when researchers with such expertise are a logical and more or less permanent component of an ongoing trajectory than when the researchers come from outside to purposefully search for a niche.

Chapter 3 provides an analysis of the application of the prototyping methodology on commercial farms over the years. The analysis provides the basis to assess opportunities for farm system models to enhance this prototyping work. The prototyping methodology was developed for the design of more sustainable farm systems, either on experimental or commercial farms in the 1990s. The main features of prototyping are: (1) quantification of goals; (2) emphasis on multiple societal goals; (3) designing as an organizing principle; and (4) iteration of system analysis, design and on-farm testing. Hypothetically, farm system modelling could enrich the prototyping methodology and vice versa. Taking a goal-oriented stance, a modelling exercise could reveal design options otherwise overlooked and extrapolation of prototyping results to other conditions and scenarios. The on-farm prototyping work could serve as a source of inspiration and information for farm system modellers. Three promising leads were identified to assess this potential, i.e. (1) exploring goals of farm systems; (2) exploring options for a change and improvement of farm systems; and (3) communication and extrapolation of project output. Analysis of more than two decades of Dutch prototyping research both on experimental and commercial farms indicated that prototyping on commercial farms is a highly localized process. Moreover, although the methodology manual suggests differently, goal formulation was not a distinctive phase of prototyping on commercial farms, hence cross-pollination with farm system modelling could not occur (lead 1). As the timely operationalization and the localization of a farm system model demand considerable effort, contributions of farm model explorations to the localized change process on commercial farms (lead 2) seem impractical and unlikely. For communication and extrapolation of prototyping output (lead 3), issue-specific (i.e. focus on a component of the system) models are increasingly used. For this purpose, we hypothesize that there may also be a role for farm system models.

In Chapter 4, an effort is made to integrate goal-based farm system modelling and on-farm research similar to prototyping in Uruguay. A farm system model, called ‘Farm Images’, was available and amendable for our purposes. A modelling study with ‘Farm Images’ was concluded in the year before an action research project with commercial farmers was initiated. The model developer became project coordinator and intended to use ‘Farm Images’ in the action research project as well. The Uruguayan case complemented the research in The Netherlands for two reasons. Firstly, the context for the research work in Uruguay deviated in several possibly relevant aspects from the Dutch work: the on-farm research was starting up and national agriculture-related policies had relatively low impact on farm management. Secondly, already existing and fruitful scientific collaboration with the Uruguayan researchers offered opportunity for the calibration and subsequent experimentation with a goal-based farm system model in the on-farm research. The learning experiences in the project indicate that the technologies incorporated in Farm Images were being tested in the project. However, both the project team and the involved farmers learned largely about, and not through Farm Images. They appreciated the capacities of the model, but the calibration and presentation of Farm Images in the project did barely affect their learning. Supposedly, the learning related to the use of Farm Images remained limited precisely because the project participants were already testing the ideas included in the model. Since Farm Images was an important source of inspiration for the formulation of the action research project through the project coordinator, Farm Images had a considerable, however indirect, impact on learning in the project.

The research reported in Chapters 2 to 4 yielded valuable insights, in particular what and when land use models can add to learning. However, the question how model development and application need to be arranged to enhance learning received less attention. In Chapter 5 we propose and test a conceptual framework that relates the work done preceding and parallel to model use to the roles models have in multi-stakeholder contexts. Three potential roles for land use models in multi- stakeholder situations have been identified: a heuristic role, improving understanding; a symbolic role, putting an issue on the political agenda; and a relational role, creating a community. A conceptual framework of the interactions between scientist, model, and societal stakeholders suggests that a land use model can only perform a role in problem solving when it is enrolled in the interactions by one or more of the stakeholders. It then gets a different status because it becomes part of the interactions, is contextualized and its role is being defined. Subsequently, this framework was instrumental to analysing three case studies of linking land use modelling to problem solving in a multi-stakeholder context. The case study analysis encompassed an inventory of the network building of scientists, societal stakeholders, and the land use model during model development and application. Subsequently, those aspects were related to the roles land use models got to perform. The comparative analysis of the case studies suggests that land use models were accepted both for their characteristic system research features, i.e., the study of interactions between components and the integrative capacity, and through ‘work on the network’. In all three cases, substantial investments were made to enrol and contextualize the concerned land use model and maintain relations with relevant stakeholders. The studied land use models performed heuristic roles in combination with at least one other role. In two cases, the model had a symbolic role additionally to its heuristic role. Also in two cases a relational role was found, i.e., the model fostered community building around the land use issue at stake. This is a role of land use models, which has rarely been highlighted in literature to date. However, we deem it a highly relevant issue for further research while the linking of social and ecological systems and the capacities of communities to manage natural resources in a sustainable way are major issues in natural resource management research these days.

