Sustainable Agriculture:
How to make it work?

A modeling approach to support management
of a mixed ecological farm

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Sustainable Agriculture: How to make it work?

A modeling approach to support management of a mixed ecological farm

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Abstract

Wolfert, J. 2002. Sustainable Agriculture: How to make it work? A modeling approach to support management of a mixed ecological farm. PhD Thesis, Wageningen University, Wageningen, pp. 278, Summary in English and Dutch.

The objective of the research described in this thesis was to develop a model that helps farmers to design a sustainable farm system. If sustainability must go beyond the level of vague statements, it must be implemented in operational farm management. Sustainable development was considered as an active design process by the farmer that should focus on creating and maintaining adaptive capacities in order to tune the farm system to an ever-changing environment. Because sustainability involves social, ecological and economic aspects, the farmer must be enabled to integrate soft and hard parameters in decision-making. From literature research in the fields of management science and sociology, a three-phase methodology was defined: (i) negotiate with the environment, (ii) solve problems in a heuristic way and (iii) implement solutions in operational control. This methodology enables the farmer to make his visions, intentions and values explicit. It was argued that the current scientific concept of agricultural production, production ecology, is not suitable for designing sustainable farm systems. A new concept was defined: ecological production, which takes the social and ecological environment as a starting point, while production is tuned to it. This requires a design-oriented approach in which the farmer is enabled to improve his skills. Management should focus on preventive and recycling management, which requires that the primary processes must be considered as a logistic chain of product flows. Based on the three-phase-methodology and the concept of ecological production, a model was developed. The model consists of several components of which the so-called Product Flow Model is the most important one. It represents the production process as a chain or network of product flows between production units, internal and external resources. Other components help to define sustainability goals and connect them with the Product Flow Model, followed by a translation into operational management, resulting in the so-called Sustainability Management Handbook. The model was tested and illustrated by two case studies on potato production and nutrient management. The model and methodology was evaluated by expert validation. The general conclusion was that the approach is suitable for implementing sustainability in operational farm management and that, potentially, it helps to improve farmer's skills, but this was not sufficiently justified.

Keywords: sustainable agriculture; organic farming; whole farm management; decision support; farming systems research; designing; modeling; beta-gamma integration

Woord vooraf

De vreze des Heren is het begin der wijsheid
Spreuken 9 vers 10a

Toen ik aan dit proefschrift begon, had ik niet kunnen bedenken hoe het uiteindelijke resultaat er uit zou zien. Waarschijnlijk is dit ook inherent aan het vak van ontwerpen, waar dit proefschrift over handelt. Systeemanalyse en modelleren, en de technische kanten daarvan, heeft mij waarschijnlijk het meest aangetrokken. Echter, voor een proefschrift moet je een degelijke verantwoording afleggen van wat je analyseert en modelleert en waarom je het op die manier doet. Zo heb ik mij verdiept in zaken als duurzaamheid, ecologische landbouw en besturingstheorieën. Gelukkig kan ik achteraf zeggen dat mij dat uiteindelijk redelijk goed af ging en het ontzettend leuk vond om te doen. Met voldoening en een beetje trots mag ik nu terugkijken op een geslaagde tijd en dit proefschrift als resultaat. Dit was echter niet gelukt zonder stimulerende mensen in mijn omgeving, waarvan ik een aantal met name wil bedanken.

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Hoewel dit project in eerste instantie officieel bij de voormalige vakgroep Ecologische Landbouw hoorde, heb ik altijd een vaste plek gehad bij de toenmalige vakgroep Informatica en huidige leerstoelgroep Toegepaste Informatiekunde. De mensen van deze groep zijn de laatste jaren dan ook mijn meest naaste collega’s geweest. Door de goede onderlinge sfeer heb ik daar altijd met plezier gewerkt en goede herinneringen aan de sociale activiteiten over gehouden. Twee mensen wil ik in het bijzonder noemen. Allereerst Rob Hartog, waarmee ik al die jaren geluncht heb. Rob, jouw interesse en vaak kritische vragen hebben mij zeker gestuurd bij het maken van het model en de verantwoording daarvan. Daarnaast wil ik Stephan van Dijk bedanken, die de laatste jaren mijn kamergenoot was. Stephan, jij mocht ik graag als klankbord gebruiken voor allerlei beschouwingen, vaak filosofisch van aard, die zeker hun weerslag hebben gevonden in dit proefschrift. Ook bedankt voor de gezelligheid en ik hoop dat jij over een aantal jaren ook zover mag zijn.

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Ede, 5 april 2002

Sjaak Wolfert

Reader’s guide

This thesis uses a modeling approach that combines concepts and theories from several different disciplines. Although the Chapters 1 to 9 are placed in a logical order, it might not be the most appropriate one for reading and understanding. While reading the theories and modeling approach in the first chapters, you might think several times: ‘What does this mean in practice?’ or ‘Provide some practical examples!’. Hence, some advises for reading are provided.

First, everybody should start reading Chapter 1 in order to get acquainted with the actual subject and scope of this thesis. Next, it is advisable to browse through Chapters 5 to 7 first. These chapters describe and illustrate the results of the model that was developed. If you are still interested in how and why the model was developed, you should continue reading Chapters 2, 3 and 4. If you take the theory behind the model specifications for granted and are just interested in the model, you could skip Chapters 2 and 3. After that, you could read Chapters 5 to 7 again for a better understanding. If you are anxious to know how other people thought about the model, you should read Chapter 8 in which the model is validated by an expert panel. Finally, Chapter 9 discusses the results of this study and summarizes the major conclusions. It also provides some suggestions and recommendations for further research, if you would like to elaborate on this approach.

Mind maps

In this thesis, you can find several so-called ‘mind maps’, that are bundled in Appendix VI. It is a type of representation that was developed by Tony Buzan (1995). They provide a compact summary of a subject that is described in the text. They are supposed to help the reader to remember and to process what was read. So, they are difficult to understand on themselves. The underlying idea is simple. A mind map uses only keywords that are connected with each other by lines, grouped in branches. The branches must be read clock-wise, usually starting at ‘one o’clock’ or indicated by numbers. Each individual branch must be read from top to bottom. Icons and pictures are used to visualize abstract words or concepts or to indicate an emotion. They are supposed to enhance the process of storing information into memory.

Although you may find the mind maps beautiful pictures, do not hesitate to add your own keywords and pictures to them (unless this is not your copy!), if you think it helps you in remembering and understanding.

Contents

1 GENERAL INTRODUCTION 21
1.1 Context 21
1.2 Scope of this thesis 21
1.2.1 Directions for solutions in space 22
1.2.2 Directions for solution in time 22
1.3 Research statement 23
1.4 Outline of this thesis 24
1.5 Positioning this thesis in Farming Systems Research 25

2 DESIGNING SUSTAINABLE FARM SYSTEMS: HOW TO INTEGRATE SOFT AND HARD PARAMETERS IN DECISION-MAKING? 29
2.1 Introduction 30
2.2 Sustainability by integration of hard and soft parameters 33
2.2.1 A perpetual relationship 34
2.2.2 Dimensions, values and aspects 34
2.2.3 Adaptive capacity for sustainable development 35
2.2.4 Adaptive management 36
2.2.5 Farm system as research focus 37
2.2.6 Conclusions 38
2.3 Incorporating sustainability into decision-making – a three phase methodology 39
2.3.1 Farm systems 40
2.3.2 Management control 41
2.3.3 Phase 1: negotiation 45
2.3.3.1 The sociological view 45
2.3.3.2 The biophysical-rational view 47
2.3.4 Phase 2: heuristic problem solving 48
2.3.4.1 Simon’s theory 48
2.3.4.2 Problem solving activities 50
2.3.5 Phase 3: operational control 51
2.4 Designing sustainable farm systems – an integrative approach 52
2.5 Summary 55
2.6 Implications for modeling 56

3 PRODUCTION ECOLOGY OR ECOLOGICAL PRODUCTION? 59
3.1 Introduction 60
3.2 Production ecology – the concept in integrated agricultural production 61

3.2.1 Production ecology 61
3.2.1.1 Yield-determining factors 62
3.2.1.2 Yield-limiting factors 62
3.2.1.3 Yield-reducing factors 62
3.2.2 Ecological implications 63
3.2.3 Social implications 64
3.2.4 Implications for farm management 65
3.2.4.1 Management control 66
3.2.4.2 External dependency 66
3.2.5 Implications for agricultural research 67
3.2.5.1 The food myth: in name of the increasing world population 67
3.2.5.2 Best farming practice? 68
3.2.5.3 Research method 69
3.2.6 Conclusions 70
3.3 Ecological production 70
3.3.1 The ecological production concept 70
3.3.2 Preventive management 73
3.3.3 Recycling management 73
3.3.4 Conclusions 75
3.4 Production ecology or ecological production? 76
3.5 Implications for modeling 79

4 A MODELING APPROACH FOR DESIGNING SUSTAINABLE MIXED ECOLOGICAL FARM SYSTEMS 81
4.1 Introduction 82
4.2 Essential concepts and ideas: some terminology 84
4.2.1 Designing: wheels within wheels 85
4.2.2 Information System 85
4.2.3 Information model, instantiation and ontology 87
4.2.4 Methodology: the philosophical basis 88
4.3 Model requirements 90
4.4 Current farm modeling approaches: why is a new approach needed? 92
4.4.1 Whole farm management models – a quick scan 92
4.4.2 Successes and failures of current and past agricultural decision support systems 97
4.4.2.1 Failures 97
4.4.2.2 Successes 97
4.4.3 A new approach 98
4.5 Modeling the object system 98
4.5.1 Product Flow Model 101

4.5.1.1 Minimal model approach 101
4.5.1.2 Ontology 102
4.5.1.3 Entity-relationship diagram 104
4.5.1.4 Software tools 105
4.5.2 Sustainability Map 105
4.5.2.1 A Multifaceted Structured Entity decomposition 105
4.5.2.2 Ontology 107
4.5.2.3 Entity-relationship diagram 108
4.5.2.4 Software tools 109
4.5.3 Sustainability Function Deployment 109
4.5.3.1 House of sustainability 109
4.5.3.2 Ontology 111
4.5.3.3 Entity-relationship diagram 113
4.5.3.4 Software tools 113
4.5.4 Sustainability Management Handbook 114
4.5.4.1 Work instructions 114
4.5.4.2 Entity-relationship diagram 115
4.5.4.3 A handbook with different views 115
4.6 Farm system design: how to use the model? 116
4.6.1 First instantiation 117
4.6.2 Incremental updating by heuristic learning 118
4.6.3 The computer, the farmer and the consultant 118
4.7 Conclusions 119

5 A GENERAL INSTANTIATION OF THE MODEL - AN INTRODUCTION TO THE CASE STUDIES 121
5.1 Introduction 122
5.2 Overview of the whole model and its instantiation 123
5.3 Product flow modeling 124
5.4 Sustainability Mapping 128
5.5 Defining operations 129
5.6 Sustainability Function Deployment 130
5.7 Sustainability Management Handbook 132
5.8 Conclusions 135

6 ECONOMIC ASPECTS AND QUALITY MANAGEMENT OF POTATO PRODUCTION AT THE MIXED ECOLOGICAL FARM SYSTEM AT THE IR. A.P. MINDERHOUDHOEVE 137
6.1 Introduction 138

6.2 Product flow modeling **138**
6.3 Sustainability Mapping **141**
6.3.1 Description of the tree 141
6.3.2 Description of connections with the product flow model 143
6.4 Definition of operations **145**
6.5 Sustainability Function Deployment **147**
6.6 Sustainability Management Handbook **152**
6.7 Conclusions and discussion **152**

7 NUTRIENT MANAGEMENT AT THE MIXED ECOLOGICAL FARM SYSTEM AT THE IR. A.P. MINDERHOUDHOEVE **155**
7.1 Introduction **156**
7.2 Product flow modeling **156**
7.2.1 Soil as an internal resource 156
7.2.2 Crop residues and green manure 157
7.2.3 The atmosphere as internal resource - biological nitrogen fixation 157
7.2.4 Animal manure 157
7.3 Sustainability Mapping **158**
7.3.1 Description of the tree 158
7.4 Discussion **174**
7.4.1 Nutrient Management 174
7.4.2 Incomplete knowledge and information 175
7.5 Conclusions **175**

8 EXPERT VALIDATION **177**
8.1 Introduction **178**
8.2 What is validation? **178**
8.2.1 Definitions 178
8.2.2 Expert validation 180
8.3 Aims of this expert validation **180**
8.4 Material and methods **181**
8.4.1 Expert panel 181
8.4.2 Preparation 182
8.4.3 Panel session 182
8.4.3.1 General introduction 183
8.4.3.2 Computer demonstration 183
8.4.3.3 Evaluation 183
8.5 Results **185**
8.5.1 First impression 185

8.5.2 The questionnaire 185
8.5.3 Strengths and weaknesses and plenary discussion 187
8.5.3.1 Product Flow Model 187
8.5.3.2 Sustainability Mapping 188
8.5.3.3 Sustainability Function Deployment 188
8.5.3.4 Sustainability Management Handbook 189
8.5.3.5 The whole 189
8.6 Discussion 190
8.7 Conclusions 191

9 GENERAL DISCUSSION AND CONCLUSIONS 195
9.1 Introduction 195
9.2 Revisiting the research questions 195
9.3 Major conclusions 205
9.4 Suggestions for further research 206
9.4.1 Model improvement and knowledge development 207
9.4.2 Improvement of the methodology 207
9.4.3 Integration with quality control systems and certification 208

APPENDICES 209
I The mixed ecological farm at the ir. A.P. Minderhoudhoeve 211
II Entity-Relationship Diagramming 213
III Data Dictionary 215
IV Example of a Sustainability Management Handbook concerning potato production 221
V Questionnaire for expert validation 231
VI Mind Maps 235

SUMMARY 249

SAMENVATTING 253

BIBLIOGRAPHY 259

AUTHOR INDEX 275

CURRICULUM VITAE 279

Is it our Job to Forecast the Future or to Fashion it?

We must look ahead at today's radical changes in technology, not just as forecasters but as actors charged with designing and bringing about a sustainable and acceptable world. New knowledge gives us power for change: for good or ill, for knowledge is neutral. The problems we face go well beyond technology: problems of living in harmony with nature, and most important, living in harmony with each other. Information technology, so closely tied to the properties of the human mind, can give us, if we ask the right questions, the special insights we need to advance these goals.

Herbert A. Simon

1 General introduction

...the softer the research strategy, the harder it is to do
(Yin, 1994, p. 16)

1.1 Context

Sustainable agriculture has become a major issue at the end of the 20^{th} century. It can be regarded as an integrated approach for social, economic and ecological problems, more popularly described as the triple P bottom line: People, Profit and Planet (SER, 2000). Sustainability is difficult to describe and define, because it is on one hand multi-faceted and on the other hand dynamic because the environment is constantly changing.

Until now, sustainability has mainly been a political issue. Firms are primarily seen as profit-making entities. To make sustainability work, the other two P's, People and Planet, should be incorporated into the management of these firms. It is observed that an increasing number of companies attempt to do this, not infrequently because sustainability has become an important attribute for image building and marketing. However, there is a risk that sustainability remains an optimistic, but vague claim in official statements (e.g. mission statements and advertisements) and is not really put into practice.

Sustainability is primarily a matter of willingness to give and take, and of developing the right attitude, a matter of negotiation between people augmented with transparent communication. Following Herbert Simon's prelude on the previous page, this thesis wants to make a modest contribution to fashioning a sustainable future by providing a methodology and model to support farmers in translating sustainability in their daily management.

In this chapter the scope of the thesis will be further demarcated followed by a research statement consisting of a research question that is divided into several sub-questions. Then an outline is given of the chapters that elaborate on these questions. Finally, this thesis' position in farming systems research is outlined.

1.2 Scope of this thesis

Sustainability can be considered at various levels in space and time. It is too much to deal with all of them at the same time. Therefore, a clear demarcation of the subject matter has to be made.

1.2.1 Directions for solutions in space

In the spatial domain, a global, a national, a regional and, agriculture-specific, a farm system level can be distinguished. This thesis chooses the farmer and his[1] farm system as the object of study. Reasons for this choice are (Stroosnijder et al., 1994; Tekelenburg, 2001):

- the farmer is the final decision-maker that has to implement sustainability at his farm; integrating sustainability in the decision-making process, leaving room for creative skills, will give better results than sustainability being imposed from above;
- farmers are increasingly regarded as society's caretakers of major natural resources like soil, water and landscape;
- indigenous knowledge is a key to local development; it's optimal use increases overall efficiency; and, due to its local-specific context, social acceptance will be high;
- if new technologies are introduced and tested at farm level, acceptance will be higher and adopted earlier.

A potential risk of the choice of farm system level is that side effects on other systems, so-called externalities, can easily be ignored (Schiere, 1995). For example, high import of animal feed keeps a local farm system producing and thus could be regarded as sustainable, but in the meantime it is depleting natural resources elsewhere. In this respect, Schiere (1995) speaks of so-called 'damning objectives'. Conway and Barbier (1990) also warn for a false sense of sustainability. With concern to these matters, many authors also indicate that it is important to take the interaction of the farm system with society into account (Fresco and Westphal, 1988; Dent, 1994; Röling, 1994b; Stomph et al., 1994). Furthermore, there are sustainability goals that are difficult to solve at individual farm system level (e.g. an attractive landscape, managing ecological food webs). These could be better approached in a more co-operative way between several farms.

1.2.2 Directions for solution in time

In time, a strategic, tactical and operational level, ranging from long term to short term, can be distinguished. The strategic level is concerned with long term decisions (> 10 years). For example, in agriculture, it deals with the choice of converting to an organic farming system. From both a policy and a farmer's perspective, it is interesting to study these strategic decisions. Most of these studies are desktop studies, using averages and general assumptions (see e.g. WRR, 1992). From a farmer's perspective, this does not justice to the large variation and differentiation that exists in reality (Van der Ploeg, 1999).

[1] For this entire thesis, a choice is made to refer to the farmer as male, although it is acknowledged that, world-wide, farmers can be either male or female

At the tactical level, decisions are made about the configuration of a farm, mostly concerning crop rotation and herd composition that are fixed for several years. Several studies at this level are also desktop studies (see e.g. Bos and Van de Ven, 1999) and some are field experiments (see e.g. Olesen et al., 2000). They also do not leave not much room for the farmer’s management skills in practice. In a participatory approach, the prototyping method of Vereijken (1997), farmer’s skills are included and practical farms are object of study.

Operational management concerns day-to-day or week-to-week decisions. It is connected with processes like sowing, plowing, feeding or milking, which are usually referred to as operations. Especially at this level, farmer’s skills become relevant. Concerning sustainability, not much research has been done yet at this level (Stomph et al., 1994).

Taking the farm system as a starting point, it can be concluded that the farmer, as a human factor, cannot be ignored. This calls for a soft systems approach (Checkland, 1990). Considering farmer’s management skills as an important factor for sustainable agriculture, this thesis focuses on the operational decision-making of a farm system. However, it should be emphasized that operational management is always derived from the tactical and strategic level, so these cannot be ignored.

1.3 Research statement

After demarcating the scope of sustainability to operational management of a farm system, the research question of this thesis can be formulated as:

- *How can sustainability be implemented in the operational management of a farm system?*

So, how can a farmer put sustainability into practice? This main question is split up into the following sub-questions:

a) *What is sustainability and what is sustainable farming in particular?*
b) *What does the management control of a farm look like?*
c) *What type of information from the farm system is needed for sustainable farming?*
d) *How does this information need to be processed in order implement sustainability in operational management?*
e) *How should this information processing be done, so that the farmer is able to evaluate and improve decision-making?*

A modeling approach will be used to answer these questions. The model should order and structure information so that the farmer is supported in implementing sustainability in his management control.

The model should be applicable to mixed[1] ecological[2] farming systems, because this type of farming system is regarded as a promising option for sustainable development. Because every farmer and every farm is unique, it should account for farm- and farmer-specific situations. This requires a very generic approach.

So, it should be clear that the model in this thesis does not provide cut-and-dried solutions to actual operational management problems like: “when should I sow?” or “at what depth do I need to adjust my plough?” No, the model should provide an environment in which the farmer is optimally supported in finding and designing appropriate solutions to these problems for himself. The model developed could be regarded as a prototype decision support system.

A practical mixed ecological farm at the ‘ir. A.P. Minderhoudhoeve’ served as an object of reference. Appendix I provides a brief description of this farm.