Chapter 6 addresses policy-oriented land use modelling work. This Chapter formed part of the preparations for and is time one of the outputs of a workshop on modelling support in policy decision-making that took place in July 2007 in The Netherlands. Eleven cases of policy-oriented modelling research were investigated. The data came from the workshop and 26 semi-structured interviews that were made in Australia and The Netherlands in preparation of the workshop. In this Chapter, two steps are made to assess appropriate approaches towards policy-oriented modelling work. First, the concept ‘boundary arrangement’ was made operational for our field of interest, computer-based systems analysis of rural development, with emphasis on the use of land for agricultural production and other environmental services. The term ‘boundary work' refers to social practices to maintain the science-policy interface, such as frequent and two-way communication, developing rules of conduct and establishing criteria for decision-making. 'Boundary arrangement' is about how actors conceive of the division of labour between science and policy and thus perform specific boundary work. Five ideal-typical boundary arrangements were discerned: 'Civil mandate'; 'Trickle out'; 'Janus face'; 'Critical participant'; and 'Knowledge broker'. In a second step, a number of critical leverage points were identified in policy-oriented modelling research and related to the five boundary arrangements. The six leverage points were: reputation of research institute and/or scientists; raising and balancing expectations; communication about and investment in the scientific basis of the modelling work; participation in model development; heterogeneous and extensive social network in policy sphere; institute mandate that secures availability of stepping stones, such as persons who invest in a heterogeneous and extensive network in the policy sphere and see opportunity to use modelling work developed in a more science sphere oriented context. For those of us functioning in a rather science sphere oriented environment, similar to the above listed 'Trickle out' arrangement, the reported work suggests that there are more options than the frequently proposed 'more participation' for increasing the probability that policy-oriented work is used, such as establishing contacts with research groups or institutes that are in a position to function as 'stepping stones', or to let a member of the group develop a social network in the policy sphere.

It was the premise of a learning enhancing effect of science-based land use models that formed the backbone of this thesis work. What we found were indeed proofs of learning through modelling. The learning took the form of a new perspective on a land use system, frequently in combination with a better understanding of the position of other stakeholders, resulting in adapted problem definitions, a changed solution space and/or the formation of new coalitions to tackle a particular land use related problem. Models were found to contribute not only to improving understanding (heuristic role) but also to agenda-setting (symbolic role) and the creation of communities (relational role). Time and again, it appeared not so much 'critical success factors' that proved helpful to understand the contribution of modelling to societal change, but rather features of a social context and/or problem solving process in place, such as actors' aspirations, intentions, and perceptions of their own abilities, social and institutional relations. Consequently, instead of rather static and distinct factors, this thesis work suggests that we need to anticipate the relatively fluid and fuzzy features of social contexts and problem solving processes to harness land use modelling for societal learning.

What do the findings imply for those who wish to pursue the use of science-based land use models to contribute to societal problem solving? First of all, the thesis work demonstrates that the contributions of land use models to societal problem solving represent ‘a window of opportunities’. The contributions are not limited to learning about a land use system but are more diverse and extend to learning about the views, norms and values of other actors, mediation of conflicts between stakeholders and community-building when the organization of stakeholders is desirable for coping with a problem. Furthermore, our research suggests that in designing a modelling strategy, equal attention needs to paid to the requirements for model development, and the embedding of the work in a given/intended societal context. Depending on the background of the research team, such modelling strategy may encompass: arranging stepping stones, e.g., to let a team member establish and maintain a social network of possible users, or to establish contacts with persons and/or organizations that can become stepping stones. At the more executive level, suitable activities are: an exploration of possible and desired roles (i.e. heuristic, relational, symbolic) of the model in the given and/or intended societal context and to assess appropriate methods to shape participation in model development in line with the envisioned roles.

# Samenvatting

Wetenschappers hebben herhaaldelijk gesuggereerd dat het beheer van land, zowel op veld-, bedrijf- als ook op regionaal niveau, kan profiteren van computer ondersteunde landgebruiksysteemanalyse. Dit heeft geresulteerd in een groot aantal computer modellen en digitaal instrumentarium bedoeld om beleid en management te ondersteunen. In het begin refereerden modelleurs aan de mogelijke besluitondersteunende functie van hun product. De verschuiving van 'besluitondersteunend systeem' naar 'lerenondersteunend instrument' reflecteert een verandering in het denken over hoe beslissingen tot stand komen. Gewone besluitvorming wordt nu beschouwd als de uiteindelijke uitkomst van een langer durend leerproces met wisselende gradaties van (doel)bewustheid. Dit type leren vindt plaats in de context van beroepspraktijken en is direct verbonden met uiteenlopende menselijke waarden.

Er bestaat nog steeds optimisme over het potentieel van deze modellen om bij te dragen aan het oplossen van maatschappelijke problemen, maar er is ook een aantal onderzoekers dat de impact te beperkt acht. Zij wijzen op de te grote aandacht voor model ontwikkeling die ten koste zou gaan van investeringen in de applicatie van modellen. Andere onderzoekers rapporteren over het gebruik van een model buiten het wetenschappelijke domein maar zij laten na impact en de redenen voor deze impact te analyseren. Tegen deze achtergrond wordt in dit proefschrift de bijdrage van landgebruikmodellen aan leren om maatschappelijke vraagstukken op te lossen geanalyseerd. Het gaat dan over het leren van agrarische ondernemers en/of landgebruikplanners op lokaal, regionaal, nationaal of international niveau om een landgebruik gerelateerd probleem op te lossen. Bijvoorbeeld hoe verschillende doelen met elkaar te verenigen, zoals het behoud van een diversiteit aan ecosysteem diensten, biodiversiteit, voedsel productie, en/of de ongewenste uitstoot van meststoffen van agrarische bedrijven. De hoofdvraag die wij trachten te beantwoorden is: Hoe, wanneer, en waarom versterkt het modelleren van landgebruik leren in de context van het oplossen van maatschappelijke problemen? Het doel van de studie is richtlijnen te ontwikkelen voor diegenen die met wetenschappelijke landgebruikmodellen willen bijdragen aan het oplossen van maatschappelijke vraagstukken.

De onderzoeksvraag richt zich op het ontwikkelen van meer begrip van de leerpraktijken van sociale actoren in veranderingstrajecten die worden ondersteund door computermodellen. De gevalsstudie benadering is een onderzoekstraditie die een contextuele analyse van de sociale dynamiek en verbanden mogelijk maakt. In ons geval hield dit het van dichtbij volgen (of reconstrueren) van gebeurtenissen en interacties in en rond een geselecteerd veranderingsproces gebruikmakend van kwalitatieve onderzoeksmethode zoals de observatie van deelnemers, diepte interviews en kwalitatieve literatuur analyse.

De leerstoelgroep Plantaardige Productie Systemen had een aantal operationele doelgebaseerde bedrijfsmodellen beschikbaar ontwikkeld, in samenwerking met andere groepen binnen Wageningen Universiteit & Researchcentrum. Doelgebaseerde landgebruikmodellen kunnen worden omschreven als instrumenten die alternatieve landgebruiksystemen suggereren op basis van geformuleerde doelen. De beschikbare en operationele doelgebaseerde bedrijfsmodellen zijn het uitgangspunt voor het empirische werk in de eerste fase van het onderzoek. In hoofdstuk 2 wordt de potentiële bijdrage van doelgebaseerde bedrijfsmodellen in een aantal Nederlandse onderzoeksprojecten onderzocht. In deze projecten werken onderzoekers, voorlichters en agrarische ondernemers samen om het functioneren van agrarische bedrijven duurzamer te maken. We tonen aan dat het niet eenvoudig is om niches te vinden voor de toepassing van doelgebaseerde bedrijfsmodellen. Model uitkomsten bleken niet overeen te komen met de vragen van agrarische ondernemers die hun eigen handelingen en die van andere ondernemers monitoren en hiervan leren. Echter, ons onderzoek suggereert ook dat doelgebaseerd bedrijfssysteemmodelleren beschikt over de eigenschappen om een waardevolle bijdrage te leveren aan reframing. Reframing is het fenomeen dat mensen het nodig achten om huidige doelen en perspectieven te bespreken en te heroverwegen. Reframing kan plaatsvinden in a situatie (i) waar belanghebbenden een wederzijdse afhankelijkheid, (ii) en genoeg druk en urgentie ervaren om nieuwe probleemdefinities te overwegen en voortgang te maken. Verder suggereert ons onderzoek dat de manier waarop een onderzoeker in een mogelijke niche binnenkomt om een model te introduceren, en/of zijn of haar positie in deze niche, significante gevolgen kan hebben voor het potentieel van modellen om een veranderingsproces te versterken. Hierom vermoeden wij dat de kansen om succesvol gebruik te maken van modelleerexpertise groter zijn wanneer onderzoekers die deze expertise bezitten een logisch en min of meer permanent onderdeel zijn van een veranderingstraject in plaats van dat ze van buiten komen om doelgericht te zoeken naar een niche.