1.4 Outline of this thesis

In order to answer the research questions that were put, this thesis is structured as follows. Chapter 2 deals with sustainability and sustainable farming. It describes a new approach for designing sustainable farm systems from a management control perspective. This approach tries to integrate hard and soft parameters in decision-making. Hence, it can be characterized as a beta-gamma interaction. This results in a first list of modeling requirements. Chapter 3 deals with the question what kind of agricultural production system is suitable for designing sustainable farm systems. Starting from the current paradigm of mainstream agriculture, production ecology, it describes a new approach for ecological production. This results in a second list of modeling requirements. In Chapter 4, all model requirements are specified further. This chapter discusses why current modeling approaches do not satisfy these specifications. After that, the specifications are translated into an actual model architecture. The model is tested and illustrated by two case studies that highlight different aspects of sustainability and link up with important principles of ecological production as described in Chapter 3. Before that, a general instantiation of the model is described in Chapter 5. It also provides a description and illustration of software tools, used to instantiate the model. This chapter serves as an introduction to the case studies and should be read in advance. Chapter 6 provides a case study of potato production, focusing on economic aspects and quality management. Chapter 7 provides a case study of nutrient management, focusing on the ecological principle of recycling. The model is validated, using expert validation, which is described in Chapter 8. For that purpose, the potato case study of Chapter 6, combined with a

[1] i.e. integration of plant and animal production.

[2] In Chapter 3, it will be explained what is exactly meant by ecological farming. Generally, ecological can be regarded as synonymous for what is often referred to as ‘organic’ or ‘biological’, but this thesis wants to go beyond current practice of this type of farming.

presentation of the model's background, has been evaluated by an expert panel. Finally, Chapter 9 returns to the research questions with a general discussion and the conclusions. Also some recommendations for further research are given. This outline is also presented in Mind Map 1 in Appendix VI.

1.5 Positioning this thesis in Farming Systems Research

The subject matter of this thesis can be put under the umbrella of Farming Systems Research (FSR). FSR is a category of agricultural research that is related to farms or farming systems. Several authors have provided an extensive review of FSR (see e.g. Schiere, 1995; Collinson, 2000). FSR is often connected with research in developing countries. In many cases, FSR is farmer-oriented, but sometimes it is oriented towards policy makers. FSR in this thesis mainly focuses on European agriculture and is farmer-oriented. Several directions or 'schools' can be distinguished within FSR. Some of these schools are briefly discussed in this section in order to position this thesis within the framework of FSR.

By studying literature on FSR, several steps and aspects can be distinguished as indicated in the first column of Table 1-1. The different steps are listed in sequential order. Analysis concerns scientific research with the purpose to describe and clarify relationships in an agro-ecosystem. Diagnosis is a systematical assessment of an agroecosystem with regard to specific objectives or problems. Design concerns a goal-oriented, well-considered laying out of the structure or a process of an agroecosystem. Implementation is the actual realization of the design in reality. Testing is comparing the results after some time with the predefined goals of the design. The agroecosystem can then be improved. Usually, steps 3 to 6 are a design cycle, which the designer has to go through several times. Dissemination concerns the spreading of knowledge or information that was retrieved by previous steps. Participation is an aspect that indicates to what degree stakeholders (in this case particularly farmers) are involved in FSR. Steps 1 to 7 are usually guided by researchers or moderators and can be regarded as a learning pathway. Self-learning indicates to what degree the farmer himself is taking these steps and is teaching himself by experience. Farm-specific means to what degree the approach is applicable to each individual farm.

Table 1-1 attempts to categorize some different schools in FSR using the steps and aspects. Farming Systems Research and Extension (FSR&E) emphasizes scientific analysis that usually takes place at experimental stations and laboratories. The knowledge derived is disseminated to farmers in the form of actual advice. Perhaps, this approach could be categorized as the classical approach of research and extension of the last decades, which is still very important.

Farming Systems Research and Development (FSR&D) takes the farm system as a starting point and while actual development of the system is part of the approach. It is characterized by a holistic approach (Shaner et al., 1982). The emphasis on scientific analysis varies, but is usually not very large. Prototyping, a method that was developed for this context by Vereijken (1997), could be regarded as a type of FSR&D. It is a participatory approach that helps farmers to improve their farm system by continuous redesign. A design is then equivalent to a prototype that is tested and improved.

Table 1-1 Classification of several Farming Systems Research schools by the presence of different steps and aspects. ++ is strong; ± is moderate; - is weak/absent. FSR&E is FSR and Extension, FSR&D is FSR and Development and QFSA means Quantitative Farming Systems Analysis. Further discussion in text.

	FSR&E	FSR&D		QFSA
steps		Prototyping	this thesis	
1. analysis	++	±	-	++
2. diagnosis	±	+	+	+
3. designing	-	+	+	+
4. implementation	-	+	+	-
5. testing	-	+	+	-
6. improvement	-	+	+	-
7. dissemination	++	-	-	+
aspects				
1. participation	±	++	++	-
2. self-learning	-	+	++	-
3. farm-specific	-	+	++	-

Quantitative Farming Systems Analysis (QFSA) could perhaps be regarded as an intermediate between FSR&E and FSR&D. The emphasis is put on a quantitative analysis of farming systems that is translated into so-called input-output models. Next, Interactive Multiple Goal Linear Programming (IMGLP) is used in combination with these models to generate different scenarios that could be regarded as different designs (Stroosnijder et al., 1994). However, because these models work with averages, the design cannot be easily implemented for an actual farm. Yet, the knowledge derived can eventually be disseminated to farmers like in FSR&E. However, results obtained so far, indicate that it is mainly used as an advisory instrument for policy makers.

The approach in this thesis can be classified under FSR&D and looks very similar to prototyping. Indeed, there are no big differences in principle, but a few differences can be detected. Until now, the focus of prototyping was mainly on the tactical level, especially on crop rotation. In other words, the design step mainly concerns the structure or configuration of a farm system. The approach in this thesis focuses on the operational level and mainly concerns the operations on a farm. The emphasis on modeling, supported by information and communication technology, is more important in this thesis. Furthermore, the idea that the farmer himself is the designer is more prevalent. Prototyping research until now mainly focused on plant production, while this thesis takes a combination of both plant and animal production into account. Finally, because variation between farmers is usually larger with respect to operational management, this thesis will put more emphasis on farm- and farmer-specificity.

2 Designing sustainable farm systems: how to integrate soft and hard parameters in decision-making?

Human beings, viewed as behaving systems, are quite simple. The apparent complexity of our behavior over time is largely a reflection of the complexity of the environment in which we find ourselves…

Herbert Simon (1996, p. 110)

Abstract

This chapter makes clear why agriculture is essential for the quality of life and therefore concerns whole societies. The relation between agriculture and society however has become gradually undermined due to serious problems evoked by too intensive ways of production. This chapter introduces why integration of soft and hard parameters in decision-making by farmers could be a solution. Is it possible to give soft issues such as farmers' visions, intentions and values a same weight in deliberations about farm economy and management? It was found that sustainable agriculture could be considered as an integrated solution for economic, ecological and social problems. It was concluded that sustainable development is a dynamic design process in an ever-changing environment. Design as such, must aim at achievement and maintenance of adaptive capacities present in natural resources. So, the farmer, being the human factor in the farm system, has to play an essential role. That brings us to the combination of relevant concepts found in scientific literature about management and sociology. The chapter terminates by presenting a methodology in three phases: (i) negotiate with the environment, (ii) solve problems in a heuristic way and (iii) control during operation. This hypothesis will be used for the definition of the information model, required for finding an answer to the research question.

Keywords: sustainability; designing; farm systems; heuristic problem solving; management control; beta-gamma interaction

2.1 Introduction

Agricultural land use is important for all societies. Therefore, agriculture is part of national policy making in almost all countries. According to the Organization for Economic Co-operation and Development (OECD), agriculture is the biggest user of land space in every country (OECD, 1996). Hence, the quality of agricultural land use has a great effect on the quality of life. When mainstream agriculture is considered to be nothing else than a production machine, fully cut off from its surroundings, negative side-effects on the quality of water, air, soil and biodiversity are kept outside the scope of production-driven farm management. Future farm management must internalize conditioning of life quality at and around production sites (UNCED, 1992). Future farm management must therefore incorporate public objectives concerning environment, biodiversity and landscape conservation. Considering present consumer's awareness about health, animal welfare and fair trade, it is expected that the scope of farm management will gradually expand. Therefore, the search for knowledge about the quality of life encounters continuous changing goals, reflected in agricultural policy making and also market demands.

After Second World War, the main question was how to raise production in order to reach self-sufficiency. When this objective was attained, other policy goals emerged. Examples are: agriculture for hunger reduction, agriculture for employment, agriculture for market development, agriculture for export and, nowadays, agriculture for improving land use. Environmental problems, mainly caused by agro-chemicals (synthetic pesticides and fertilizers), made policy makers aware that technology-driven agricultural production should integrate public objectives concerning the quality of life. However, it takes quite some time to get agricultural production systems on other tracks. Environmental quality or well-protected biodiversity have no price mechanism in the market. Markets generally do not negotiate about ethics, welfare or fair prices. Moreover, most modern farms have become very much dependent on external investments. Later, technological developments increased costs for agricultural production and markets became saturated, and farmers got serious economic problems. Owen, cited by Van der Ploeg (1999), says that farmers are squeezed between their investor's objectives. Public concern grew considerably at the end of the 20th century. New issues such as animal welfare, diseases, genetically modified organisms and food safety appeared as new concerns. Most decision-makers in agriculture accept that farm practices must change now. Farming has lost its protected position. It becomes a demand-driven production sector, where profitability and delivering of public services should be integrated in management skills of future farmers. It is argued that creating management tools that integrate soft and hard parameters can solve the present crisis in agriculture. Soft parameters require normative judgment: man's opinion is involved. Hence, their definition and desired value is subjectively determined. In contrast, hard parameters can be objectively defined according to general agreed rules. The question is how to approach such a conflict of visions? Koningsveld (1986) says that a problem is an *anomaly* when it can be solved by new technologies. A problem becomes a *crisis* when new technologies cannot, or when society will not accept them. In the latter case, Koningsveld pleads for a paradigm shift that improves social acceptation of the demanded technology. Here, society is considered as a coordinated complex of acting individuals.

A paradigm shift is connected with philosophy. In this respect, Van der Wal (1997) says that the domination of logic-positivistic thinking in science and technology inherently contains some hidden conflicts. These conflicts can be identified by three attitudes:

- Nature is matter and is open for influence, manipulation and modification. This concept legitimates that knowledge about and redesign of nature must be connected. The test of an idea is: “it works”.
- Human beings are living creatures. For their survival they must explore and (re)design nature and divert borders. Macpherson (1973) speaks of human beings as *infinite desirers* and hence as *infinite consumers* and *infinite appropriators*.
- Values, norms and sense cannot be defined objectively. They germinate in human’s mind and are therefore bound to subjective experiences.

These attitudes provide interesting points of departure for the explication of the desired form of farm management.

- *Nature as matter* creates knowledge about natural laws. The better we understand those laws, the more we may manipulate nature for improving of human mankind’s financial situation. Most attention is paid to those parts of nature, ecosystems, farms and organisms that are valuable for production. Mostly, these parts are identified at a low integration level (e.g. seeds, tubers, meat). Human beings are considered to be independent from nature. They may dominate and exploit natural resources. Future managers are thus allowed to use nature infinitely.
- *Nature as carrier of human beings* creates knowledge about processes between the component parts of nature (e.g. physiology, food chains, evolution). The better we understand the conditions under which they take place, the more we know about the limits of nature. Beyond these borders, the quality of life will decrease. Future managers are thus allowed to limit their ambitions to nature’s carrying capacity.
- *Nature as philosophy of human beings* creates culture. Values, norms and sense making are inspired by nature, but originate in the human mind.

Future farm management should integrate all these attitudes. Farmers are producers of biomass, protectors of self-organizing capacities in living systems and farmers are sense making beings.

The crisis in agriculture may be reduced when hard parameters on one hand and sense making activities related to the quality of life (soft parameters) on the other hand, get equal attention in decision-making. This means that decision-making becomes more complex. Hence, facilitation by adequate information systems may greatly support decision-making. But how could farmers implement visions, intentions and values in everyday management? First, the farmer must learn to make his vision, intentions and values explicit so that they become manageable. Secondly, he must be in touch with them at any moment of decision-making, so that he really does what he intended to do. Thirdly, he must be able to link decision-making and the result of it in order to develop pathways for changes. In this process, it is implicitly acknowledged that farmers improve their management skills step-by-step. Such management no longer relies on logic-positivistic information only, but also on vision, intentions and values, incorporated in farmer's attitude or experience.

This seems to be impossible. Hence, visions, intentions and values often tend to remain vague objectives in policy documents and mission statements of firms. They are put into practice without hard evaluation. There is one exceptional example. Many European companies incorporated values concerning labor quality in their human resource management. That contributed to the companies' dignity and quality, without loosing profitability; labor became a target instead of a device. This acts as an inspiring example. It should be added that during the last years more initiatives have been taken by companies to incorporate social responsibility into their management (Graafland, 2000; SER, 2000).

In relation to the step-by-step improvement of management, learning-by-doing or learning-from-practice is important to mention (Tekelenburg, 2001). It is related to heuristics. A usable definition of heuristics in fairly general wording is the one given by Beer (cited by Hofstede (1992):

> Heuristic (contraction of 'heuristic method'); a set of instructions for searching out an unknown goal by exploration, which continuously and repeatedly evaluates progress according to some known criterion.

Röling (1994a) considers learning pathways as emerging properties. This means that knowledge involved cannot be taught, but it is obtained by everyday practice, careful observation and evaluation about what has happened. Knowledge as an emerging property is not based on experiments but based on experience. Society demands farm management of the latter type. It means that an operational method must be found that offers farmers a tool for that. This chapter presents the results of literature research about the possibilities for heuristic learning by farmers. The problem is how farmers could involve visions, intentions and values, beside of farm economic data, equally weighted in everyday decision-making.

The results are presented stepwise. Section 2.2 further defines the problem statement by exploring methods for integration of farm economy and societal demands, using *sustainability* as a central theme. Section 2.3 presents a method for incorporation of sustainability in farm systems by farm managers. Section 2.4 describes how this method is embedded in the context of general research, technology development and extension or consultancy. Section 2.5 provides a summary and Section 2.6 describes the implications for modeling, laying a bridge to Chapter 4. A summary of this introduction is provided by Mind Map 2 in Appendix VI.

2.2 Sustainability by integration of hard and soft parameters

Heuristic learning concerns the art of integrating hard and soft parameters. Hard parameters are for instance productivity, efficiency, technology or farm economy. Soft parameters concern visions, intentions, societal demands or ethics. The first can be experimentally researched. Knowledge about the latter is the result of many years of experience. Mainstream agricultural research so far addressed research questions in a logic-posivistic, and thus experimental, way. Efforts to integrate farm economic and environmental demands resulted in integrated agriculture. This form of agricultural land use became the mainstream paradigm in agricultural science. It is based on the idea that ongoing improvement of input efficiency finally results into a fully integrated economic and environmental farm production, where the ratio input versus output tends to grow to one (De Koeijer, 2002; Goewie, 2002)

According to Lampkin (1990), organic agriculture is based on a complete new paradigm. It says that farm production must be done under the restriction of a balance between input and output. Or in other words, what the farmer removes from his land should be added by natural resources at or around the site of production. Farm technology and farm management should be designed according to this balance.

Integrated agriculture can be seen as an approach that mainly addresses environmental problems. It is a systems approach, but does not really add something new to agricultural scientific knowledge (Koningsveld, 1986); it is not a structurally new paradigm.

Organic agriculture cannot be compared with integrated agriculture in such a way that it can be considered to be an answer to environmental problems, because it already existed before environment and nature became an issue. Opposite to integrated agriculture, agricultural research hardly contributed to organic agriculture. Nevertheless, organic agriculture is now regarded as a promising option for addressing environmental problems as well as some economic and ethical questions. Following the famous Brundtland report ‘Our common future’ in 1987, which introduced the term sustainability, a new idea for agriculture was introduced: *sustainable agriculture*. This idea will first be briefly described and then some conclusions will be drawn.

2.2.1 A perpetual relationship

Sustainability refers to the relationship between human society and its biophysical environment. Man is dependent on the environment and thus he has to maintain this relationship in such a way that it (in principle) can last forever (Hardin, 1968). Hence, it is a very anthropocentric concept. Röling (1999) emphasizes the aspect of negotiation in this relationship as he says:

> Sustainability also emerges from systemic interaction in the sense that it can only come about as a result of a negotiated agreement to take less from common goods (e.g. groundwater) and give more to public goods (e.g. biodiversity).

This process of agreement is very much related to the basic attitudes of Van der Wal (see p. 31) that were described in the previous section. Actors concerned need to identify their own attitude and define their values and norms with regard to the relationship between man and nature and also with regard to people among each other. So, a balance needs to be found between individual wishes and public interest. Section 2.3.3 will come back to this negotiation aspect in more detail.

2.2.2 Dimensions, values and aspects

Van der Werff (1993) distinguishes three dimensions of sustainability. The first dimension is time. This deals with the assessment of the effect of current activities on the future. The second dimension is space. Sustainability can be applied at farm, regional or higher levels. With the choice of a certain level one has to be aware of the consequences of the choice of system boundaries. A system may be sustainable at the expense of other systems elsewhere, so in fact it is not sustainable; then you could speak of so-called ‘damning objectives’ (Schiere, 1995). The third dimension has to do with values that can be assigned to several aspects of sustainability. These aspects can be subdivided into economic, ecological and social aspects. With respect to these aspects, again, a difference can be made between a collective and individual perception. Concerning the ecological aspect, a relationship between society and its biophysical environment was acknowledged, but from an individual viewpoint, a socio-economic sustainable relationship also has to be maintained. For example, a farmer has to maintain his ecological resources in order to produce. At the same time, he needs a certain economic profit for subsistence of his farm. For this profit he depends on markets. These markets increasingly have certain wishes about the way the farmer works. This example makes it clear that these aspects are usually interrelated and there will be trade-offs between them. This forces the farmer to assign his personal values to these aspects. The whole set of values can be regarded as a style of farming (Van der Ploeg, 1999). The conclusion is that all dimensions play a role and in reality, they cannot be separated from each other. This means that research *can* focus on one dimension or one aspect, but in practice, all dimensions and aspects play a role at the same time.

2.2.3 Adaptive capacity for sustainable development

If sustainability concerns the need of future generations, sustainability should principally be related to long-term goals. However, because our myopia[1] is not adaptive (Simon, 1996), we do not know how the future environment, ecologically and socio-economically, will be (Park and Seaton, 1996). The only constant is that the environment will always change. Hence, sustainability is required to be a dynamic concept. Frequently, it is compared with the concept of biological evolution, in which organisms are adapted to the changing environment by selective forces that are determined by their adaptive capacity.
Fresco and Kroonenberg (1992) state that:

> … in order to be sustainable, land use must display a dynamic response to changing ecological and socio-economic conditions.

Conway and Barbier (1990) recognize this also when they define sustainability as:

> the ability to maintain productivity, whether of a field or farm or nation, in the face of stress or shock.

Adaptive capacity enables a system to respond to the changing environment (Park and Seaton, 1996). This adaptive capacity is mainly constituted by variability or diversity of this response (Almekinders et al., 1995; Hobbs and Morton, 1999). In this respect, Van der Ploeg (1999) cites Jacob:

> … diversity is a way of coping with the possible. It acts as a kind of insurance for the future. Selection from pre-existing diversity appears as the means most frequently used in the living world to face the unknown future.

[1] Simon uses this term as an important metaphor in his book. Myopia (also called nearsightedness) is a term from optometry and indicates the condition in which the visual images come to a focus in front of the retina of the eye resulting especially in defective vision of distant objects. While it is generally negatively regarded as a defect for individual human beings, Simon sees it as a positive defect of society; without myopia there would be no evolution. If our decisions depended equally on their remote and their proximate consequences (so not myopic), we would never act but would be forever lost in time.

Again, we have to make a distinction between a collective and individual point of view. For example, the external environment for a region is different from the one of a farm. For a farm, it is important to maintain diversity in its ecological properties, while for a region it is important to have different types of farms or farm styles.
Usually, there is also variation in the environment itself which means that selective forces are local-specific and in its turn this must result in different local-specific sustainable systems. Van der Ploeg (1999) stresses that it is important that this selection takes place *ex post*. He argues that governments and agricultural researchers often tend to carry out an *ex ante* selection, by proclaiming what farm types and farming styles will be sustainable for the future. This is impossible because the future is largely unknown and unpredictable. Moreover, this can lead to unsustainable situations, because strict applied policy derived from this concept can possibly eliminate variability, which could lead to disastrous situations when the future turns out to be different than was thought.
Sustainable development is a step-by-step redesign process of gradual change in which no end states or final goals can be defined (WRR, 1995). This does not mean that there are no goals at all, but they should not be too far away from a present state. There must be a balance between present and future (Simon, 1996; Van der Ploeg, 1999). Simon (1996) talks about local optima conformed by stable aggregates[1,2]. One single, global optimum only exists in theory and is utopian. When local optima are reached, new ones come into sight that can be searched for. This can also be compared with the biological concept of co-evolution: new states of a system form a niche for other possibilities that did not exist before.
In conclusion, research concerning sustainability should not only focus on the long-term future, but should focus more on the adaptive capacity in order to cope with this future. The next question is: what can be done to achieve and maintain adaptive capacity?