Hoofdstuk 3 geeft een analyse van de toepassing van de prototyperingsmethodologie op commerciële agrarische bedrijven door de jaren heen. Op basis van deze analyse worden mogelijkheden geidentificeerd voor bedrijfsmodellen om dit prototyperingswerk te versterken. De prototyperingsmethodologie werd ontwikkeld voor het ontwerpen van duurzamere bedrijfssystemen, zowel op experimentele als ook met commerciële bedrijven. De belangrijkste eigenschappen van prototyperen zijn: 1.

kwantificering van doelen; 2. nadruk op uiteenlopende maatschappelijke doelen; 3. ontwerpen als een organiserend principe; 4. herhaling van systeem analyse, ontwerp en testen op agrarische bedrijven. In de literatuur wordt gesteld dat bedrijfssysteemmodellering een bijdrage zou kunnen leveren aan de prototyperingsmethodologie. De drie belangrijkste aanknopingspunten zouden zijn: 1. het verkennen van doelen voor bedrijfssystemen; 2. het verkennen van opties voor het veranderen en verbeteren van bedrijfssystemen; 3. communicatie en extrapolatie van projectresultaten. In tegenstelling tot wat de methodologiehandleiding suggereert was op commerciële bedrijven de formulering van doelen geen duidelijk te onderscheiden fase in het prototyperingstraject. Vandaar dat kruisbestuiving met bedrijfssysteemmodellering op het eerste aanknopingspunt niet plaatsvond. De tijdige specificatie en operationalisatie van een bedrijfssysteemmodel vereist aanzienlijke inzet. Ons onderzoek wijst uit dat het prototyperen op commerciële bedrijven een zeer gelokaliseerd proces is, dat wil zeggen sterk verschillend tussen lokale situaties. Daarom lijkt een bijdrage door middel van modelverkenningen aan de gelokaliseerde veranderingsprocessen op commerciële agrarische bedrijven onwaarschijnlijk (aanknopingspunt 2). Voor de communicatie en extrapolatie van uitkomsten van prototyperen (aanknopingspunt 3) worden onderwerpspecifieke (d.w.z. gericht op een component van het bedrijfssysteem) modellen steeds vaker ingezet. We vermoeden dat voor dit specifieke doeleinde er wellicht ook een rol is weggelegd voor bedrijfssysteemmodellen.

In hoofdstuk 4 wordt een poging gedaan om in Uruguay doelgebaseerd bedrijfssysteem modelleren te integreren met op prototyperen lijkend onderzoek op agrarische bedrijven. Er was al een bedrijfssysteemmodel ontwikkeld: ‘Farm Images’. Een onderzoek met behulp van Farm Images werd afgerond in het jaar voordat een actieonderzoeksproject met agrarische ondernemers startte. De modelleur werd de projectcoördinator en had het voornemen om Farm Images in het actieonderzoeksproject te gebruiken. Er waren twee redenen waarom deze Uruguayaanse gevalsstudie goed aansloot bij het in Nederland uitgevoerde onderzoek. Ten eerste week de context van het onderzoek in Uruguay in een aantal mogelijk relevante aspecten af, zoals de vroegere fase waarin het onderzoek met commerciële bedrijven zich bevond en de relatief kleine invloed van nationaal landbouwgerelateerd beleid op bedrijfsmanagement. Ten tweede bood de goede verstandhouding met de Uruguayaanse onderzoekers de mogelijkheid om Farm Images te kalibreren en er vervolgens mee te experimenteren in het Uruguayaanse project, zelfs al bestond er aanzienlijke onzekerheid over mogelijke uitkomsten. De met het project gerelateerde leerervaringen geven aan dat technologieën die werden meegenomen in Farm Images werden getest in het project. Echter, zowel het projectteam als de betrokken boeren leerden voornamelijk over en niet van Farm Images. Ze waardeerden de mogelijkheden die het model bood maar de calibratie en presentatie van Farm Images beïnvloedde nauwelijks hun leren dat samenhing met het project. Waarschijnlijk bleef het leren dat verband hield met het gebruik van Farm Images beperkt omdat de projectdeelnemers de ideeën die geïncorporeerd waren in Farm Images al testten. Echter, Farm Images was een belangrijke inspiratiebron bij het formuleren van het actieonderzoeksproject. Om deze reden had Farm Images een aanzienlijke, maar indirecte, invloed op het leren in het project.