2.2.4 Adaptive management

Park and Seaton (1996) talk about sustainable pathways that on the short term must be viable and in the long term sustainable. This means that management should be realistic and feasible, but focused on adaptability and thus diversity. This could be described by the term *adaptive management* that was coined by the ecologist Holling (1978) and is broadly used in the field of ecology and nature conservation (see e.g. Hobbs and Morton, 1999; Holling,

[1] Simon illustrates this by his famous parable about two watchmakers, Hora and Tempus. They both make watches from the same parts. Each time they are interrupted (e.g. by customer phone calls), the current watch they are making, falls into pieces and they have to start again. However, Hora first makes several stable subassemblies and then puts these together to one watch. When Tempus is interrupted, he has to start all over again, while Hora can start at the level of subassemblies and in this way he will finish the watch much faster. The difference will become larger when they are interrupted more frequently.

[2] Within the context of farming, stable aggregates can be regarded as specific combinations of labor objects (e.g. crops, animals), resources (e.g. machines, concentrates) and labor (Van der Ploeg, 1999).

1999; Lefroy et al., 1999). Again, the essence of adaptive management is characterized by step-by-step, experiential and experimental learning (Johnson, 1999; Röling, 1999).
More specifically, Simon (1996) points at two complementary mechanisms that keep a system in a steady state in response to environmental changes: *homeostatic mechanisms* that make the system relatively insensitive to the environment and *retrospective feedback adjustment* to the environment's variation. Homeostatic mechanisms are especially useful for handling short-term fluctuations. Feedback mechanisms adapt the system to long-term fluctuations, by continually responding to discrepancies between the system's actual and desired states. Management should be focused on these self-regulation mechanisms.
Natural scientists tend to think that the steady state can be well predicted and controlled, while social scientists regard it as an emergent property from an interactive learning process between the ecosystem and human actors (Röling, 1994a). In this thesis, the latter view is more adhered to.

2.2.5 Farm system as research focus

Many definitions and descriptions of sustainability and sustainable agriculture have already been published (for a good overview and discussion, see Hansen (1996)). In practical terms, sustainability is usually regarded as an integrated solution to economic, ecological and social problems (Almekinders et al., 1995). Hence, the farm system[1] is regarded as the most important starting point, because agro-economic, agro-ecological and psycho-sociological factors come together at that level (De Koeijer et al., 1999). So, in this view the farmer as a sense making being plays an important role. Park and Seaton (1996) recognize this when they say:

> It is unlikely that adaptability at the level of agroecosystem processes can be maintained unless the farmers themselves have the ability to demonstrate adaptive behavior.

Many research concerning sustainable agriculture is of analytical nature and has resulted in many *sustainability indicators* that could be used to compare different farms or farming systems (see e.g. Weterings and Opschoor, 1994; GRI, 2000; OECD, 2000; UN, 2001). However, although indicators are useful to a certain extent, they suggest that sustainability can be measured and assessed, but this view is considered to be too simplistic. It regards sustainability too much as a static concept. In the previous sections, it was concluded that sustainability concerns interactive relationships that must be sustained and this means that sustainability is a dynamic concept because the environment of resources and society is

[1] While it is explicitly referred to individual farms in this thesis, the term 'farm system' is adhered to instead of 'farming system' that is more reserved for a class of similar farm systems as suggested by Fresco and Westphal (1988).

constantly changing. Hence, it is better to speak of sustainable development instead of sustainability as a static term (WRR, 1995). Part of this development will be autonomous and cannot be influenced (Park and Seaton, 1996). For a substantial part, human actors actively determine sustainable development. Active development is synonymous for design[1]. In this respect, sociologists refer to the term *agency* (Van der Ploeg, 1994) and in farm systems the farmer can be regarded as the most important *agent of change*. He is the final decision-maker that reflects policy concerning sustainability (De Koeijer et al., 1999). Especially this aspect is often left out in current research on sustainable agriculture. Farming System Research (FSR) is expected to address this omission, but FSR applied to Western agriculture often stops after the analysis and diagnose phase, while it should continue with the next phases of design, implementation, test and improvement (Mettrick, 1993; Vereijken, 1997). Prototyping is a design method that addresses this omission (Vereijken, 1997). Another design method (sometimes referred to as Quantified Farming Systems Analysis (QFSA) (Stroosnijder et al., 1994; Rossing et al., 1997b)) to design sustainable farm systems goes no further than the design phase. This is because this method applies a mathematical optimization technique, Multiple Goal Linear Programming, Linear programming assumes that goals and pathways to reach these goals are well known and defined (Simon, 1996), which is opposite to the description of sustainability in the previous sections. The method implicitly assumes the farmer to be a *'Homo Economicus'*, a rational decision-maker. This is considered not to be realistic when designing farm systems in practice.

2.2.6 Conclusions

Implementation of sustainability in practice means that all its dimensions and aspects must be dealt with at the same time. For sustainable agriculture, the farm system level seems to be an important level to work on this. Sustainable development is regarded as a dynamic design process carried out by the farmer as a sense making being. This process should be aiming at creating a sufficient adaptive capacity in order to respond effectively and fast enough to the ever-changing environment. Diversity and self-regulation are prerequisites to create and maintain this adaptive capacity. The problem is now reduced to the question about how to incorporate this notion of sustainability in a farmer's decision-making process. The description of sustainability is summarized in Mind Map 3 in Appendix VI.

[1] Although the term design will be used in this thesis, the term redesign would be more appropriate because in case of farm systems you cannot speak of a zero starting point, but you start redesigning from an existing situation.

2.3 Incorporating sustainability into decision-making – a three phase methodology

Science is about discovering how the world works. Designing is about solving practical problems and changing something (Van Eijnatten, 1992; Simon, 1996; De Leeuw, 2000). This leads to different views on a farm system, although this is sometimes not recognized. Passioura (1996) points at this when he says:

> Most members of the American Society of Agronomy probably think of themselves as agricultural scientists. The Dutch, however, who are very practical people, call their graduates in agriculture *engineers*. I think that much of the debate that surrounds the use of simulation models in agriculture arises from confusion about the difference between science and engineering.

Results from scientific research cannot be directly applied to farm systems (Leaver, 1994; Leeuwis, 1999). One of the main reasons for this is the human factor, the farmer and other people involved in the farm system, that plays an important role in the translation of science into practical knowledge. This is, among others, the very difference between natural and social sciences. Simon (1997) argues that it is not the ethical aspect (subjectivity versus objectivity) that makes the difference between them. It is also not the complexity of the object of study, although social systems are much more difficult to study, because experiments under conditioned laboratory conditions can hardly be applied. The difference is to be found in the *inclusion* of human beings in the object of study. Natural sciences exclude this aspect as much as possible. Social sciences have to include it. That makes social research so difficult. Human beings are sense making beings and part of a larger social system. So, they can change the development of that system by their behavior that is influenced by knowledge, memory and expectations. Moreover, human behavior may change according to the pattern of mutual interactions inside the system they belong to. Human beings exhibit non-deterministic behavior because they have knowledge about the forces that influence their behavior that in its turn can change that behavior.

So, a *crucial point* in designing farm systems is that the farmer himself is the designer. From this perspective, scientists play a role in the design process by thinking about how this can take place in an optimal way. Thus, scientists are not optimizing the farm system itself but optimizing the design process of a farmer! This is a new approach in agricultural science. Optimization of the design process means that the farmer is enabled to make better decisions and to improve his system continuously.

The following sub-sections present a methodology on how sustainability, as described in the previous section, can be operationalized at the level of a farm system by a design process. Integration of natural and social sciences, beta-gamma interaction, will be the leading thread, running through this section. First, the farm system is looked at from different points of view. Then the design process is considered as a form of management control that has to deal with setting goals and means. From this, it is concluded that three phases can be distinguished: negotiation, heuristic problem solving and operational control.

2.3.1 Farm systems

A definition of a system, which is generally used in many systems approaches, is (Spedding, 1994):

> a group of interacting components, operating together for a common purpose (or at least in a coordinated way), capable of reacting as a whole to external stimuli: it is unaffected by its own outputs and has a specified boundary based on the inclusion of all significant feedbacks.

Fresco and Westphal (1988) define a farm system as:

> a decision-making unit comprising the farm household, cropping and livestock systems, that transforms land, capital (external inputs) and labor (including genetic sources and knowledge) into useful products that can be consumed or sold.

Shaner et al. (1982) give an implicit definition of a farm system when they define the Farming Systems Research and Development (FSR&D) approach as:

> an approach to agricultural research and development that views the whole farm as a system and focuses on the interdependencies among components under the control of members of the farm household and how these components interact with the physical, biological, and socio-economic factors not under the households' control.

These definitions consider a farm as a rather isolated system, focusing on the farm household that regulates the biophysical subsystems. They comprise the risk that farm development is regarded as a deterministic mechanism that is predetermined by the external stimuli outside the boundary that cannot be influenced. Long (1984) and Van der Ploeg (1999) do not agree with this supposition and emphasize (i) the interplay and mutual influence of local and extra-local factors and structures and (ii) the agency that enables the farmer to influence external structures and the way these external structures ultimately influence the development of their farm. Agency could be defined as the capacity to create own futures. Van der Ploeg (1999) even prefers not to speak of external structures and just distinguishes an internal structure as a socio-technical network (author's translation from Dutch):

> a specific constellation of diverse modes of ordering that specifically interact and define together the most obvious actions and possibilities for development.

Related to the analogy between sustainability and biological evolution described in Section 2.2.3, it means that sustainable development of a farm system is not only determined by the 'genes of the farm', but can be actively influenced by the farmer, being a sense making, behaving decision maker.
So, defining boundaries in a system might be useful to gain insight into the system, but there is a risk in it. Röling (1994b) has reincorporated the risk of choosing boundaries in his definition of a system:

> a system is a construct with arbitrarily defined boundaries for discourse about complex phenomena to emphasise wholeness, inter-relationships and emergent properties.

He further argues that sustainable development therefore requires a *coupled system* between:

- a *'hard' agro-ecosystem* constructed according to biophysical science and managed on the basis of instrumental reasoning;
- a *'soft' platform* constructed according to social insight and managed on the basis of strategic and communicative reasoning.

This coupled system can be regarded as a soft system (Checkland, 1990) that Spedding (1994) defines as:

> a system in which objectives are hard to define, decision taking is uncertain, measures of performance are at best qualitative and human behaviour is unpredictable.

However, Röling adds that soft systems as such do not exist; they emerge through negotiated agreement and become temporary constructions. This means that a farm system, seen as a coupled system, will always be local-specific as a result of the interplay with the environment.
In the next sections, the coupled system of Röling is taken as a starting point. It will be worked out further, using insights from management science.

2.3.2 Management control

De Leeuw (2000) mentions five conditions for effective management control:

- a management objective for the total system;
- a model of the production system;
- information on the environment and production system;

- potential control measures;
- an information-processing capacity.

Fig. 2-1 shows a scheme of a farm system and its environment from a regulative perspective. It distinguishes a managed system (production system), a managing system (farmer) and an information system. The production system and the environment provide the information system with actual and historical data. Furthermore, data about management control itself can be stored so that the farmer is able to reflect on his decisions in the past, in combination with the state of the production system and the environment. This self-reflection can support actual decision-making. The environment must be considered in its broadest sense: data on social, economic and ecological parameters can be provided.

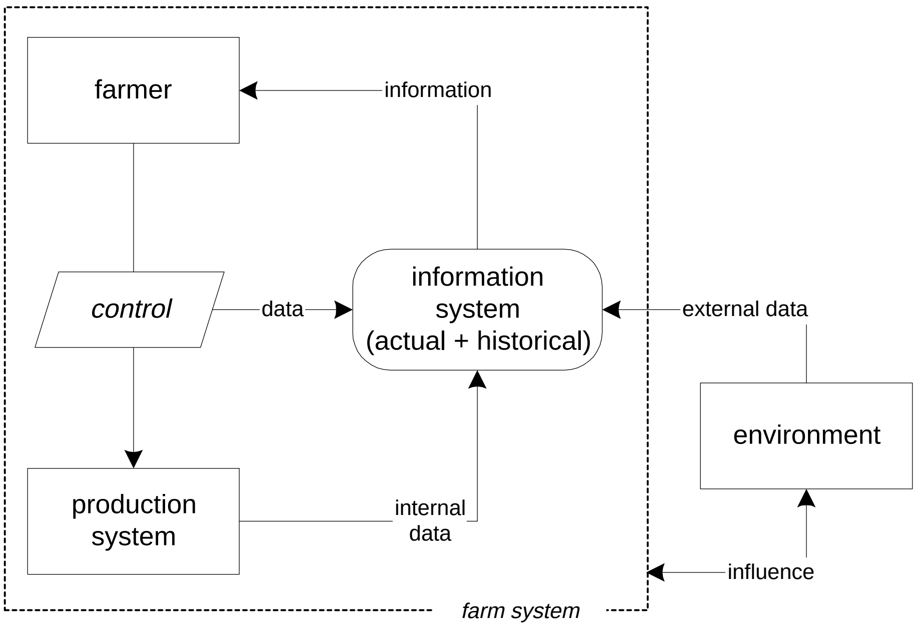


Fig. 2-1 Management from a regulative perspective (adapted from De Leeuw, 2000)

Management control takes place based on information that is provided by the information system. The contents of the information system depend on monitoring activities and the format can range from a hand-written notebook to a sophisticated software application. In the context of sustainability that involves many complex data on economic, ecological and social aspects, a software application might be indispensable. The information system transforms raw data into useful information. This means that the right data must be combined and transformed into useful information. The question about what is *useful* information is also dependent on the manager's style (Keen and Scott Morton, 1978). The usefulness of information is determined by its soundness and relevance (De Leeuw, 2000). Information is sound when it is accurate, controllable, precise and consistent, and when its validity range is provided. Information is relevant when it is problem-related, comprehensible and available in time. This does not mean that information always must be scientifically approved; the farmer can also rely on his experience.

Management control can be regarded as a problem solving activity. Fig. 2-2 shows the origin of a problem. The scheme emphasizes that problem definition is value-related: it depends on a subjective perception of reality. The farmer has goals for his farm system that can be translated into a model of the desired farm system. These goals will also determine the model of the production system: only those components will be taken into account that are relevant to one or more goals. The model of the production system also depends on how the farmer perceives reality. Both the model of the desired farm system and the model of the production system depend on the farmer's real life system that is defined by De Leeuw (2000) as (author's translation from Dutch):

> the whole set of personal suppositions and views that determine the (subjective) perception of reality.

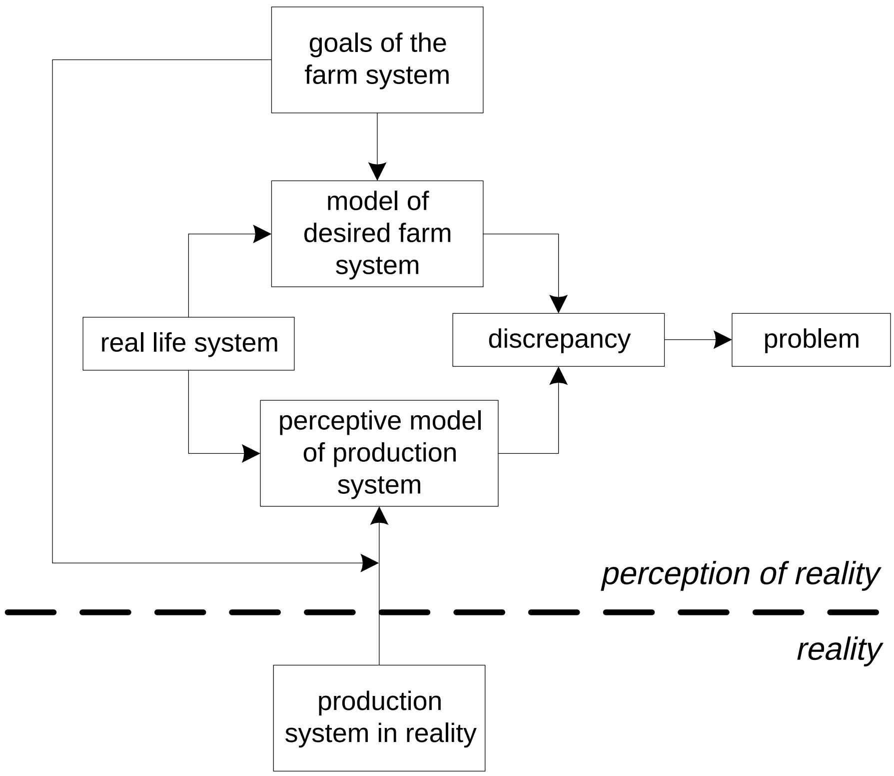


Fig. 2-2 The problem origin as a perception of reality (De Leeuw, 2000).

So, it also has to do with attitudes towards nature and society (see p. 31). Now, a problem can be defined as a discrepancy between the model of the desired farm system and the perceived model of the production system. The complexity of problems depends on the complexity of goals and the relation to the production system. It is not always clear in advance what information from the production system is related to a certain goal and if this information is easily obtainable. Besides, some information needs to be evaluated against the personal real life system. In this case, management scientists speak of *unstructured* problem situations (Simon, 1977; Keen and Scott Morton, 1978). This will be further discussed in Chapter 4.

As mentioned in the five conditions for effective management control, potential control measures are needed to achieve goals. These are usually referred to as *means*. Means are related to one or more goals. However, means are often also goals in themselves, related to means at a lower level. In this way a goal-means hierarchy can be distinguished that at the highest level deals with unstructured problems and at the lowest level with structured ones. Simon (1997) defines this goal-means hierarchy as:

> a series of anticipations that connect a value with a state in which this value is realized and these states in their turn with the behaviors that evoke them. Each element in this series can be either a goal or a mean, dependent on the question whether the connection is concerned with value-side or the behavioral-side of the series.

For example, a dairy farmer sets a certain goal on his economic results. An obvious mean is milk production of the cowherd that in its turn can be set as a goal. This goal can be reached by a combination of several means. One farmer will focus on the production per cow, another on fodder production and a third one on efficient use of machinery. Thus, several styles of farming can be distinguished (Van der Ploeg, 1994) that are determined by the normative behavior of the farmer.
Summarizing, operationalizing sustainability from a management control perspective can be seen as a process of defining a goal-means hierarchy, ranging from unstructured to structured. In this process three phases are distinguished:

- *negotiation* – In this phase, the farmer sets strategic goals and means of his farm in negotiation with the environment and in reflection with his own real life system. Values are translated into personal and local-specific norms.
- *heuristic problem solving* – In this phase, the farmer tries to operationalize his norms by finding appropriate means. It is still characterized by unstructured or semi-structured goals and related problems; solutions are not obvious in advance. Hence, it is characterized by heuristic learning.
- *operational control* – This phase concerns daily management, which is characterized by routines. Goals and means, that are outcomes from the previous phase, are clearly structured. It is characterized by habituation.

This largely corresponds to the usual subdivision of strategic, tactical and operational management (Anthony, 1965). It is a hierarchy with the negotiation phase at the top and operational control at the bottom. By means of this hierarchy, farmers are enabled to involve visions, intentions and values (soft parameters), beside hard parameters into everyday decision-making. The whole hierarchy should be established in a step-by-step manner and will always be subject to change. In the next sections the three phases are described in more detail.

2.3.3 Phase 1: negotiation

Two contrasting views are presented: a sociological view and a biophysical-rational view. They are illustrated in Fig. 2-3.

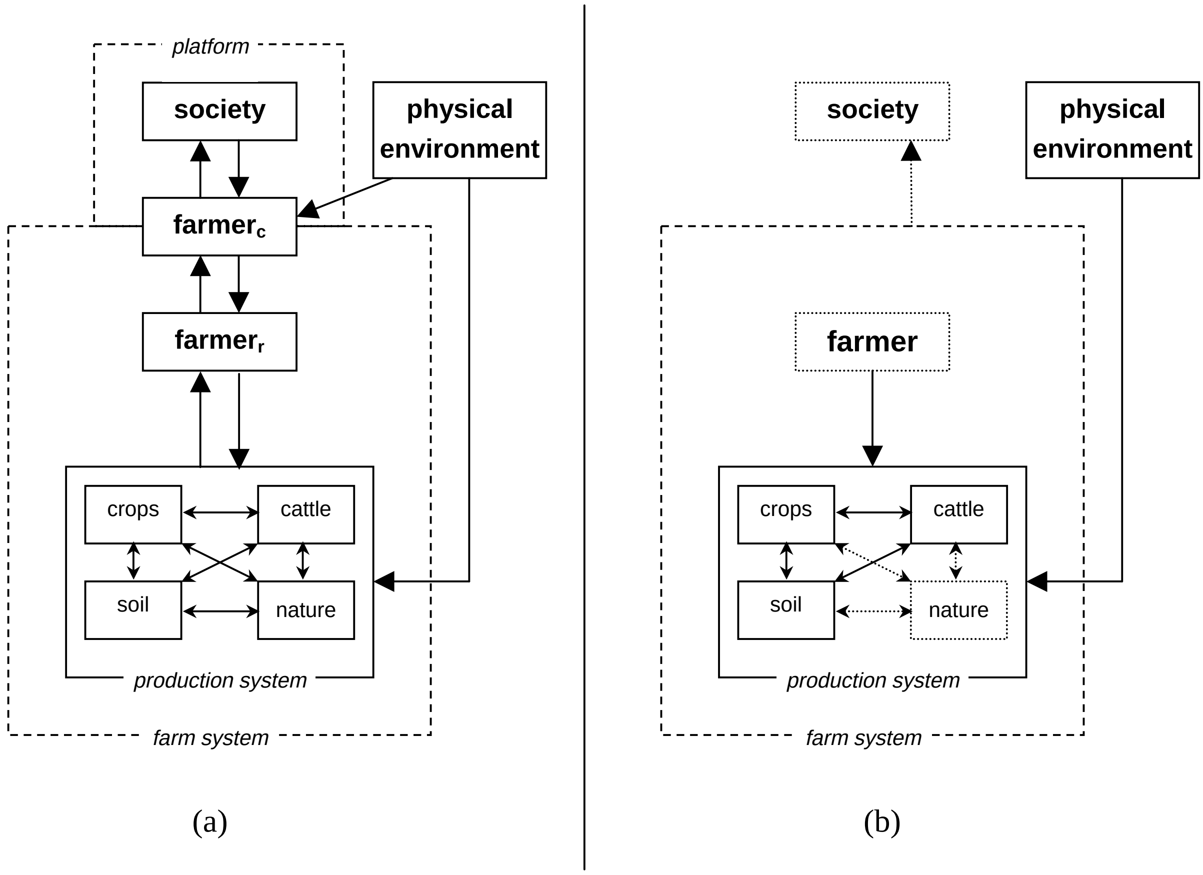


Fig. 2-3 Two different views on a farm system emphasizing the communication aspect. a) the sociological view (b) the biophysical-rational view. Further explanation in text.

2.3.3.1 The sociological view

Fig. 2-3a represents the sociological view on the farm system. The production system is formed by interactions between crops, animals, soil and nature. Nature refers to production factors that are not primarily used for production like wildlife, ditches, shrubs, etc., but still can be very important for production. The scheme might suggest that nature is a separate compartment of the production system, but it is emphasized that it should be regarded as interwoven with the other ones (Smeding, 2001). This will be further elaborated in Chapter 3. The farmer in the middle is the one that regulates the production system (farmer$_r$). The arrows between the production system and the farmer indicate that this regulation is a co-interaction with the production system. Agency can also be assigned to the production system, which means that an actual state of the production system influences the way the farmer regulates it[1].

Beside the farmer's role as a regulator, a role as communicator can be distinguished, indicated as farmer$_c$. (Of course, in reality, it is one and the same person or household). In that role, he communicates with the environment, i.e. society, and looks at the physical environment (weather and climate). Communication with society is the aforementioned soft platform of the coupled system. Farmer$_c$ provides information to society about his farm system and the way he is producing and society provides its demands concerning the farm system. These demands concern products and production methods, which are value-related. In this way, the platform acts as a normative center for the farm system. From this platform, farmer$_c$ assigns certain values to the properties of his farm system and this will influence the way he regulates the production system. This is in line with the value dimension of sustainability as described in Section 2.2.2. This mechanism forces the farmer to establish his personal opinion on attitudes that were identified (see p. 31).

If society is regarded as the whole of consumers, citizens, purchasers, banks and all other groups of actors, the sum of the farm system and platform can be compared with the socio-technical network of Van der Ploeg (see p. 40).

The physical environment directly influences the production system, but 'hard' information from this environment is also interpreted by farmer$_c$ that results in a way of regulation of farmer$_r$ so that the effect on the production system is altered. For example, the effect of heavy rainfall can be influenced by the way the farmer has managed his soil. In a sustainable farm system, this effect will be stabilized by homeostatic mechanisms.

The distinction between farmer$_r$ and farmer$_c$ is also is in line with what was said about the main difference between social and natural sciences and what Giddens (cited by Röling (1994b)) refers to as the 'double hermeneutics':

> knowledge produced about human actors re-enters society, is interpreted and affects human action... People actively construct their own realities through learning in social processes

In the context of this thesis, it means that the farmer reflects on his own behavior of regulating the production system and will change this behavior through learning processes. This will be further elaborated in the second phase, heuristic problem solving.

[1] A simple example of this kind of agency is that the configuration of chairs and tables in a living room very much influences the way that people converse with each other in this room. In this case this configuration is setup by people, but in a farm system there are several autonomous forces that will finally influence the farmer's regulation.

2.3.3.2 The biophysical-rational view

Fig. 2-3b represents the biophysical-rational view on the farm system. In this view the biophysical production aspect of the farm system is emphasized. In accordance with the aforementioned definition of Fresco and Westphal (see p. 40), it focuses on 'useful products that can be consumed or sold'. Production is partly determined by factors that are not under farmer's control (see definition of Shaner et al. on p. 40). Regulative control is regarded as ideally optimal, according to biophysical models of crop growth extended with optimal fertilizer and pest control recommendations. The farmer is regarded as a *'Homo Economicus'*, a rational decision-maker who rationally makes decisions according to economic optimization models. Obviously, this farmer is idealized and does not exist in reality; it is a *virtual farmer* as Van der Ploeg (1999) calls him. He argues that, although in reality he does not exist, he exists in the mind of many agricultural scientists and policy makers and this caused many problems in current agriculture. Pretty and Shah (1997) mention in this respect that

> the failure to involve people in design and maintenance can have considerable long-term social impacts.

The production system is principally the same as in the sociological view. However, as indicated by the dotted lines, nature and its interactions with other compartments are not considered as relevant. This does not mean that they are non-existent; actually nature *is* influenced but in a negative way. Nature, which is interwoven with other compartments (mainly the soil), is only seen as a biophysical resource that can be exploited. It is obvious that these ideas very much correspond to the three basic attitudes of western science and technology mentioned in Section 2.1.

The arrow to society is one-way directed and dotted, which indicates that there is an influence of the farm system on society, but this is not taken into account. There is no interaction that influences the farm system itself. Society itself is also dotted, which means that in this view it is also idealized, like the farmer is idealized. It is thought to consist of rational thinking people that think the same as the rational farmer. In analogous terms, you could speak of a *virtual society*. Agricultural researchers that use the biophysical-rational view (perhaps unaware), often state that production methods and technologies should be *acceptable* for society. However, what is acceptable, is then very much determined by the scientists and technologists that develop them. The question is then whether in reality it will be *accepted* by society. This may be one of the reasons for the current crisis in agriculture.

Although this biophysical-rational view might seem to be a caricature, it is still a rather dominating view in agricultural research. In the concept of Integrated Agriculture, nature is taken into account in the production system, but the emphasis is merely on sparing nature instead of co-operation. Chapter 3 will deal with this issue in more detail. The axiom of the farmer as a '*Homo Economicus*' is also still rather dominant. It seems to be difficult for agricultural research to take variation in farmers into account (Van der Ploeg, 1999; Miele, 2001) and bounded rationality (Simon, 1977) as a starting point.

In conclusion, it is clear that the difference between the two views is the human factor. It can be concluded that, concerning the design of sustainable farm systems, the sociological view is more appropriate, because it better corresponds to reality and ascribes a central role to the farmer, who is the final designer and decision-maker in practice. His skills to create a basis for sustainable development (agency!) are fully acknowledged. It incorporates negotiation with society. It leaves room for assigning personal values to sustainability aspects. This does not mean that the biophysical-rational view is totally wrong or useless. It has contributed and will contribute to general knowledge about crop and animal production that can be referential input for the learning process in the sociological model. The biophysical-rational view is a model that can be used in science that tries to reveal processes, under laboratory conditions. The sociological view is a model that can be used in designing farm systems under real conditions. The two model views must be seen as complementary. Section 2.4 will come back to this topic.

2.3.4 Phase 2: heuristic problem solving

2.3.4.1 Simon's theory

The negotiation phase deals with the environment of the farm and results in several goals that can be interpreted as norms for the farm system. These goals are still not very structured, so a mathematical optimization algorithm could not calculate the optimal mix of means in order to reach the goal. In this respect, Simon (1997) speaks of *bounded rationality,* which means that (i) knowledge in a certain situation is incomplete and always fragmented, (ii) we cannot fully predict the consequences of certain choices, and (iii) for practical reasons we can only choose and explore one or a few alternative(s). Hence, problem solving is mostly characterized by a search. Simon (1996) says that:

> heuristic search is the principle engine for human problem solving…

and

> …the processes of problem solving are the familiar processes of noticing, searching, modifying the search directions on the basis of clues.

He compares problem solving with a search through a maze (see Fig. 2-4). Each node in a maze represents as a suboptimal solution and decision-making then means walking from one node to another. At each node, the decision maker has to ask himself: what action next?

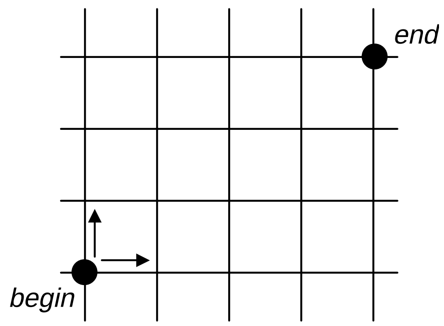


Fig. 2-4 Searching through a maze. There are many possibilities to walk from begin to end. What are the best ways?

Theoretically, there would be numerous pathways from one node to another node that lies somewhat further away. In practice, only a few pathways can be tried out. However, Simon argues that the search is never completely blind, but based on clues that enable the decision maker to prioritize between several choices and choose the most promising pathway(s). The clue is a metaphor for heuristics that are established by experience-based or experimental learning. Hence, a more experienced farmer may have more and better clues than an inexperienced colleague. Clues can also show the difference between more or less smart farmers. Furthermore, these clues can be farm- and farmer-specific and may not be transferable one-on-one to other farm systems. If it is possible, it is also better to try out several pathways at the same time like the saying says: 'don't put all your eggs in one basket'. Other, more promising ones can replace pathways that turn out to be less suitable. This indicates that there is no distinct beginning or end of the search and that one has to prioritize continuously.

Another important thing Simon has found by studying human problem solving is that in most cases a satisfactory solution marks the end of a pathway, but it is usually not the most optimal one. One reason is that it usually does not pay off to try to get the most out of such a situation. Another reason is that once a satisfactory solution is found, a better view is obtained on other promising pathways that can be explored. This can be compared with tasting wines: as soon a good wine has been found, a new horizon arises with new goals and one wants to search for better wines. It is related to the curious nature of human beings and also an ever-changing environment will induce this process.

Simon's method or tool for heuristic problem solving is *means-ends analysis*. This can be divided into an afferent and efferent part. The afferent part has a sensory nature and is oriented to the outer environment. It translates the problem into the difference between the present and desired state (see also Fig. 2-2). The efferent part consists of actions or transformation pathways that represent a change in the farm system. The efferent part consists a mechanism for selection that is subdivided into a 'table of connections' that connects the goals (or ends) with pathways (means) and a 'progress detector' that indicates to which degree a goal is reached. The next section will describe in more detail what activities are connected with means-ends analysis.

2.3.4.2 Problem solving activities

Simon (1977) distinguishes three phases in decision-making or problem solving:

- *intelligence* – finding the occasion where to start problem solving or to make a certain decision;
- *design* – inventing, developing and analyzing possible courses or pathways to solve the problem;
- *choice* – choosing between the most promising pathways.

He also emphasizes that in most cases you can distinguish 'wheels in wheels', which means that within one cycle of intelligence-design-choice one or more similar sub-cycles can be distinguished.
Usually, this design cycle is split up in more detail. Goewie et al. (1997) conclude that there is a striking agreement in such splitting up between authors from different fields. In Fig. 2-5, the general design or problem solving cycle is depicted.

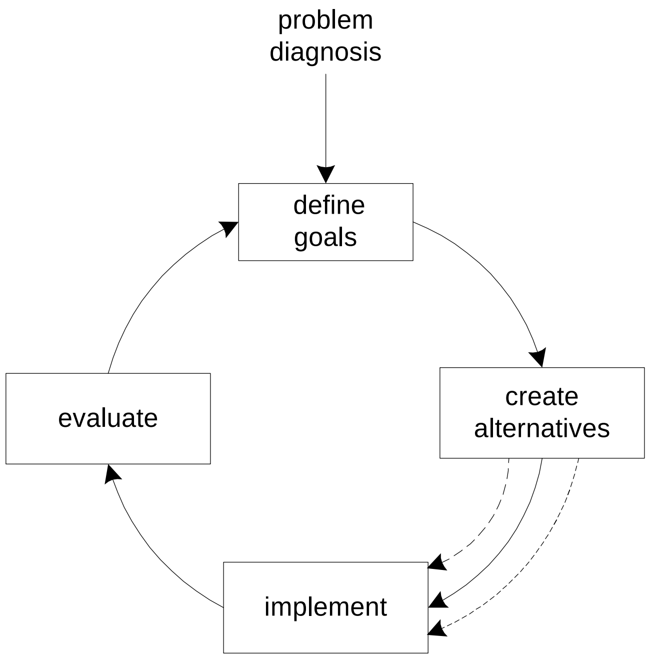


Fig. 2-5 The general design or problem solving cycle (based on Hall, 1962; Roozenburg and Eekels, 1991; Van Eijnatten, 1992; Rossing et al., 1997a; Vereijken, 1997; De Leeuw, 2000).

It is initialized by problem diagnosis that transforms a problem into a controllable management problem (De Leeuw, 2000) with goals that serve as performance indicators; this corresponds to Simon's intelligence phase. Next, several alternative pathways have to be designed and their consequences must be estimated. The designer, i.e. the farmer, can use models for this purpose, ranging from mental models based on experience and implicit knowledge to sophisticated computer models. Furthermore, he can use external knowledge like professional literature, study groups with colleagues and internal knowledge like historical data on past decisions (see Fig. 2-1). It is always better to implement more alternatives so that they can be compared with each other. However, in some cases it is only possible to implement just one alternative. The different alternatives are evaluated with regard to the defined goals. If goals are not met sufficiently, the designer has to go through the cycle again and define different alternatives. If goals are met to a certain degree, the most promising alternatives can be continued and perhaps other ones can replace some worse alternatives. When results are satisfying with regard to the goals, new goals can be defined or existing goals can be altered.

In conclusion, the design cycle is an iterative and continuous cycle aiming at better achievement of goals in order to solve problems. Learning-by-doing can be regarded as continuously going through the design cycle. In this way, the farmer gains more experience, resulting in improved heuristics that are specific for his farm system. Goals and problems become more structured although it is utopian to think that all goals and problems will finally become structured, because the environment changes continuously and goals are changing accordingly. However, that part that has become structured should be implemented in daily management. This is done in the third phase: operational control.

2.3.5 Phase 3: operational control

Operational control is defined as daily routines that are the result of the previous phases of negotiation and heuristic problem solving. This is a process of habituation; good practices must be incorporated into daily management. Operations are demarcated tasks that are part of primary processes. A primary process is a basic process that transforms input into output. Primary processes in a farm system are for example milk production, potato production or grassland production. Operations in a farm system are for example milking, sowing or plowing. Primary processes and operations will be further discussed in Chapter 4.

The term ‘routine’ indicates that operational control concerns structured tasks: goals are clear, information requirement is clear and it is clear what should be done under different conditions. These kinds of tasks can be typically included in handbooks. Farm handbooks do exist already in most countries, but these are rather general. From the previous sections, it can be concluded that more farm-specific handbooks are needed. In industry, customized handbooks are usually used in large organizations with many employees. This makes it easier for new or temporary employees to know how to operate and it assures consistency throughout the whole organization. A farm system usually consists of only one farmer and sometimes a few temporary workers so a formalized handbook does not seem to be

necessary. Once a farmer has learned something (by heuristic problem solving), he will not forget it easily (Vijverberg, 1996). However, it is also true that quite some decision situations (e.g. sowing or yielding) return only once a year (Zachariasse, 1974). Besides, sustainability is such a complex, multi-faceted subject, that the farmer's memory will soon be insufficient and therefore we also plead for a formal handbook in a farm system. A handbook is also in line with the current trend of obligatory registration of farming practices by means of certification (see e.g. Eurep/gap agreement, www.eurep.org).
Obviously, the handbook should be part of the information system in Fig. 2-1.

So far a methodology was described that can be used to incorporate sustainability into the whole decision-making process of farm management. Vision, intentions and values are translated to and implemented in daily management. The methodology does not prescribe how sustainability, in terms of predefined goals and means, should be translated and implemented in the farm system. Rather, this process is regarded as a design process that should be carried out by the farmer himself. The methodology provides a framework that helps to optimize this design process, which means that the farmer is enabled to improve his decision-making continuously. The three-phase-methodology is summarized in Mind Map 4 in Appendix VI. The next section describes the broader context of this design process.

2.4 Designing sustainable farm systems – an integrative approach

Fig. 2-6 describes the context of designing sustainable farming systems. The design cycle of the farmer in practice, as depicted in Fig. 2-5, is regarded as the most important starting point: he designs his own local-specific farm system according to his vision, intentions and values that are set and developed by a negotiation process. However, it was mentioned that in the heuristic problem solving phase, the farmer has a need for external knowledge. This knowledge can be provided by applied agricultural science that usually obtains it by experimental research, which is different from design-oriented research. In Table 2-1, a comparison is made between experimental and design-oriented research. An important conclusion that can be drawn from this comparison is that they are each other's counterparts. Experimental research produces knowledge that can serve as input in design-oriented research. The objective of design-oriented research is that it helps to solve practical problems. The objective of experimental research is to obtain statistically valid knowledge about phenomena in reality. Fig. 2-6 indicates that the design cycle also produces knowledge, namely practical theories. Practical theories have been obtained by heuristic problem solving. They are not statistically valid, but the farmer knows by experience that they work. It is suggested that these practical theories should be used as input for applied sciences. This could result in knowledge that better corresponds to practice. Van der Ploeg (1999) says that it should be even more of a challenge to, specifically, look at those practical theories that contradict with existing scientific knowledge.

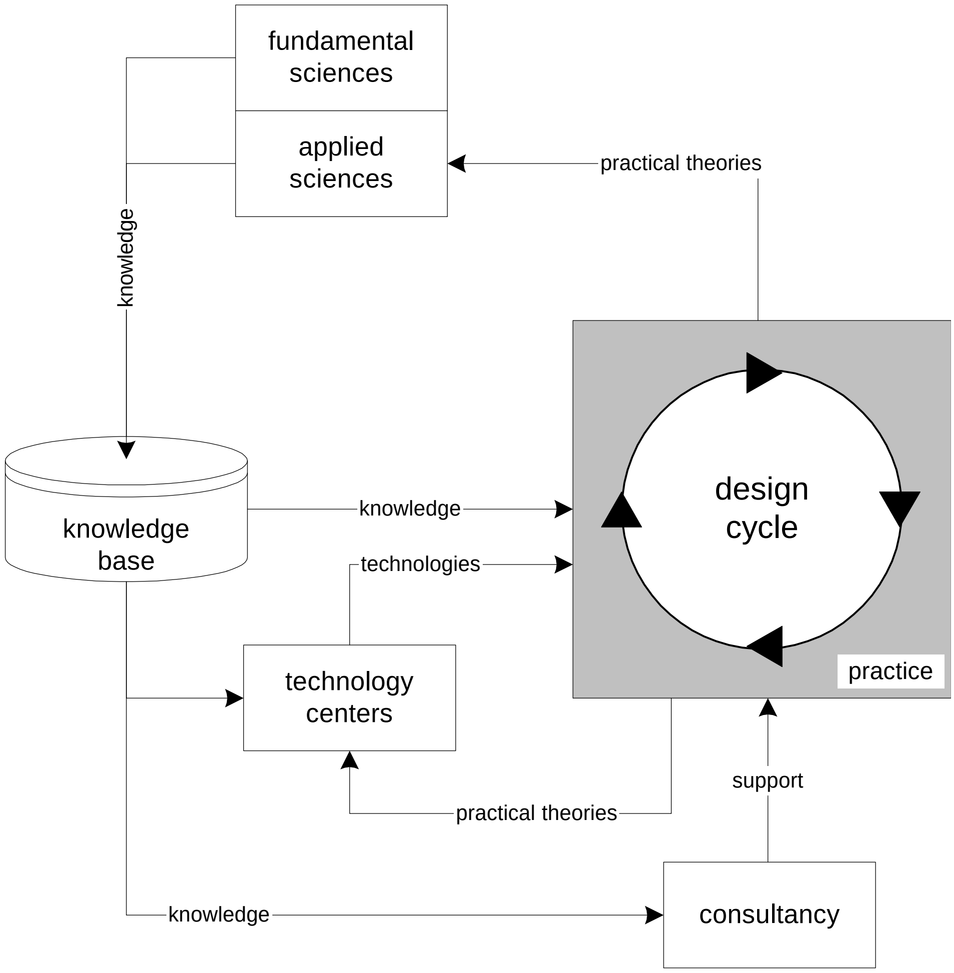


Fig. 2-6 The context of designing sustainable farming systems (after Van Eijnatten, 1992).