Het onderzoek beschreven in hoofdstukken 2 tot en met 4 leverde waardevolle inzichten op, vooral wat betreft wat en wanneer landgebruikmodellen kunnen bijdragen aan leren. De vraag hoe modelontwikkeling en -applicatie dienen opgezet te worden om leren te versterken kreeg minder aandacht. In hoofdstuk 5 wordt een conceptueel raamwerk geïntroduceerd en getest dat het werk vooraf en parallel aan modelgebruik relateert aan de rollen die modellen vervullen in een context waarin meerdere belanghebbenden actief zijn. In een dergelijke context worden voor landgebruikmodellen drie mogelijke rollen geïdentificeerd: een heuristieke rol, verbeteren van begrip; een symbolische rol, een onderwerp op de agenda krijgen; en een relationele rol, het creëren van een gemeenschap. Een conceptueel raamwerk van de interacties tussen wetenschapper, model en maatschappelijke belanghebbenden suggereert dat een landgebruikmodel alleen een rol kan vervullen bij het oplossen van problemen als het opgenomen wordt in interacties tussen belanghebbenden, door een of meerdere belanghebbenden. Het krijgt dan een andere status omdat het deel wordt van de interacties, het wordt gecontextualizeerd, en de rol van model wordt gedefinieerd.

Het investeren in interacties tijdens modelontwikkeling en -toepassing blijkt een belangrijke verklarende factor voor de rollen die landgebruikmodellen vervullen. Met het conceptueel raamwerk is in drie gevalsstudies nader onderzoek gedaan naar het verbinden van het modelleren van landgebruik en het oplossen van problemen. De analyse van de gevalsstudies omvatte een inventarisatie van de relaties en de interacties in het netwerk van wetenschappers, maatschappelijke belanghebbenden en het landgebruikmodel tijdens modelontwikkeling en -toepassing. Vervolgens werden deze aspecten gerelateerd aan de rollen die landgebruikmodellen krijgen toebedeeld. De vergelijkende analyse van de gevalsstudies suggereert dat landgebruikmodellen werden geaccepteerd voor zowel hun karakteristieke systeemonderzoekeigenschappen, d.w.z. de studie van interacties tussen onderdelen en een integrerende capaciteit, alsook het ‘werk aan het netwerk’. In alle drie gevalsstudies werden substantiële investeringen gedaan om het betreffende landgebruikmodel deel te maken van het netwerk van onderzoekers en belanghebbenden. De bestudeerde landgebruikmodellen vervulden allen heuristieke rollen gecombineerd met tenminste 1 andere rol. In twee gevalsstudies had het model had een symbolische rol naast een heuristieke rol. Ook in twee gevalsstudies werd een relationele rol werd gevonden, d.w.z. het model bevorderde het bouwen van gemeenschappen rond een specifiek landgebruik-vraagstuk. Dit is een rol van landgebruikmodellen waar nauwelijks aandacht aan wordt besteed in de literatuur. Echter wij beschouwen het als een zeer relevant onderwerp voor verder onderzoek. Het verbinden van sociale en ecologische systemen en de capaciteit van gemeenschappen om natuurlijke bronnen te beheren op een duurzame wijze zijn belangrijke onderwerpen in recent onderzoek rond het beheer van natuurlijk bronnen.