Beside knowledge, the designing farmer will also have a need for technologies that can be provided by technology centers. Technology centers can be institutes or firms that use knowledge that is provided by science, beside knowledge developed on their own. It is indicated that these technologies also should be developed in close co-operation with the practical design cycle of the farmer so that they match with the actual needs of the farmer.

It is emphasized that the farmer himself should be the main designer of his own farm. However, we also concluded that sustainability is a complex subject that involves much information. In that case, it might be useful that a consultant supports the farmer’s design process. This might be even more useful when the information system (see Fig. 2-1) consists of sophisticated software that requires certain advanced skills to use. Consultants could specialize themselves in these skills so that the farmer can concentrate on his primary design process. A main prerequisite is that the process remains transparent.

Table 2-1 A comparison between experimental and design-oriented research (after Goewie et al., 1997).

	SETUP/REPORT OF EXPERIMENTAL RESEARCH	SETUP/REPORT OF DESIGN-ORIENTED RESEARCH
1.	**Introduction (problem of research)** From literature research a demarcation is made to a suitable research question. Explaining observations is being emphasized.	**Introduction (problem of design)** There is nothing that needs to be clarified, but something needs to be changed. Knowledge is supporting this objective and not vice versa.
2.	**Research question (problem within research)** By literature research it is determined what hypotheses/theories are already put.	**Practical problem** Facts in daily reality do not correspond to certain social values and objectives; it is tried to bridge the gap. Examples: environmental policy, nature conservation, public health, farm economy
3.	**Hypothesis (assumed relationships within the problem)** By literature research it is investigated what methods and techniques are described or can be invented in order to test the hypothesis. (The assumed way is: observation ⇒ induction ⇒ deduction.)	**Technique proposal** This can be equipment, receipts, production mode or extension system that brings ideal and reality together. By experience and literature research it is tried to find previous attempts that can be further elaborated. (The assumed way is: analysis ⇒ synthesis ⇒ simulation.)
4.	**Material and methods** An experiment is conducted	**Material, methods and models** A model is constructed
5.	**Results** The experiment results are evaluated against the background of the hypothesis.	**Results** Deductions, based on that model are made. The result is a conditional prediction. The result concerns the behavior of the design in practice.
6.	**Discussion** Quality assessment, strengths and weaknesses of the findings.	**Discussion** It is evaluated under which conditions what scenario satisfies best in practice.
7.	**Conclusion** Knowledge is obtained in order to clarify some phenomenon; laws in nature are revealed.	**Decision** If the design really works, it can be further developed for use in practice. If not, you have a intermediate design that has to go through a new design cycle.

Fig. 2-6 does not provide a complete picture. As mentioned in Section 2.3.1, the farm system is embedded in a whole socio-technical network in which several other components and links can be distinguished. Fig. 2-6 highlights the technical aspect of designing. In common practice, the components and interactions will function like was described. In some cases, when the farmer has to deal with really complex problems, a project can be defined in which there is a close cooperation between one or more farmers, scientific researchers, technology centers, consultants and other partners. That is what is usually referred to as participatory or action research. If a negotiation phase is involved in such a project, it is emphasized that not only technical, but also social actors like consumer organizations, environmental or ethical associations should be involved.

2.5 Summary

Agriculture is in crisis. This manifests itself in the collision between agriculture and society. The crisis is related to the human attitude towards nature and the assessment of values and norms. Hence, a solution is searched for how a farmer can be enabled to express vision, intentions and values in an equally important way as hard economic goals in decision-making. Therefore, he should learn how to make them explicit, keep in touch with them and link them with farm results. Sustainability is generally regarded as an integrative approach to solve problems in agriculture. Because it has several dimensions, it is a complex and dynamic concept. To be sustainable, it is necessary to maintain an adaptive capacity in order to be able to respond to an ever-changing environment. Adaptive management that is directed to diversity and self-regulation can reach this. The response is not deterministic; the farmer, as a human factor, influences this response. Sustainability is an emergent property that is established by an interactive design process between the farmer and his environment. Hence, the farm system, in which the farmer plays a central role, is obviously an important starting point for sustainability.

Many sustainability approaches do not take the farmer and his skills into account. Approaches that do so, often exhibit a static and deterministic view on the farm system and its environment or only a few aspects of farming (e.g. biomass production) are taken into account. Social science may compensate for this in emphasizing the soft aspect, i.e. the human factor, of a farm system and recognizing the multifaceted, dynamic situation with which a farmer is faced in reality. However, social science does not really provide a way to manage this. Hence, management literature was consulted and the management control paradigm of the De Leeuw, as represented in Fig. 2-1, is taken as a starting point. Management control is presented as a way of problem solving in which a goals-means hierarchy has to be set. At many points, the farmer has to attach values to goals and means, indicating the relation to attitudes. Furthermore, it is explained that problem solving is aiming at converting an unstructured problem into a structured one. This is a heuristic, step-by-step, but goal-oriented process.

Synthesizing the results from these different fields, a methodology is developed that can be used to incorporate vision, intentions and values into everyday decision-making of a farmer. The methodology is presented as an iterative design process in which three phases can be distinguished: (i) negotiation, (ii) heuristic problem solving and (iii) operational control. In the negotiation phase, the farmer is communicating with his environment to make his vision, intentions and values explicit. From this phase several norms are derived that can be regarded as semi-structured problems. In the second phase, heuristic problem solving, the farmer is trying to make these problems more structured. This phase is one of searching and learning in which results are linked with the norms that were set. In this way, the farmer is improving his skills. The third phase, called operational control, is aiming at habituation of what was learned from the previous phase. It is a good idea to put these ‘habits’ in a kind of handbook, which makes the whole process auditable. This is in line with the current trend of certification.

The design process by the farmer for his local-specific farm system should be the basis for designing sustainable farm systems. However, he is also operating in a socio-technical network. He is supported by scientific knowledge, technologies and advisory services. These should correspond to the specific needs of the farmer that are outcome of the design process. Hence, agricultural research should not only focus on optimizing the farm system itself, but on optimizing the design process.

Thus, a solution is found that can help to overcome the crisis in agriculture. The solution is searched for through a methodology for farm management that makes it socially compatible and thus sustainable. The methodology is an integration of natural, social and management sciences (beta-gamma interaction).

2.6 Implications for modeling

The idea behind the objective of this thesis is that a computer information system provides significant support in designing sustainable farm systems. Before an information system can be built, an information model has to be developed. The theory described in this chapter implicitly provides the general requirements for such an information model. In this section these requirements will be made more explicit. It deals mainly with the general structure of the model. In Chapter 4, where actual modeling takes place, more detailed specifications are listed.

From the theory described, it can be concluded that the model should combine management control, a sociological view of the farm system (emphasizing communication and soft aspects) and heuristic problem solving. In other words, a combination must be made of Fig. 2-1, Fig. 2-2, Fig. 2-3 and Fig. 2-5. This is done in Fig. 2-7, where details of the previous figures are left out. The two gray blocks *environment* and *production system* indicate the system components that exist in reality. The parallelograms indicate a process or action in which the farmer is actively involved, but each time playing a different role. In fact, they represent the three phases as described before. All other components represent a model, a perception of reality. Arrows that do not contain text explicitly can be read as *'is derived from'*.

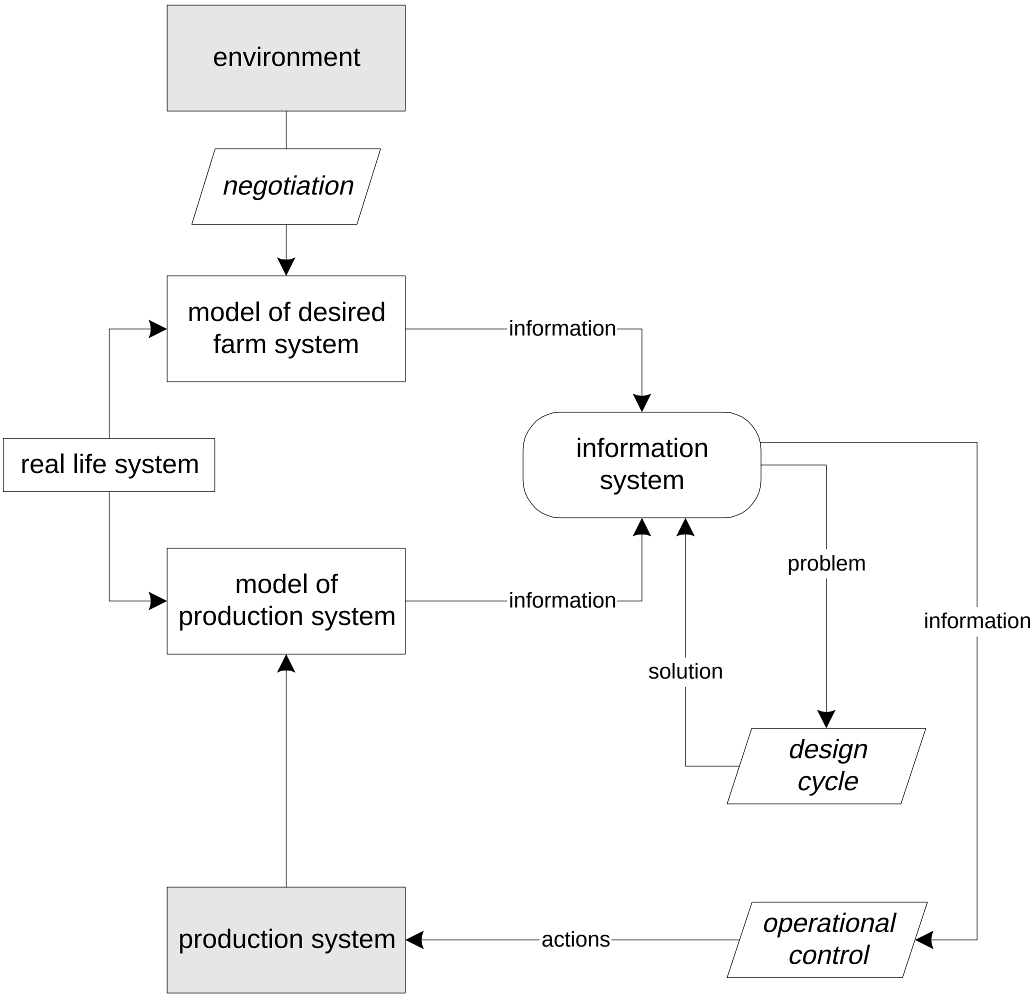


Fig. 2-7 General structure of requirements for the model to be built.

A model of the desired farm system is derived from negotiation with the environment in combination with the farmer's real life system. This model should consist of a goal-means-hierarchy, in which unstructured goals become more structured. The model should provide a sufficient degree of flexibility, so that goals and means can easily be changed. Furthermore, it should represent the hierarchy in a transparent way, so that visions, intentions and values of the farmer are made explicit.

A model of the production system is derived from the production system in reality and also the farmer's real life system. It should provide sufficient points of application for the goals and means that are defined in the model of the desired farm system.

The model of the production system should also provide actual data of the production system. This information is stored in the information system. Combining this information with information on goal values, derived from the model of the desired farm system, discrepancies or problems can be detected. Thus, a main function of the information system is to provide a framework to make the *table of connections* between goals and means and a *progress detector* in order to see to what degree goals are reached.

The problem that is diagnosed forms the input for the design cycle. From the design cycle, solutions are derived. These solutions make up the input for the information system in two different ways. First, solutions can mean an extension of the table of connections: more elements of the production system are involved in reaching a certain goal than was initially thought. Secondly, solutions can contain instructions for operational management, which should be stored in the information systems in the format of a handbook. This information is transformed into actual actions by operational control. In this way, the production system is managed and by monitoring, progress can be detected and this closes the circle.

It would also be possible to incorporate information of the design cycle itself in the information system. For example, what experiments are carried out, what are the results, etc. Although this can be very interesting, it falls outside the scope of this thesis.

In conclusion, two models should be developed: a model of the desired system and a model of the production system. These should be further combined in an information system. The whole should be supportive to designing sustainable farm systems.

3 Production Ecology or Ecological Production?

Zo nam de HEERE God den mens, en zette hem in den hof van Eden, om dien te bouwen, en dien te bewaren.

Genesis 2 verse 15[1]

Abstract

This chapter focuses on the present discussion about the (dis)advantages of integrated and ecological farming. Which are the characteristics involved and what about the related needs of the manager? Production ecology as a unifying concept behind mainstream and integrated agriculture is discussed at first. The conclusion is that that concept is oriented towards input-efficiency. Environment and nature are balancing items in that concept. The ‘matter-input-output-relationship’ dominates all priorities in decision-making, farm management and research or extension agendas. The other concept, ecological production, gives priority to the environment or nature and considers farm economy as balancing item. That does not mean that ecological farming is not profitable, on the contrary. It is concluded that profitability of ecological production is in ecologization of farm economy. Sustainable development of ecological farming systems is in management of the cyclic farm-bound processes. Sustainable farming is in creating preventive management and in caring for cyclic processes among farm-bound natural resources. This form of management considers the farm production system as a logistic chain of products, which is also the main requirement for modeling. It is concluded that ecological farming is better for encountering the demands concerning sustainable agriculture. Due to its controlled experimental basis, production ecology is suitable for deepening our understanding about crops and related improvement of yields without increased burdening of environment and nature. In that concept however, farmers stay dependent from externalities such as synthetic chemicals, extension, research institutes and Governments very much. That does not improve farmers’ skills in management and awareness about societal needs.

Keywords: production ecology; ecological production; recycling management; preventive management; self-regulation; sustainability

[1] From the Dutch translation ‘Statenvertaling’ of the Bible. The English translation in the King James version says: “And the LORD God took the man, and put him into the garden of Eden to dress it and to keep it.”.

3.1 Introduction

Chapter 2 described the process of designing a sustainable farm system. Sustainability was mainly defined as establishing and maintaining adaptive capacity in order to respond adequately to the complex and dynamic environment. Basically, this is applicable to all kinds of farming. Ultimately, it manifests itself in the way the farmer is controlling his production system. However, the production system must be able to follow the adaptation process within boundaries of sustainability. So, a farmer could use fast-acting instruments like chemical fertilizers or pesticides to respond quickly, but this conflicts with the ecological and social aspects of sustainability. Hence, a farmer should invest in more long-term measures. These will finally be reflected in certain properties of the production system, particularly in the soil (Droogers and Bouma, 1997; Sonneveld et al., in press). Thus, the production system could be considered as an emergent property from the interaction between the ecosystem and farmer's control. The question is what type of farming practice would be appropriate for achieving the desired production system?

In practice, there are two forms of farming that aim at sustainability: integrated and ecological farming. In integrated farming, the ratio between input and output should tend to one (De Koeijer, 2002). In ecological farming, output minus input should tend to be equal to zero (Lampkin, 1990). Both approaches want to prevent burdening of production surroundings, but the decision-making involved differs. In integrated farming, management tries to improve efficiency of input application at farm system level. The more the farmer can produce, the better the efficiency per unit of applied artificial input. The best efficiency exists when the farmer could remove all artificial input through his harvest, leaving the production site almost untouched. Then, the farm system, in particular the soil, is considered to be nothing more than a substrate. Management of ecological farming takes place under the condition that output must be obtained by replacing artificial input by natural, farm-bound input. Artificial external input must be prevented as much as possible. Then the farm system, in particular the soil, is a production factor by itself. In other words, integrated farm management opts for increasing production by optimization of the input/output ratio. Ecological farm management opts for increasing farm profitability by optimizing farm decision-making (Goewie, 2002). The latter is close to the notion of designing sustainable farm systems as described in Chapter 2.

Hence, this chapter will focus on ecological farming as actual object of further study. For a deep understanding of the principles involved in ecological farming, the focus will first be on the aforementioned input/output discussion, taking production ecology as the concept for mainstream farming (Section 3.2). Section 3.3 will describe a concept for ecological production and focus on management principles that are inherent to this type of production. Finally, in Section 3.5, the implications for modeling will be described.

3.2 Production ecology – the concept in integrated agricultural production

In this section, the concept in integrated agricultural production is discussed. For this discussion, the unifying concept of production ecology, which is described in several papers (see e.g. Rabbinge, 1993; Van Ittersum and Rabbinge, 1997), is used as a framework. These papers mention that it is primarily applicable to crop production, but an analogous concept can be described for animal production as well. First, the concept will be described and then its implications for practice will be discussed.

3.2.1 Production ecology[1]

The production ecology concept is diagrammed in Fig. 3-1. The horizontal axis indicates the hypothetical level of production in biomass per unit of area. On the vertical axis three production conditions are distinguished that determine a certain yield level, ranging from actual yield level to potential yield level. These yield levels are determined by three groups of factors.

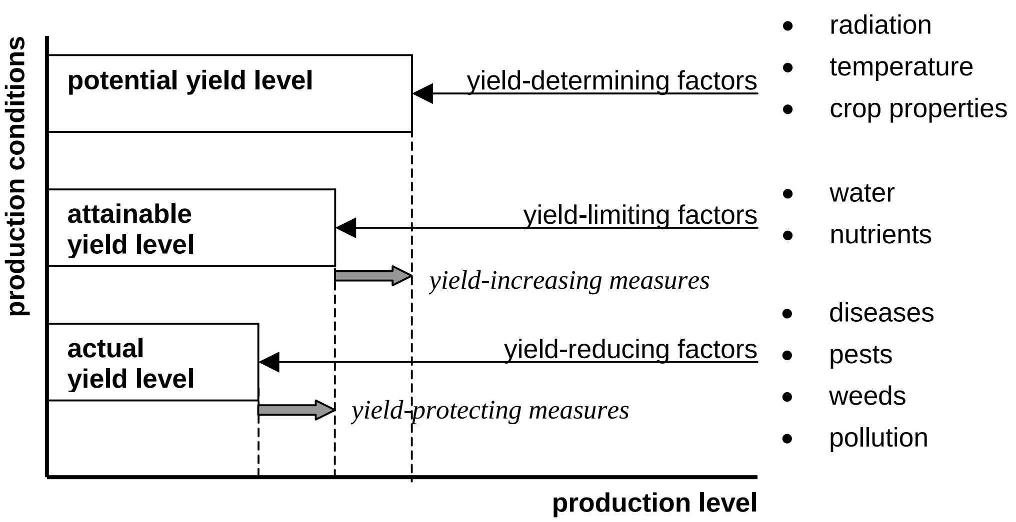


Fig. 3-1 A schematic representation of how the production ecology concept looks at agricultural production. The horizontal axis indicates the physical production level. The vertical axis indicates three production conditions that are accompanied by a certain production level. Production ecology focuses on bridging the yield gaps towards potential production. The actual yield level is a resultant of opposite forces: yield-limiting factors versus yield-increasing measures and yield-reducing factors versus yield-protecting measures. Further explanation in text.

[1] The text for the description of this concept is largely taken from the 5-year report (1995-1999) of the C.T. de Wit Graduate School for Production Ecology (Kropff et al., 2000)

3.2.1.1 Yield-determining factors

Yield-determining factors determine the potential yield level, which is realized when crops grow with ample supply of water and nutrients. Yield-determining factors include site-specific environmental variables such as light and temperature determined by meteorological conditions, which depend on location and day of the year, and species-specific characteristics concerning physiology, phenology and geometry of leaves and roots. Situations where potential growth rates are reached are rare (sometimes in greenhouses or irrigated systems). However, understanding of these principles forms the basis for understanding plant production systems.

3.2.1.2 Yield-limiting factors

Yield-limiting factors comprise abiotic resources such as water and nutrients, which limit the growth rate of the crop to a value below the maximum at which their supply is suboptimal. The associated yield level is called attainable yield. Management of yield-limiting factors focuses on optimal fertilization practices. These are studied in close association with natural and man-made water regimes in soils, which can be strongly influenced by management practices.

3.2.1.3 Yield-reducing factors

Yield-reducing factors reduce the attainable to actual growth. Reducing factors are both biotic (plant pests and diseases, weeds) as well as abiotic (pollution). Management of yield-reducing factors aims at dealing with pests, diseases and weeds, emphasizing integrated pest management practices based on biological control mechanisms.

In conclusion, the production ecology concept is focused on bridging the yield gaps between actual, attainable and potential yield in order to increase production. With respect to this objective, it has been very successful. Not that it has been directly used by farmers, but indirectly it has had a significant influence on farming practice by technologies and the whole network of agribusiness, institutions and policy, referred to as the ‘expert system’ by Van der Ploeg (1999). Obviously, this concept corresponds to the biophysical-rational view on the farm system, described in Chapter 2, of which it was concluded that it was not very suitable for designing sustainable farm systems. Hence, the question is whether an on-going influence of this expert system on farm practice will be sustainable by looking at the compatibility with the ecological and social environment and what the consequences are for farm management and agricultural research.

3.2.2 *Ecological implications*

The potential yield level is a theoretical concept. In reality, aiming at this level leads to overburdening of the local ecosystem (Almekinders et al., 1995). In ecological sense, the potential yield level is not only determined by meteorological conditions and crop characteristics, but also by location-specific physical and biological conditions of the soil and natural surroundings (Altieri, 1999; Hobbs and Morton, 1999; Neher, 1999).

The production ecology concept is highly ‘matter’-oriented with reference to the yield of functional biomass (e.g. potatoes, milk, grass, etc.). In practice, the yield-increasing and -protecting measures have also been very matter-oriented, expressed by the intensive use of input like fertilizers and pesticides (Almekinders et al., 1995). So, this combination has led to an emphasis on matter-input/matter-output-relations that are also easy to quantify, standardize, control and optimize. However, in ecosystems, matter and processes are each other’s counterpart. Cyclic processes make that matter and energy flow through the ecosystem. These processes are dynamic and are constituted by a concatenation of organisms, organized in food webs (Neher, 1999; Smeding, 2001). For example, animal manure is decomposed by several organisms, above and underground, into several other material particles like nitrogenous components. Crops, which serve as feed for the cows, take up these components. Cows produce manure and that closes the cycle. It is reasonable to assume that organisms that play a role in this cycle also play a role in other ones. It is also reasonable to assume that when these processes are not recognized explicitly, many organisms disappear so that biodiversity, in the meaning of functional food webs, is reduced (Hobbs and Morton, 1999; Lefroy et al., 1999; Neher, 1999). This reduces the ability to react to changes in the environment (e.g. sudden appearance of pests) and thus sustainability decreases (Altieri, 1999; Neher, 1999).

One solution to overcome pests is searched for in applying chemical pesticides to protect the crop (crop protection measures). These pesticides in their turn will kill other organisms so that the self-buffering capacity of the ecosystem will decrease further (Altieri, 1999). For efficient application, a homogeneous environment, which can be reached for example by deep and intensive soil tillage, is favorable. This further degrades diversity (Altieri, 1995; Pretty and Shah, 1997). Another solution that is searched for in the crop itself is by applying genetic engineering so that the crop is able to resist diseases.

An indirect consequence of high input is that much (fossil) energy is used to develop and produce it. The effect is that one of the most positive features of agriculture, namely transforming solar energy into energy that is contained by food and raw materials, starts to change into the opposite, namely that fossil energy (that originates from plant material) is transformed into food and raw material (Van der Werff, 1993; Hobbs and Morton, 1999; Neher, 1999). This is definitely not a sustainable development.

In conclusion, a matter-oriented agricultural production tends to become increasingly dependent on external input. Application of this input homogenizes the natural ecosystem and reduces biodiversity in the form of functional food webs. Overdoses of pesticides and intensive soil tillage destroy natural buffers and regulating processes so that the self-regulation of the ecosystem is further decreased. Crop management becomes a rat race in which the battle is gradually fought out at a lower integration level till the level of DNA is reached. This partly explains the current interest for the field of genomics. At the molecular level there is no basic difference between a cow, a wheat plant or a wooden fence. In other words, the relation with the environment, i.e. the higher integration levels, is lost increasingly. Interference at the molecular level may solve a very specific problem, but the effect on the environment is unknown. It is risky when in a sterile laboratory natural mechanisms like fertilization are evaded, because in an open environment these kinds of results would naturally be inhibited by environmental feedback mechanisms.

3.2.3 Social implications

In the previous section, it was argued that matter-oriented agriculture leads to degradation of the soil and the whole ecosystem. Beside that this is not desirable from an ecological point of view, this also conflicts with what is desirable in society. A natural landscape, which is typically defined at a higher integration level, does not fit into the production ecology concept either. In practice, it means that agricultural and natural landscape elements are increasingly segregated (Van Mansvelt and Mulder, 1993; Almekinders et al., 1995). In countries like the Netherlands, with a high population density, this development is also not desirable, because people are confronted with agriculture without an attractive landscape, as soon as they step out of their door.

Another aspect, which is related to consumers, is food quality. Quality and quantity is often each other’s counterpart like if they were in communicating vessels. Too much emphasis on quantity goes at the expense of quality and *vice versa*. Production ecology focuses on bridging the gaps from actual to potential production and thus on quantity. In practice, this has indeed led to a production increase and to a commodity-oriented agriculture, with increasingly less attention paid to quality. One important consequence is that products become less tasty and structured, because they are grown in a relatively short time period with ample availability of water and nutrients. Usually, these products become also more susceptible to pathogens that have to be eliminated by applying pesticides. And that is another issue consumers are increasingly concerned about.

The focus on production also carries a self-conflicting mechanism in itself, often referred to as the *treadmill*. A farmer can only gain more profit by producing more quantity or by reducing costs. In practice, this has led to over-saturated markets that reduce prices again so that more quantity is needed to earn a reasonable income. Cost reduction or efficiency increase has led to a cost shift to the environment, living animals or perhaps other systems in developing countries (Schiere, 1995); issues that are also increasingly subject to public concern.

The treadmill mechanism unavoidably also leads to increasingly bigger farms with less workers (Van Mansvelt and Mulder, 1993; Van der Ploeg, 1999). This implies that labor at a farm often becomes boring and unattractive. The distance between the farmer and his land and animals becomes larger. It will also have an impact on rural communities that tend to disintegrate.

In conclusion, there are several negative linkages, or disconnections, between production ecology and society. A solution must be searched for in a closer contact between farms and society that is constituted by citizens and consumers. Beforehand, it is not always clear what society wants and what is feasible for farmers. Therefore, a negotiation process, as described in Chapter 2, characterizes this contact.

3.2.4 Implications for farm management

Production ecology is very much a disciplinary concept. In disciplinary research, all system-disturbing factors are excluded by reducing the research question. But that is not farmer's reality. He faces many production-disturbing factors at the same time. So, evidence-based prescriptions by extension seldom match farmer's production conditions.

Concerning the potential yield, political and social factors and market regulations often determine the potential yield more than climatic factors. A good example of this is the agricultural policy of the European Union. In order to reduce Europe's subsidies for agriculture, production quota were launched legally as inhibitors of unlimited production intensification. The set-aside law even rewards farmers for doing nothing with their land. Hence, from a farmer's perspective, potential yield level is not very interesting to know or to strive for.

Concerning the attainable yield, environmental norms (on e.g. nitrate leaching) are also determining this level. Hence, it does not make much sense to calculate for example the nutrient application for potential crop growth if at the same time the maximum level for nitrate leaching is exceeded.

In practice, the concept of growth-reducing factors that determine the actual yield level has mainly led to short-term yield-protecting measures, namely killing of actual damaging organisms. This can have a large effect on food webs and biodiversity. Besides, it restrains a farmer to develop a vision to invest in preventive, long-term measures. The farmer is taught in how to smooth diversities inside his production system (Almekinders et al., 1995). Monoculture (even at the genetic level), conditioning of soil characteristics and eradication of food webs help to bring the farm into the same condition as the experimental production sites, where the preferred output-input ratio occurred. Making the farm more alike a laboratory, farmer's production costs increase, resulting in less profitable farm economy.

3.2.4.1 Management control

The production ecology concept leads to a form of agriculture in which everything is happening within one season and at each new season the farmer starts again in the same starting position. Long-term processes and development are hardly taken into account. In practice, this is translated into deep soil tillage and preventive killing of potential damaging organisms before sowing. In this way, the soil is considered to be a substrate. In other words, it is strived for to make agriculture as independent as possible from the ecosystem. The natural ecosystem has become the final balancing item on the budget. However, nature always tends to strike back and thus it is a very risk-seeking strategy. As agriculture tends to reduce diversity, nature exhibits counter forces directed towards diversity. In this regard, the agroecosystem in production ecology could be compared with a pioneer ecosystem (Odum, 1971).

Human control of such an agroecosystem is very intensive. Measures rely heavily on material input and technology and less on self-regulation of the system, resulting in a more and more unstable system. This process can be compared with a juggler that has to keep more and more balls in the air (Goewie, 1993). Measures are based on predictions about the behavior of the agroecosystem that were derived from experiments under controlled conditions. This results in standard advices that hold for each farm system, but it completely ignores the complexity of the system in reality (Hobbs and Morton, 1999). The calculations are only based on physical-chemical and sometimes bio-chemical parameters of the agroecosystem, but this is a very reduced view on the agroecosystem; biological, ecological and social factors are not included (Van der Werff, 1991).

Besides, there is hardly any room left for the craftsmanship of the farmer. This has also reduced the labor quality on farms. Many farmers, in particular arable farmers, admit that the work on the farm sometimes becomes rather boring: in a certain region, every farmer does the same thing at the same time in the same way. Standard rules tell the farmer when and how much he has to fertilize, spray, etc. This explains that one of the main motivations of farmers that shifted from conventional to organic agriculture, is that they feel themselves continuously challenged and have rediscovered the joy in their work.

In conclusion, a concept like production ecology lacks possibilities to develop control methods at a higher integration level. Instead of that, the agroecosystem is represented in a simplified way and control methods are based on singular, linear, cause-effect relations.

3.2.4.2 External dependency

It was concluded that more and more sophisticated and expensive technologies are needed to bridge the yield gaps and fight against disturbing forces. As a consequence, the farmer will become increasingly dependent on external input. There is a risk that he becomes, aware or unaware, a kind of operations manager of multinationals (which are the only ones that can invest in these expensive technologies) that often totally control the farm supply markets and in many cases also the sales markets. In practice, it becomes obvious that the farmer is squeezed in the production chain from supplier to consumer. He faces ever-increasing costs and lower prices (the treadmill), while at the same time he is held responsible for all negative effects on the environment that are mainly caused by high external inputs. This causes another dependency the farmer is faced with: the government that has to develop a whole arsenal of regulations.

Heavy use of inputs has led to unavoidable losses to the open environment. In the first place there are concerns about synthetic chemicals that by nature do not occur in ecosystems. It is difficult and expensive to make assessments of the effect of these chemicals on the environment. Secondly, in practice, bridging the gap to the attainable yield has led to overdoses of fertilizers (Almekinders et al., 1995). Especially nitrate leaching to the ground and surface water and volatilization of ammonia to the air is a main problem. Steadily, this leads to a huge and complex system of regulations for farm systems. Beside environmental rules, this system was lately extended with regulations on animal welfare, food security and genetically modified organisms. Such a regulation system is expensive to maintain and control. For that reason, the government has in some cases decided to prescribe generic regulations that force the farmer to work in a specific way (e.g. manure injection, mineral accounting systems). This hampers innovation of farmers to develop their own, perhaps better, methods to solve problems.

Farmers have adapted their farms to these external dependencies and sometimes invested a lot of money for this reason. Farmers have little or no grip on these external forces. In practice, this has turned out to be very risky, because farm systems have become rather inflexible and get stuck as soon as the external system changes, for example when certain pesticides become forbidden. And because agriculture is in crisis (see Chapter 2), it is very likely that this external system will change under pressure of society. This process has already started.

3.2.5 Implications for agricultural research

3.2.5.1 The food myth: in name of the increasing world population

After Second World War, the need for self-sufficiency in Western Europe was the legitimate reason to increase agricultural production. Nowadays, self-sufficiency is not a reason anymore. Still it is generally believed that agricultural production should be increased because of the increasing world population. However, this view implies that the world is regarded as one big nation with a global government or a kind of regulating institute that can establish self-sufficiency at a global level and that takes care of an even distribution of food. This is of course far from reality. It was already concluded that production increase is not a valid option for West-European farmers, because they face all kinds of social, economic and ecological constraints. Production increase is of course a relevant option for that countries or regions, which did not yet reach a level of self-sufficiency. An attempt was made in the so-called Green Revolution, which was constituted by the production ecology concept. This has mainly resulted in high-input agriculture, which meant that the countries concerned became dependent on Western technology and capital. Actually, in many cases the production was, and is, still in the hands of Western companies. From a political point of view, this is not a very sustainable situation. Besides, there are numerous examples of this approach that turned out to be not quite sustainable from an ecological point of view, because it resulted in environmental pollution or erosion (Conway and Barbier, 1990; Pretty and Shah, 1997). Hence, it can be concluded that agricultural development should take place in a more local context and in a more sustainable way.

Another argument that could be used to focus on production increase is that agricultural production can take place on an increasingly smaller piece of land. This will however lead and has already led to a type of factory farming. It was already concluded that this would usually coincide with heavy environmental loads. Besides, current discussions indicate that this way of farming is undesired by society.

3.2.5.2 Best farming practice?

The scientific, technological driven production ecology concept works according to the bio-physical-rational view of the farm system (see Chapter 2): the farmer and his management, or better said, his craftsmanship, is hardly taken into account (Stomph et al., 1994; Schiere, 1995). He is assumed to work according to the ‘best technological means’ or the ‘best farming practice’. This implies that there should exist only one best type of farm. However, this is not in line with the empirical variation between farms and styles of farming that is found in reality (Van der Ploeg, 1999). The conclusion could be drawn from this that either most farmers are mismanagers (Pretty and Shah, 1997) or that this idea is totally wrong. Variation of the environment, in social, economic and ecological sense, causes several different niches that also change in time. So, it cannot so easily be concluded that one farm or farmer is better than another, because they may both operate within a different niche. Besides, because of the changing environment, the best farmer of today can be the worst of tomorrow.

The early British writer Googe (cited by Schiere (1995) already said:

> Farmers cannot thrive by manure (and machinery) alone. On the contrary (...) the best doung for ground is the Maister’s foot, and the best provender for the house is the Maister’s eye.

which indicates the importance of craftsmanship. It is also true that the use of a certain method or technology gives better results as the farmer has learned how to work with it (Röling, 1994a; Sevilla Guzmán, 1994; De Koeijer et al., 1999). So, science and technology are not useless, but they have to be incorporated in an appropriate way into a specific type farm system and a specific type of farm management. Then the results can be different, but it is not warranted to say that one result is always better than the other, because it depends on the environment and also on the specific values that a farmer attaches to these results (see also Chapter 2).

In conclusion, the production ecology concept gives rise to the wrong impression that there would be one best farming practice. Besides, no attention is paid to a farmer's skills.

3.2.5.3 Research method

Research within the concept of production ecology is largely based on experimental research that has increasingly moved to a lower biophysical integration level. Expectations from research fields like genetic engineering, molecular biology and nanotechnology are high. This kind of research is based on observations of measurable properties of an organism or entity. Explaining the behavior of this organism or entity from these observations is attempted. In other words, the whole is explained from the parts. However, this will lead to a half or reduced view of reality (Van der Wal, 1997). The German philosopher Kant already said (author's translation from German[1]):

> Only those things we can make ourselves, we can understand completely.

This also explains the aforementioned matter-orientation of agriculture. The other half of reality consists of interactions in the form of processes. One attempts to integrate and synthesize the knowledge obtained through models. This explains why most crop growth models (e.g. SUCROS (Goudriaan and Van Laar, 1978)) start with the photosynthesis equation in which carbon dioxide and water is transformed into carbohydrates. As such, these models can be used for scientific purposes, for example, to clarify certain phenomena. However, in current agricultural research, the next step is that these models form a basis for management models, for example, in combination with precision agriculture (Bouma et al., 1995; Van Bergeijk, 2001). This also explains why these models mainly work with artificial fertilizer for example and not with composted farmyard manure. In the latter case namely, biological processes are very important and this is not a simple matter-input-matter-output relationship (Hobbs and Morton, 1999). In case of artificial fertilizer, the process is, that it totally dilutes in the soil and nitrogen is directly available for crops so that it can be considered as a direct matter-input-relation (remember: soil is only a substrate!).

[1] Originally in German: Denn nur das, was wir selbst machen können, verstehen wir aus dem Grunde.

Management rules, like application of fertilizer, cannot only be based on laboratory or field experiments (Leaver, 1994), but should be developed in the local-specific social, ecological and economic environment of a farm system. This requires an interdisciplinary and heuristic approach.

3.2.6 Conclusions

The production ecology concept works according to the biophysical-rational view of the farm system (see Chapter 2). In essence, it means that the natural ecosystem, society and the farmer are not included. They are like balancing items on the budget, while production is the starting point. It is argued that pursuing this concept, inevitably leads to severe tensions between agriculture on the one hand and ecology and society on the other: it is a risk-seeking concept. Farm systems become specialized and capital controlled and highly dependent on external inputs and external actors like multinationals and the government. This makes them inflexible and reduces the ability to adapt to the changing environment and therefore make them unsustainable. Research was, and is, too much focused on bridging the yield gaps, on matter production using matter input, and methods at a low integration level. The production ecology concept is not incorrect in itself, but it is based on a restricted view on agriculture in reality. In the next section, another concept for agricultural production, ecological production, will be presented that has a broader focus. Mind Map 5 in Appendix VI summarizes the production ecology concept and its implications.

3.3 Ecological production

In this section ecological production is presented as the complementary alternative for production ecology. After explaining the basic ideas behind the concept, it is described how these should be implemented in farm management.

3.3.1 The ecological production concept

Fig. 3-2 represents the complementary concept of production ecology, which is also expressed in the name *ecological production*. While in production ecology the focus is on the potential yield level, in ecological production the focus is on a sustainable yield level, accepting that this is lower than the potential yield level (Ewel, 1999).
A sustainable yield is defined by local-specific, environmental factors that have social, ecological and economic aspects. In accordance with the methodology that was defined in Chapter 2, the farmer has to negotiate with social and economic actors to define an appropriate yield level. Furthermore, a sustainable yield level is defined by ecological factors like soil type and natural surroundings that together can be indicated as the carrying capacity of the local ecosystem. This carrying capacity is not easily to determine (Weterings and Opschoor, 1994). An indirect, pragmatic approach can be used by saying that carrying

capacity is not exceeded when soil, water and atmosphere, at and around the place of production, are kept clean. Governmental laws provide norms for clean soil, water and air. Taking these norms as a starting point, farm management, as a heuristic problem solving process, focuses on controlling natural resources in such a way that they finally reach a state of self-buffering. This means that the ecological processes, contained within these resources, work properly so that matter concentrations remain below an acceptable level. Then, soil is no longer considered as a substrate, but as a living system that should be cared for as well. For example, when an ecological farmer applies organic fertilizer, he is not only taking nutrients for a desired crop production level into account, but also nutrients for maintaining soil buffers.

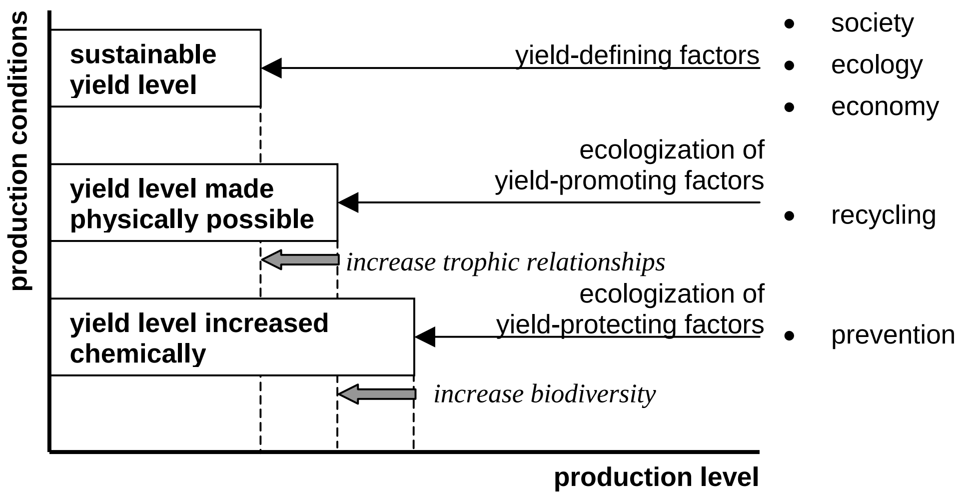


Fig. 3-2 A schematic representation of how the ecological production concept looks at agricultural production (adapted from Goewie, 1996) in reaction to the concept of production ecology (see Fig. 3-1). The horizontal axis indicates the physical production level. The vertical axis indicates three production conditions that are accompanied by a certain production level. Ecological production focuses on a sustainable yield level that is defined by economic, ecological and social factors. The yield level that can potentially be reached in the production ecology concept by chemical and physical measures is substituted by ecologization of yield-promoting and yield-protecting factors. This is done by increasing trophic relationships and functional biodiversity. Further explanation in text.