Hoofdstuk 6 gaat over beleidsgeoriënteerd modelonderzoek van landgebruik. Dit hoofdstuk vormde een onderdeel van de voorbereidingen, en is tegelijkertijd een van de resultaten van een workshop die plaats vond in juli 2007 in Nederland en ging over ondersteuning van beleidsontwikkeling met behulp van modellen. Elf cases van beleidsgeoriënteerd modelonderzoek werden onderzocht op basis van het workshop materiaal en 26 semi-gestructureerde interviews die werden gehouden in Australië en Nederland ter voorbereiding van de workshop In dit hoofdstuk worden twee stappen gezet om te voorzien in een basis voor het bepalen van toegesneden benaderingen van beleidsgeoriënteerd modelonderzoek van agrarische productie en andere omgevingsdiensten van land. Eerst werd het concept ‘grenswerk’ operationeel gemaakt voor ons interesseveld, computerondersteunde systeemanalyse van agrarische productie en andere omgevingsdiensten van land. Vijf ideaaltypische grenswerk arrangementen werden onderscheiden: ‘Civiel mandaat’; ‘Doorsijpelen’; ‘Janushoofd’; ‘Kritische deelnemen’; en ‘Kennismakelaar’. Deze ideaaltypes zijn niet bedoeld om te corresponderen met alle karakteristieken van een specifieke gevalsstudie maar benadrukken bepaalde elementen van belang die kunnen worden gevonden in veel gevalsstudies in het interesseveld. In een tweede stap werden een aantal essentiële hefboompunten geïdentificeerd in beleidsgeoriënteerd modelwerk en vervolgens gerelateerd aan de vijf grenswerk arrangementen. De vijf punten waren: reputatie van onderzoeksinstituut en/of onderzoekers; creëren en balanceren van verwachtingen; communicatie over en investeren in de wetenschappelijke basis van het modelwerk; heterogeen en uitgebreid sociaal netwerk in het beleidsdomein; mandaat van instituut dat zorgt voor de beschikbaarheid van ‘opstapjes’, zoals personen die een heterogeen en uitgebreid netwerk onderhouden in de beleidssfeer en mogelijkheid zien om modelwerk te gebruiken dat is ontwikkeld in een meer wetenschap georiënteerde context. Voor degenen die functioneren in een vooral wetenschap georiënteerde omgeving, gelijkend op het hierboven genoemde ‘Doorsijpelen’ arrangement, suggereert het gedane onderzoek dat er meer opties zijn dan het vaak voorgestelde ‘ meer participatie’ om de waarschijnlijkheid te verhogen dat beleidsgeoriënteerde onderzoek wordt gebruikt, zoals het leggen van contacten met onderzoeksgroepen of instituten die in een positie zijn om te functioneren als ‘ opstapjes’, of een lid van de groep een sociaal netwerk laten ontwikkelen in de beleidssfeer.

De premisse van een lerenversterkend effect van op wetenschap gebaseerde landgebruikmodellen vormde de ruggengraat van dit proefschrift. Wij vonden ook daadwerkelijk bewijzen van leren door modelleren. Dit leren had de vorm van een nieuw perspectief op een landgebruiksysteem, vaak in combinatie met een beter begrip van de positie van andere belanghebbenden, resulterend in aangepaste probleem-definities, een veranderde oplossingsruimte en/of de formering van nieuwe coalities om een landgebruik gerelateerd probleem aan te pakken. Het onderzoek toont dat modellen niet alleen bijdragen aan het verbeteren van begrip (heuristieke rol) maar ook aan het opstellen van de agenda (symbolische rol) en het creëren van gemeenschappen (relationele rol). Steeds weer bleken het niet zozeer ‘kritische succes factoren’ te zijn die hielpen om de bijdrage van modelleren aan maatschappelijke verandering te begrijpen, maar eerder eigenschappen van een sociale context en/of een specifiek probleemoplossingproces, zoals aspiraties, intenties en percepties van eigen capaciteiten van actoren, en sociale en institutionele relaties. Kortom, dit promotieonderzoek suggereert dat we in plaats van nogal statische en onderscheidbare factoren, de relatief vloeibare en vage eigenschappen van sociale contexten en probleemoplossingprocessen moeten beschouwen om landgebruikmodellering klaar te maken voor maatschappelijk leren.

Wat betekenen deze bevindingen voor degenen die het gebruik van op wetenschap gebaseerde landgebruikmodellen nastreven om bij te dragen aan maatschappelijk probleem oplossen? Ten eerste toont dit promotieonderzoek aan dat de bijdrages van landgebruikmodellen aan maatschappelijk probleem oplossen een ‘vat vol mogelijkheden’ vertegenwoordigt. De bijdrages beperken zich niet tot leren over een landgebruiksysteem. Ze zijn diverser en dekken ook leren over perspectieven, normen en waarden van andere actoren, bemiddeling van conflicten tussen belanghebbenden en het ontwikkelen van gemeenschappen wanneer het organiseren van belanghebbenden wenselijk is voor het omgaan met een probleem. Verder suggereert ons onderzoek dat de aandacht gelijkelijk dient verdeeld te worden over de eisen voor modelontwikkeling en het inbedden van modelwerk in een gegeven of voorziene maatschappelijk context bij het ontwerpen van een modelleerstrategie. Afhankelijk van de achtergrond van het onderzoeksteam kan een dergelijke modelleerstrategie het regelen van ‘opstapjes’ omvatten, bijvoorbeeld door een teamlid een sociaal netwerk van mogelijke gebruikers te laten bouwen en onderhouden of contacten te leggen met personen en/of organisaties die opstapjes kunnen worden. Op het meer uitvoerende niveau zijn geschikte activiteiten: een verkenning van mogelijke en wenselijke rollen (d.w.z. heuristiek, relationeel, symbolisch) van het model in de gegeven of voorziene maatschappelijke context, en het bepalen van geschikte methodes om participatie in modelontwikkeling vorm te geven in lijn met de voorziene rollen.

# PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

**Review of Literature (3 credits)**
- Contributions of farm system models to farm innovation processes (2002)

**Writing of Project Proposal (7 credits)**
- Towards a next generation of explorative farm models-enhancing their capabilities in strategic innovation processes (2002)

**Post-Graduate Courses (7.2 credits)**
- Qualitative methods; Radboud University, Nijmegen (2003)
- Interfaces between science and society: epistemological and ethical implications; Radboud University, Nijmegen (2005)
- Land science; Wageningen University, Wageningen (2007)

**Discussion Groups / Local Seminars and Other Scientific Meetings (5.3 credits)**
- Discussion group on sustainable land-use and resource management (2002-2004)
- Part of the organizing committee of two international workshops on the use of computer models outside science in Wageningen (2003, 2007)
- Conference “where science meets society”(2004)
- Seminar series “communication and space for change”(2006-2007)
- KNAW day on interdisciplinary research (2007)

**PE&RC Annual Meetings, Seminars and the PE&RC Weekend (3.6 credits)**
- PE&RC science day “global change and biodiversity” (2003)
- Introduction weekend (2003)
- Mansholt introductory course (2003)
- PE&RC science day ”biological disasters” (2004)
- Mansholt science day “the impact of social sciences on decision making” (2004)
- PE&RC science day “scientific research: who pulls the strings” (2006)

**International Symposia, Workshops and Conferences (7.1 credits)**
- IFSA symposium “new visions for rural area’s” (2006)
- Farming systems design (co-author of keynote speech, oral presentation and convener of a session) (2007)

# Curriculum Vitae

Barbara Sterk (Utrecht, 1977) studied at Wageningen University. She combined a MSc in Crop Science with extracurricular education in international public management. During her studies, she worked on the transfer dynamics of nitrogen in a leek intercropping system (Switzerland), stakeholder participation in land use modelling (Malaysia), the contributions of farm system research methodologies to effective knowledge for action (The Netherlands), and the impact of European fishery policies on the shrimp fishing sector in The Netherlands.

As a member of the local branch of the International Association of Agricultural Students (IAAS), she was part of the organizing committee of international meetings, seminars and exchange weeks. Furthermore, she initiated a development-oriented project in Mexico carried out by Mexican students and students of three Dutch universities. In the academic year '98-'99, she worked in the position of elected president for the International Headquarters of the IAAS (Leuven, Belgium).

In 2002, Barbara started the PhD research described in this thesis with the chair groups Plant Production Systems and Communication & Innovation Sciences of Wageningen University. At present, she is employed as a PostDoc researcher with the Land Use Planning group at Wageningen University to elaborate on the relations between science and action with a focus on spatial issues and the practice of planning at the level of landscapes. In addition, she works for the Science Shop of Wageningen University and Research Centre as an intermediator between researchers and less-endowed groups in society.

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