Assuming that management control is a heuristic problem solving process, it means that sustainable production can be increased when carrying capacity is increased. Stimulating ecological processes of natural resources can increase carrying capacity, so that the buffering capacity increases. In the ecological production concept, this can be reached by *ecologization* of farm management. As indicated in Fig. 3-2, ecologization of farm management consists of ecologization of yield-protecting and yield-promoting factors aiming at increase of biodiversity and trophic relationships. In comparison to production ecology, ecologization means that the yield-increasing measures (physical homogenization of the natural ecosystem) and yield-protecting measures (chemical pesticides) must be substituted by ecologically appropriate measures (Altieri, 1999). This does not mean that each chemical pesticide is substituted by a biological or environmental-friendly variant, but it requires integrated methods in time and space. Ecologization focuses on ecological processes that are dependent on each other in time and space (Jordan, 1995). Management control should focus on this mutual dependency and take care of a smooth concatenation of processes. Hence, this type of management can be characterized by prevention and recycling. This will be further elaborated in the next sections.

In conclusion, the ecological production concept takes the environment as starting point and production becomes the balancing item on the budget. As suggested in Fig. 3-3, the hypothesis is that a sustainable yield level can be equal to the actual yield level within the production ecology concept. There are already sufficient examples from practice that confirm this hypothesis, where yields on organic farms are on average 80% of the yields of adjacent, conventional farms (Van Mansvelt and Mulder, 1993).

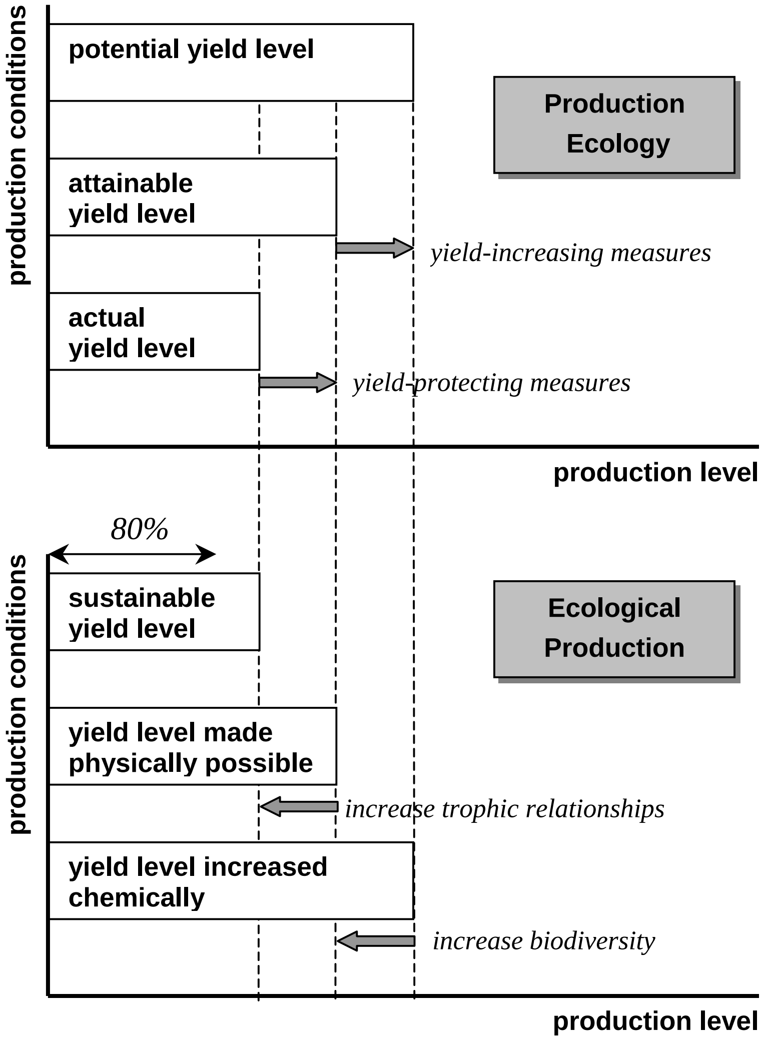


Fig. 3-3 A comparison of production ecology and ecological production. Production ecology is working against nature, while ecological production is working with nature. The actual yields that are currently reached in organic farming are about 80% of the actual yield level in production ecology. The hypothesis is that the sustainable yield level in ecological production is equal to the actual yield level in production ecology. Further discussion in text.

From Fig. 3-3 it also becomes clear that production ecology is constantly working against nature, while ecological production tries to work with nature. This makes that in ecological production, agricultural production becomes ecological compatible. Because this attempted to be reached by ecological measures, it will also become socially compatible. It is emphasized that the farmer himself mainly defines a sustainable yield level. That is why the term yield-*defining* factors is preferred in ecological production rather than yield-*determining* factors in production ecology.

3.3.2 Preventive management

Ecologization of yield-protecting measures (see Fig. 3-2) focuses on healthy plants and animals, without use of pesticides and preventive medications like antibiotics. Instead of these quick-acting means, stress must be avoided by prevention.
Instead of fire-fighting symptoms of unhealthy crops or animals, the farmer must try to find out how several ecological processes are influencing each other. Health is considered to be related to the quality of input into ecological production processes. The idea is that the quality of intermediate products of a whole production chain determines the quality of this chain. The farmer can monitor the result or output of processes, by looking at certain product properties, and try to control them by developing appropriate recipes. Therefore, prevention should be connected with a series of management processes or operations that are linked with each other in time and space. So, for example in one production chain, operations like soil tillage, fertilizing and sowing are determining the health of a crop that is grown. If this crop is used for feed, it will influence the health of the animals that eat it. The production of a crop on a certain field will determine the health of the soil that is left behind and used for another crop the next year. Preventive management should be further translated into management rules that must be followed when carrying out operations. Again, these rules will be the result of heuristic problem solving. This concept is analogous to Quality Assurance, which is successfully used in manufacturing industries for many years already (Peratec, 1994).
Preventive management is also related to habitat management. The farmer must prevent infestations by viruses, fungi, insects, nematodes and birds by stimulating natural predation. Predators and antagonists will easily populate the farm if sufficient biodiversity at farm level can be induced. So, in ecological production, the farmer must create an environment that sustains a food web, a chain of eaten and being eaten (Smeding, 2001). Therefore, it is necessary that the farmer is trained in carefully observing phenomena occurring within his crops (Van de Fliert, 1997).

3.3.3 Recycling management

Ecologization of yield-promoting factors (see Fig. 3-2) focuses on nutrient availability based on the general material cycle of ecosystems, which is represented in Fig. 3-4. Nutrients are released by mineralization and taken up by plants. Plants are degraded into basic material like compost or manure that is applied to the soil. Then, mineralization starts over again. Recycling management should care for constant and gradual degradation of organic matter, for appropriate mineralization of degraded material (e.g. compost, humus, manure) and for appropriate uptake of minerals by plants (Altieri, 1999). It involves three phases:

- uptake of nitrogen, phosphorus and potassium by crop production sustained by leguminous plants, VA-Mycorrhyza and stone dust,
- stimulation of degradation of plant and animal residues and
- stimulation of mineralization processes and stimulation of nutrient uptake by the crop.

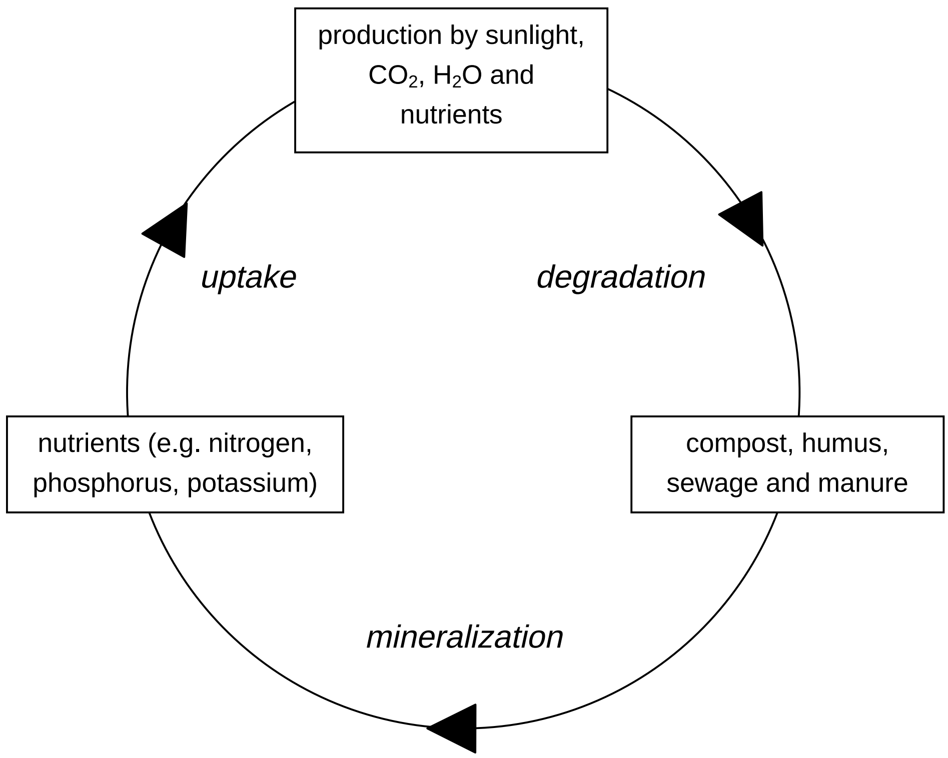


Fig. 3-4 General material cycle in ecosystems.

In principle, Fig. 3-5 represents the same cycle, but now from a mixed farm system's perspective. The soil is gray-colored, because it can be considered as the pivot on which everything turns or recycles (Neher, 1999). Crops take up nutrients from the soil and additional nitrogen from the air when leguminous crops are involved. Animals consume crops as feed, while crops also leave the farm system as food or possibly feed. Animals possibly also consume additional external feed. Meat or milk produced by animals leave the farm. Animals also produce manure and possibly together with external manure, this is applied to the soil. Volatilization is a possible source of loss of nutrients from the farm system. The same holds for leaching and denitrification processes in the soil. Deposition from the air is an additional source of nutrients. This describes the long material cycle. A short cycle can be identified between soil and crops, by means of crop residues. Beside recycling, this scheme also provides a general picture of the nutrient balance at farm system level.

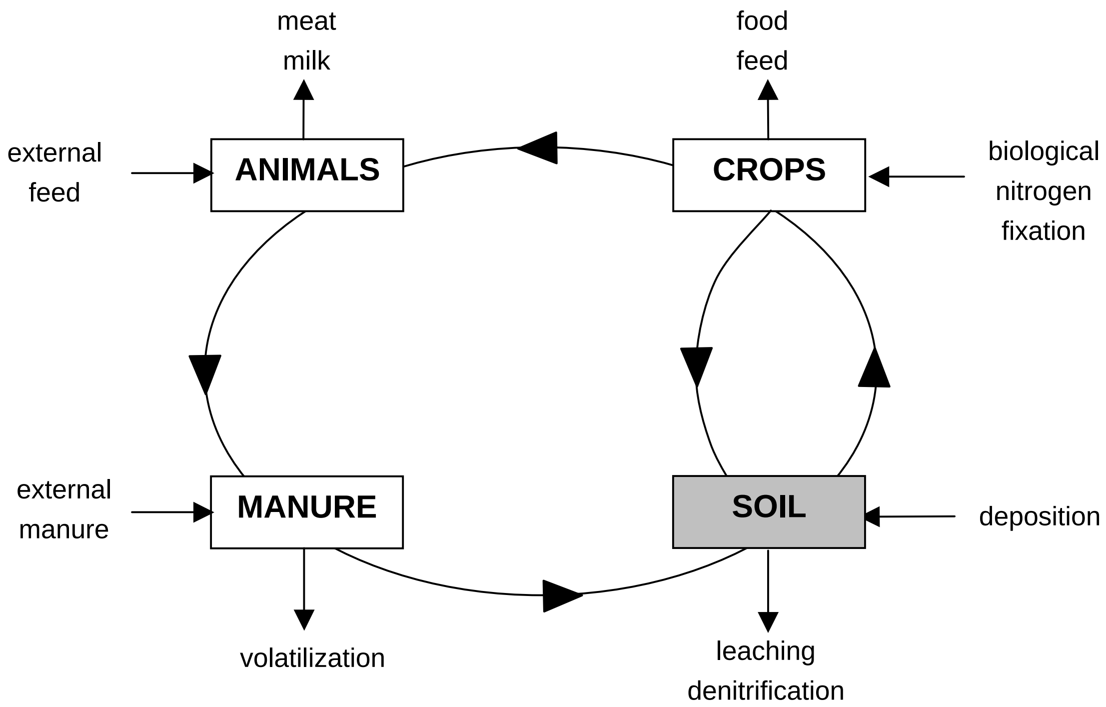


Fig. 3-5 Material cycle at farm system level. A long cycle (including animals and manure) and a short cycle (between crops and soil) can be identified. Further explanation in text.

Soil, crops, animals and manure are involved in all kind of operations of farm management. Operations provide points of application to influence the material cycle and also the nutrient balance. Not just agricultural products like potatoes, wheat and milk are important, but also residual products like manure and crop residues become so. They are intermediate products in the production cycles that coincide with ecological material cycles. Product quality, constituted by several properties (e.g. nitrogen content, color, structure), determines the quality of the whole cycle. In recycling management, these cycles should be identified and product properties should be influenced in a positive way. Again, this is characterized by a heuristic learning process. Besides, recycling management should take care of a sound balance of nutrients at farm level, in accordance with the input = output-rule that was defined as a basic rule for ecological agriculture.

3.3.4 Conclusions

Ecological production aims at a sustainable yield level that is defined by social, economic and ecological factors. With respect to ecological factors, carrying capacity of the local-specific environment is determining the yield level. In order not to exceed this carrying capacity, ecologization of yield-protecting and -promoting factors is a prerequisite.

Ecologization focuses on controlling ecological processes and is characterized by preventive and recycling management. Although these two types of management were discussed separately, in practice they will usually coincide and co-operate with each other. The common basis is that ecological processes are dependent on each other in a cyclic way and are linked together by intermediate products. Management should focus on the quality of these intermediate products so that processes are positively stimulated and the whole process chain or cycle is optimized. This will enlarge the carrying capacity of the agroecosystem and finally lead to higher yields. In this way, ecological sustainable production coincides with an economic sustainable production. Because this is reached by replacing chemical input, it will also make it more socially compatible.

Preventive and recycling management is implemented by concrete operations. What exactly should be done during these operations, is not clear in advance, but is characterized by heuristic problem solving. Through experience and experiments, the farmer has to identify the appropriate cycles and intermediate products and which are the desired values for properties of these products. This corresponds to the methodology as described in Chapter 2.

It can be concluded that mixed farming (integration of plant and animal production in one farm system) is favorable for ecological production (see also Holling, 1995). Then, the farmer has the complete material cycle under his own control. Besides, mixed farming can also have other benefits like a broader crop rotation by including grasslands and forage crops, spreading of income risks and spreading of labor input (Lantinga and Van Laar, 1997; Neher, 1999). On the other hand, specialized farm systems have the benefit of a smaller knowledge domain, so that a specialized farmer can learn faster. This disparity can be converted into synergy when two or more specialized farmers in a region start to co-operate with each other. A shared information system could be very useful in such a situation. Mind Map 6 in Appendix VI summarizes the ecological production concept.

3.4 Production ecology or ecological production?

Table 3-1 summarizes and compares production ecology and ecological production with respect to the aspects of sustainability, the type of research and management control.

Production ecology strives for potential production, based on economic motivation, and is only constrained by natural factors. Ecological production strives for sustainable production by taking also social and economic factors into account.

With respect to ecological aspects, production ecology takes production as starting point and the environment as the balancing item, while ecological production reverses this. In ecological production, carrying capacity determines the production level. In practice, production ecology will result in segregation of nature and agriculture and homogenization of the ecosystem. Instead, ecological production will integrate nature, and manage diversity that is essential for production (Almekinders et al., 1995).

Table 3-1 A comparison for several aspects of production ecology versus ecological production.

production ecology	ecological production
social/economic	
• potential production	• sustainable production
– natural factors	– social, economic and natural factors
ecological	
• production	• environment
	– carrying capacity
• nature segregation	• nature integration
• homogenization	• orchestrating diversity
research	
• best practice	• farm(er)-specific
	– diversity
	– farm styles
• low integration level	• high integration level
• ceteris paribus experiments	• farm-bound experiments
management control	
• matter-oriented	• process-oriented
• external input	• closed cycles
	– internal input
• input-output optimization	• process optimization
	– recycling management
• single process optimization	• whole chain optimization
	– logistics
• risk-seeking	• risk-avoiding
– high control level	– self-regulation
	– preventive management
• short term	• long term
– linear steady state	– cyclic steady state
• technology	• farmer’s skills
	– learning

Concerning research, production ecology works from the point of view that, ideally, there is one best farming practice. On the other hand, ecological production acknowledges the local-specific environment of the farmer and farm system, which leaves room for diversity in good practices and farm styles (Hobbs and Morton, 1999). Research within production ecology largely takes place at a low integration level: the whole is explained from the parts. Explanation of how an agricultural system works is derived form *ceteris paribus*

experiments. Ecological production research is more design-oriented and works with farm-bound experiments, which automatically means that relevant factors in practice are taken into account and thus takes place at a high integration level.
Management control within production ecology is focusing on matter production, using external 'matter-input' to reach this. Ecological production is focusing on ecological processes, constituted by cycles. These cycles are stimulated and maintained by internal input (e.g. manure, crop residues). An additional benefit is that the farm becomes less dependent on external forces from the chemical industry and politics. So, while production ecology is focusing on optimization of input-output relations, ecological production is focusing on optimization of ecological processes. This is put into practice by preventive and recycling management. Hence, in production ecology, optimization usually concerns one specific process, while ecological production tries to optimize the logistics of a whole chain or cycle of processes. Because in production ecology the ecosystem is stressed and susceptible to pests and diseases, it tries to strike back, resulting in a high and intensive control level. Therefore, management control within production ecology is risk-seeking. In ecological production, preventive management, aiming at a lower susceptibility to diseases, stimulates self-regulation of the ecosystem. Therefore, management control within ecological production can be characterized as risk-avoiding, preventive management. This is accompanied by a long-term horizon, while production ecology works with a short horizon. Each year it starts in the same position: a plowed, homogenized soil (substrate) on which a crop is grown. In other words, production ecology considers the steady state of the ecosystem, which is important with regard to sustainability, as a linear process. Ecological production considers the steady state of an ecosystem as a cyclic process (Hobbs and Morton, 1999).
Finally, production ecology emphasizes technology as the main mean to reach the objective of production, while ecological production emphasizes farmer's skills that can be improved by heuristic learning.

In conclusion, the main point is that production ecology takes production as a starting point and the environment is the balancing item on the budget. It was argued that there is a serious risk in this concept that the environment is irreversibly damaged, so this is not sustainable. Ecological production turns this around and puts the environment in the forefront, while a satisfying production level is aimed at. This is in line with the task, God gave to men, as cited above this chapter. Men are ordered to cultivate the earth, but at the same time to preserve it. The King James version nicely puts this with the word 'dressing', which indicates to do this with love and care. Referring to the three attitudes towards nature that were identified in Chapter 2, production ecology is only based on the attitude of 'nature as matter', while ecological production also takes 'nature as carrier' and 'nature as philosophy' into account.

Referring to Table 2-1 in Chapter 2, it is concluded that production ecology belongs to the area of experimental research, while ecological production belongs to the area of design-oriented research. Production ecology produces detailed knowledge about single processes. This knowledge can help to understand whole process cycles in agricultural practice. In this way, production ecology can be servant to ecological production in a complementary way, but production ecology research results cannot be directly applied in practice. Ecological production should be applied to designing sustainable farm systems and when it is applied in practice, it will deliver important and relevant questions that can be solved by experimental research (see also Fig. 2-6 in Chapter 2). However, before that stage is reached, the farmer himself can already solve many problems. Thus, it can be concluded that ecological production is in line with the methodology for designing sustainable farming systems as described in Chapter 2, while production ecology is complementary to this.

3.5 Implications for modeling

If the ecological production concept is taken as a point of departure for the model in this thesis, then what are the implications for this? Referring to Fig 2-7 in Chapter 2, it will especially have consequences for how the production system is modeled.
From the description of preventive and recycling management it can be derived that:

- Management control should be based on the cyclic dependency of ecological processes and should stimulate a smooth concatenation of them.
- The farmer should gain insight in how ecological processes are influencing each other by identifying the products that are involved in process chains or cycles.
- Therefore, he should identify and monitor properties of intermediate products that serve as indicators for the quality of ecological processes
- Next, he must find out, by heuristic problem solving, which is the optimal range of the values of these properties and, most important, how he can keep them within this range.
- Because a farmer is not just a keeper of the ecosystem, but wants to have sufficient production, influencing of product properties must be connected with common farm operations, like sowing, plowing, milking, etc.

For the model this means that:

- The primary production system should be modeled as a *logistic chain of products* that represents flows between production processes.
- The farmer should be enabled by the information system to aggregate information from the production system so that *cycles as chains* of processes can be identified.

- This aggregation should somehow be connected with goals that were defined in the model of the desired farm system.
- The production processes should be modeled as delimited units of farm operations.
- The information system should enable the farmer to associate operations with properties of intermediate products.
- Furthermore, it should be possible to work out these associations in concrete guidelines for operations.

It was also mentioned that internal, natural resources, of which the soil is the most important one, should be maintained in ecological production. For the model this means that:

- The model of the production system should explicitly define these *internal resources* and these should be connected with production processes, so that they can be influenced.
- Hence, the information system should enable the farmer to include these natural resources in the product cycles that are identified. In this way, influencing can be translated in the same way into guidelines for operations

Finally, in ecological production, the farmer wants to compensate for the amount of nutrients that is exported from the farm system (output = input). Furthermore, the few external products that are imported are not self-produced, so it is important to obtain qualitative information about them. For the model this means that:

- The production system should be modeled in such a way that information on import and export of products can be easily obtained.
- The information system should provide this information and also enable the farmer to gain insight in how this balance can be positively influenced. Again, this influencing can be connected with the product cycles that are defined.

Because of the heuristic character of ecological production management, the model should be generic, so that the information it contains can be continuously updated and changed. This will also leave room for local-specific conditions and various styles of farming.
So far some general requirements for modeling are listed. In Chapter 4, where actual modeling takes place, they will be further translated into formal specifications. In this way, the model contributes to a rationalization of ecological production without simplifying the dynamic complexity of the agro-ecological system. Because this approach is new, and not yet implemented in practice, it can be expected that ecological farming practices still can be significantly improved (Hobbs and Morton, 1999; Lefroy et al., 1999).

4 A modeling approach for designing sustainable mixed ecological farm systems

Information modeling is supposed to take place according to predefined requirements. But arranging and relating data in a model often results in unexpected surprising insights.

experience of many colleague modelers

Abstract

This chapter describes the development of an information system that supports farmers in designing sustainable farm systems, based on ecological production principles. It defines a new modeling approach, because it is argued that existing farm management models are too specific and do not correspond to real word decision-making and management practice. The information model consists of a process model and a data model. The process model consists of several submodels. The Product Flow Model represents the production system as a logistic chain or network of processes and intermediate products. The Sustainability Map represents the sustainability goals in a hierarchical way and connects them to the Product Flow Model by identifying relevant product flow cycles or chains. These connections are further elaborated by Sustainability Function Deployment, which makes associations between operations and flow properties. Finally, these associations are translated into critical control points and accompanying work instructions in the Sustainability Management Handbook. An entity-relationship diagram that can be instantiated as a relational database represents the data model. Software tools were developed to view and manipulate the data in this database. This makes it possible to evaluate and improve decision-making with respect to sustainable development. It is concluded that the information system supports the farmer in making his visions, intentions and values explicit, that it corresponds to the principle of heuristic problem solving and that it assures sustainability in his daily, operational management. Furthermore, it is in line with the principles of preventive and recycling management of ecological production.

Keywords: modeling; whole farm management; management information system; decision support; sustainability; ecological production; product flows; farm management handbook

4.1 Introduction

This Chapter describes a modeling approach that supports the design process of sustainable farm systems as described in Chapter 2 and which satisfies the principles of ecological farm production as described in Chapter 3. First, an overview of the whole modeling process, and the application of the model, is described. It is schematically summarized in Fig. 4-1. Three parts can be distinguished: information system design, farm system design and future development; the latter falling outside the scope of this thesis.

The basic idea is that supporting the farmer with an adequate information system optimizes farm system design. This means that the farmer is enabled to make better decisions and improve his system continuously. The process of information system design is shown in the left part of Fig. 4-1. The objective is not to develop an information system for a specific farm system, but to develop a generic template, indicated as an information system-template (further abbreviated as IS-template) that can be dynamically instantiated for a specific farm system. The IS-template consists of an information model and a database application.

To develop this template, conceptualization of the object system at its base takes place. Conceptualization is a very essential part of this thesis. It deals with the question of how the production system and managing process should be modeled in order to support farm system design. Conceptualization takes place according to requirements that are derived from the theory, described in Chapters 2 and 3. In Section 4.3, these are summarized and specified further. After listing the requirements, it is discussed why existing agricultural management models do not satisfy them and why a new approach is needed (Section 4.4). For conceptualization, existing models from literature are used, together constituting the model base. The actual conceptualization step is described in Section 4.5.

A concrete mixed ecological farm system at a farm in the Netherlands the ‘ir. A.P. Minderhoudhoeve’ (further abbreviated as APMeco), was used as a reference object system for developing the IS-template (APMeco is described in Appendix I). Conceptualization took place by an iterative process. Several versions of the IS-template were developed and an advisory committee regularly them evaluated against specified requirements. Besides, the committee checked if instantiations for APMeco resulted in a valid representation of this object system. Because of time, it was not possible to carry out a complete instantiation for APMeco, but Chapter 5, 6 and 7 provide some illustrative cases. A final evaluation and validation by external experts is described in Chapter 8.

The final developed IS-template can be instantiated for other farm systems (indicated by arrows 1 and 2) in order to support sustainable farm system design, based on ecological production principles. This process is shown on the right in Fig. 4-1. Therefore, a first instantiation is carried out for the farm. From then on, the farm system can be further

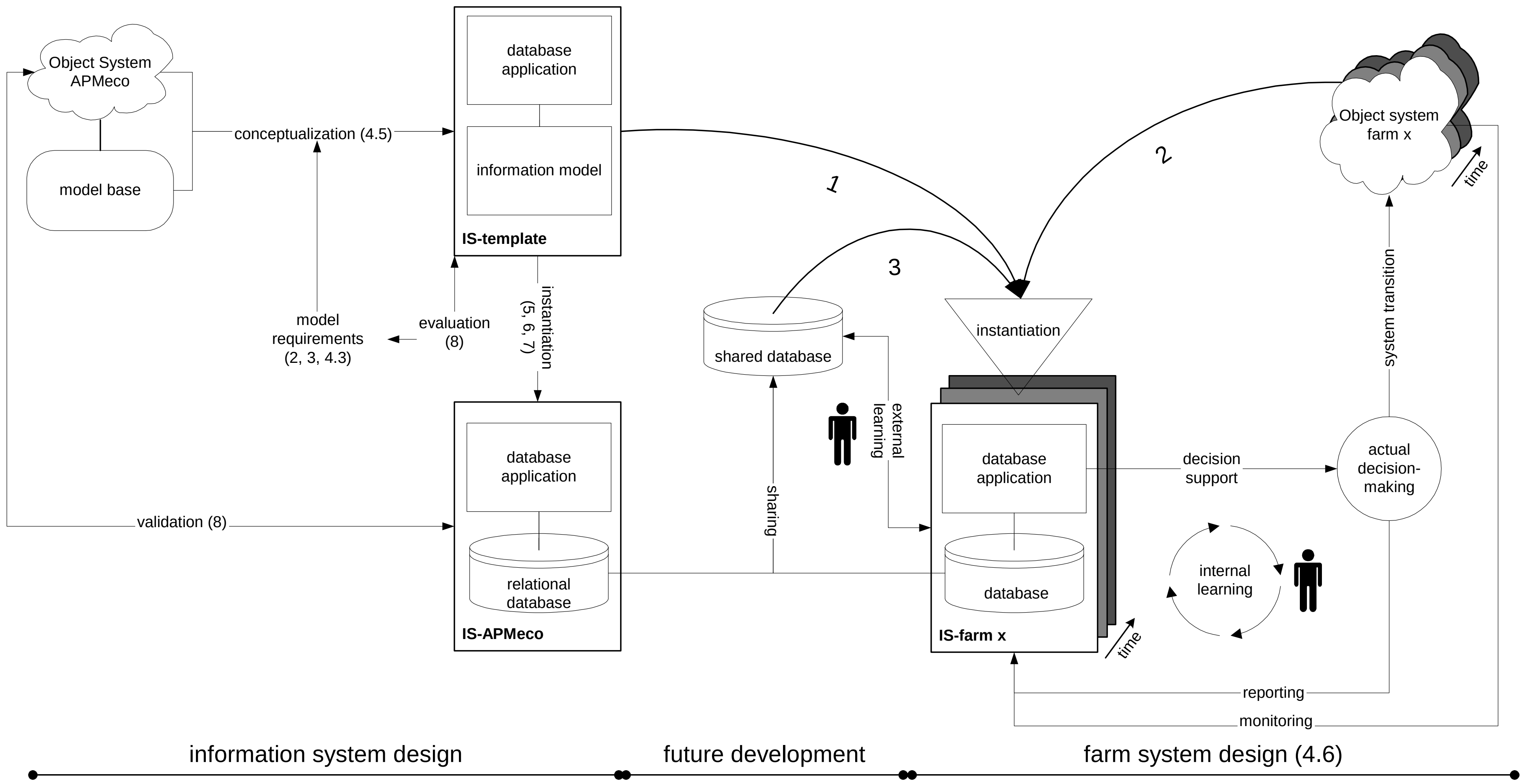


Fig. 4-1 The whole picture of system development. The left part shows the development of the information system template, the right part shows how this template should be used in farm system design and the middle part shows possible future development. Numbers between parentheses indicate in which section or chapter the item concerned is discussed. Further explanation in text.

redesigned according to the three-phase-methodology that was described in Chapter 2; this is characterized as the *internal learning* loop. This means that the farmer makes actual decisions, in which he is supported by the information system. A decision results in a transition of the object system through time (indicated by the shadow-effect), which is reflected in the information system by monitoring the object system. Besides, the decision itself is also reported to the information system, which makes it possible to evaluate results from certain decisions. As a result of this evaluation, the farmer can learn and decide to redesign his management control, which results in a transition of the information system (indicated by the shadow-effect). The puppet next to the internal learning loop emphasizes that evolution of the information system is not an automated process, but requires human judgment and interaction. The whole process of farm system design and internal learning is further described in Section 4.6.

In the future, information from several farms that use this information system could be shared in a database (shown in the middle part of Fig. 4-1). This provides opportunities for *external learning*. By looking at how colleague farmers are controlling their system, the farmer can get ideas for his own farm system. This takes place already in practice of course, but the shared database could further facilitate and support this process. Another potential application of a shared database is that it can speed up the instantiation process (indicated by arrow 3). For example, when a potato production process is already instantiated for several farms, a default potato model can be derived from this, which can be used for new instantiations. Customizing this default model, instead of beginning from scratch each time, could save much time. An outline of this chapter is provided by Mind Map 7 in Appendix VI.

The chapter starts with a description of some fundamental concepts and ideas of information modeling.

4.2 Essential concepts and ideas: some terminology

The field of information modeling, and in general, information and communication technology (ICT) is imbued with jargon, concepts and design methods and methodologies. However, general definitions are not always available and there is not always general agreement on them. Besides, taking into account that this is a multidisciplinary thesis, aiming at a broad group of readers, it is necessary to provide some background information about these matters. Finally, in information modeling, normative choices have to be made and in this section these will be made explicit. This section does not intend to provide a complete and thorough overview of information modeling, but will discuss those topics that are necessary for understanding the remainder of this chapter.

4.2.1 Designing: wheels within wheels

A design method uses existing methods that were also once designed, which in their turn can use other basic methods that were also once designed. So, in designing, one can usually distinguish ‘wheels within wheels’ (Simon, 1977; De Leeuw, 2000). In this thesis, it should be clear that the farmer designs his farm system (shown on the right hand side of Fig. 4-1) supported by the information system for which a template was designed in this thesis (shown on the left hand side of Fig. 4-1). The information system, used by the farmer, contains actual information about his specific farm system. The IS-template can be considered as a meta-information system, which only contains a framework that tells how information should be arranged and how elements are related to each other. Instantiation is the process of filling in actual data according to the template structure.

4.2.2 Information System

Management information systems are systems that are meant to provide information to managers in order to manage and control purposeful actions (Beulens and Van Nunen, 1988). Avison and Fitzgerald (1995), and also De Leeuw (2000), emphasize the human dimension and define such an information system as a human activity or social system, which may or may not involve the use of computer systems. From the previous chapters it is obvious that this human dimension is certainly included in the modeling approach in this thesis. A computer system is considered as a supporting tool, but it becomes indispensable in situations with a high and complex data and information density, which is the case in the problem domain of this thesis. It can supplement human processing capacity by pre-filtered information and by doing fast calculations that will increase effectiveness in decision-making (Parker, 1999; Hammer, 2001).

Several authors have made an attempt to classify different types of information systems of which a summary is listed in Table 4-1.

The classification in the first column is based on the classical distinction between management levels according to Anthony (1965): operational control, management control and strategic planning. The second column classifies the information system for the situation in which it can be applied, ranging from unstructured to structured situations. In case of structured tasks, it is clear what has to be done and all relevant information is readily available. In structured problem situations, the problem and also the variables that define the solution to the problem are clear. In semi-structured and unstructured situations, the problem and also the way to solve it are less clear to very unclear. However, it should be noted that degree of structure depends on the person who looks at it. For example, a game of tic-tac-toe is a structured problem for most adults, but is unstructured, and therefore challenging, for a five-year-old kid.

Table 4-1 A typology of information systems (a synthesis of Simon, 1977; Keen and Scott Morton, 1978; Beulens and Van Nunen, 1988; Avison and Fitzgerald, 1995). The rows list the different types information systems; the columns provide a classification of them. Gray cells indicate what topics are covered most by the information system in this thesis. Further discussion in text.

information system types	management level	situation	support goal	(model) basis
Management Information Systems (MIS)	management control	structured tasks	efficiency	analysis/reports
Management Science/ Operational Research (MS/OR)	operational control/management control	structured problems	better solutions	mathematical optimization
Decision Support Systems (DSS)	management control/strategic planning	semi-structured/ unstructured	effectiveness	information models/heuristics

The third and fourth column indicate what kind of support the information system is aiming at and what methods are used to reach this. In case of structured tasks, the situation is static and will not change on the short term. In that case, it pays off to strive for higher efficiency, i.e. to get a higher output with less input. This can be done by studying data that are derived from analyses, usually aggregated in reports (e.g. on sales, variable and fixed costs). In case of structured problem situations, the objective is to find out what is the optimal solution, provided that all relevant variables are identified and quantified (e.g. hours of labor, kilograms of input). The solution can be found by using mathematical optimization techniques (e.g. linear programming). In case of semi-structured or unstructured situations, the environment for decision-making is usually dynamic. Then it is necessary to look for a satisfactory, effective solution and it does not pay off to strive for the highest efficiency. Besides, this point cannot be easily determined because of many uncertainties and normative choices involved. The methods used are heuristics, based on gained experience and information models that represent the relevant information of the system in reality in such a way so that insight into the situation will be increased. This means that unstructured problems become more structured, so that tasks also become more structured.

A classification, like provided in Table 4-1, helps to understand and characterize information systems that were developed in practice. Some information systems can be classified into one row of the table, but often an information system covers more rows or different cells. This is the case with the information system in this thesis. As described in Chapter 2, this approach is aiming at transforming unstructured problems into structured tasks. The result of this process can be characterized as a management information system, although the emphasis is not laid on efficiency, but on effectiveness: what are the critical actions during farm operations that most effectively determine the goals of the whole farm system? The way to achieve the answer to this question is mainly connected with the management control level. Although the farmer is supported in searching for better solutions, this search is mainly based on heuristics rather than on mathematical optimization. In conclusion, the information system as developed in this thesis can be characterized as a hybrid system between a decision support system and a management information system. The gray cells in Table 4-1 indicate which keywords are covered most by this hybrid information system.

4.2.3 Information model, instantiation and ontology

As indicated in Fig. 4-1, the IS-template consists of an information model and a database application. The information model is the heart of the template. After instantiation, the information model becomes a database with actual data. The database application provides an interface for viewing and editing the data.
Beers et al. (1994) provide a definition of an information model that can also be applied to the information model in this thesis:

> In an information model, the information system of an organization is described. It consists of (i) a data model in which the data are described that are used or produced in the organization, and (ii) a process model in which the activities are described which take place in the organization. For every process, it is specified what data are used and what data are created by the processes.

To create generic models that can be re-used, rules for the representation formalism of the process model must be formally specified. This is part of the conceptualization step (see Fig. 4-1). This is often referred to by the term *ontology*. Gruber, cited by Borst (1997) defines ontology as:

> an explicit specification of a conceptualization

A formal language (e.g. predicate logic) often represents this specification, so that statements are unambiguous and thus can be translated to a computer system. An ontology can be considered as an instrument for developing an information system.
Section 4.5 describes the process and data model, divided into several sub-models. Together, they provide a representation of the farm system in reality. The process model of the managing and managed system will be formalized, using their own specified representation. A standard representation formalism, entity-relationship diagramming, is used to represent the data model (see Fig. 4-5). A brief description of entity-relationship diagramming is

provided in Appendix II. An entity-relationship diagram can be easily translated into a relational database and additional software components.

4.2.4 Methodology: the philosophical basis

The development of the IS-template and the way it is instantiated for a specific farm system, can be characterized as a methodology. Avison and Fitzgerald (1995) provide a working definition of a methodology:

> A collection of procedures, techniques, tools and documentation aids which will help the systems developers in their efforts to implement a new information system. A methodology will consist of phases, themselves consisting of sub-phases, which will guide the systems developers in their choice of the techniques that might be appropriate at each stage of the project and also help them to plan, manage, control and evaluate information systems projects.

However, in this definition, the added value of the term *methodology* to the term *method* is not very large. Hence, some argue that a distinction between these two terms does not make much sense. Avison and Fitzgerald provide another definition of a methodology:

> A methodology represents a way to develop information systems systematically. It must have a sound theoretical basis, although it will be based on 'philosophy', 'interests' and 'viewpoint' of the people who developed it.

Philosophy and viewpoint are also very important in this thesis, as was discussed in detail in Chapters 2 and 3. Avison and Fitzgerald come up with a framework that was adapted from Lewis (1994) and is shown in Fig. 4-2. It distinguishes two dimensions: ontology and epistemology.
Ontology was already discussed before as an essential basis of conceptualization. In this context, it is used in its more original, philosophical context and is concerned with the essence of things and nature of the world. In this dimension, two extreme positions are distinguished: realism and nominalism. Realism postulates that the universe comprises objectively given, immutable objects and structures (Hirschheim, cited by Avison and Fitzgerald (1995)). Nominalism on the other hand postulates that reality is a social construct, a product of human mind (Hirschheim and Klein, 1989). It is an emergent property that becomes clearer in a 'learning-by-doing way'.

Epistemology relates to the way in which the world may be legitimately investigated and what may be considered as knowledge and progress. Again two extreme positions are identified: positivism and interpretivism. Positivism implies the existence of causal relationships, which can be investigated using scientific methods. Interpretivism implies that there is no single truth that can be 'proven' by such investigation. Different views and interpretations are potentially legitimate. The way to progress is not to try and discover the one and only 'correct' view, but to accept the differences and seek to gain insight by deep understanding of such complexity.

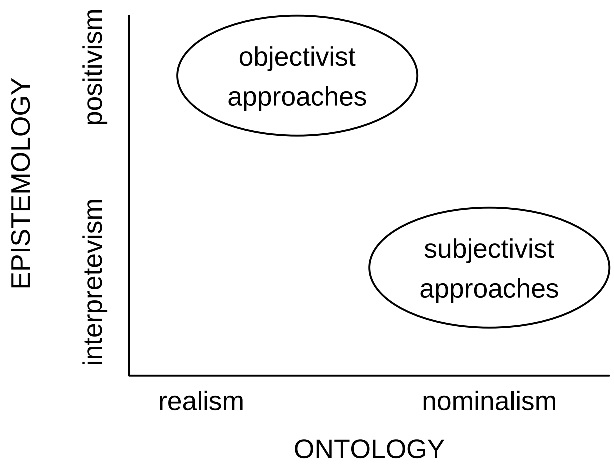


Fig. 4-2 Framework for analyzing the underlying philosophies of methodologies (adapted from Lewis (1994) by Avison and Fitzgerald(1995)). The methodology in this thesis uses a subjective approach. Further explanation in text.

Now, in this framework, two positions can be distinguished that characterize the philosophy or viewpoint that underlie a methodology: an objectivist approach or a subjectivist approach. From the theory described in Chapters 2 and 3, it is derived that the methodology in this thesis has to follow a more subjectivist approach, although extremes should be avoided. Goals and means are not completely set in advance, but they are gradually set more precisely as a result of heuristic problem solving. So, causality is there, but in many cases will not become fully clear and cannot be defined and controlled in advance. The farm system will never reach an ultimate desired state, because in an ever-changing environment new challenges will always appear so that (new) goals and means will be (re)set. It is also left to the farmer to attach his own values to goals and means (nominalism). From the concept of ecological production, as described in Chapter 3, it is derived that the modeling approach should not be based on one best practice, but there is room left for using different ways to reach the same goals (interpretivism).

4.3 Model requirements

At the end of Chapters 2 and 3 general model requirements were derived from the philosophy or viewpoint as described in those chapters. From the three-phase-methodology, a general structure was represented, which is copied in Fig. 4-3, now focusing on the components that should be translated into an information model (indicated as gray blocks).

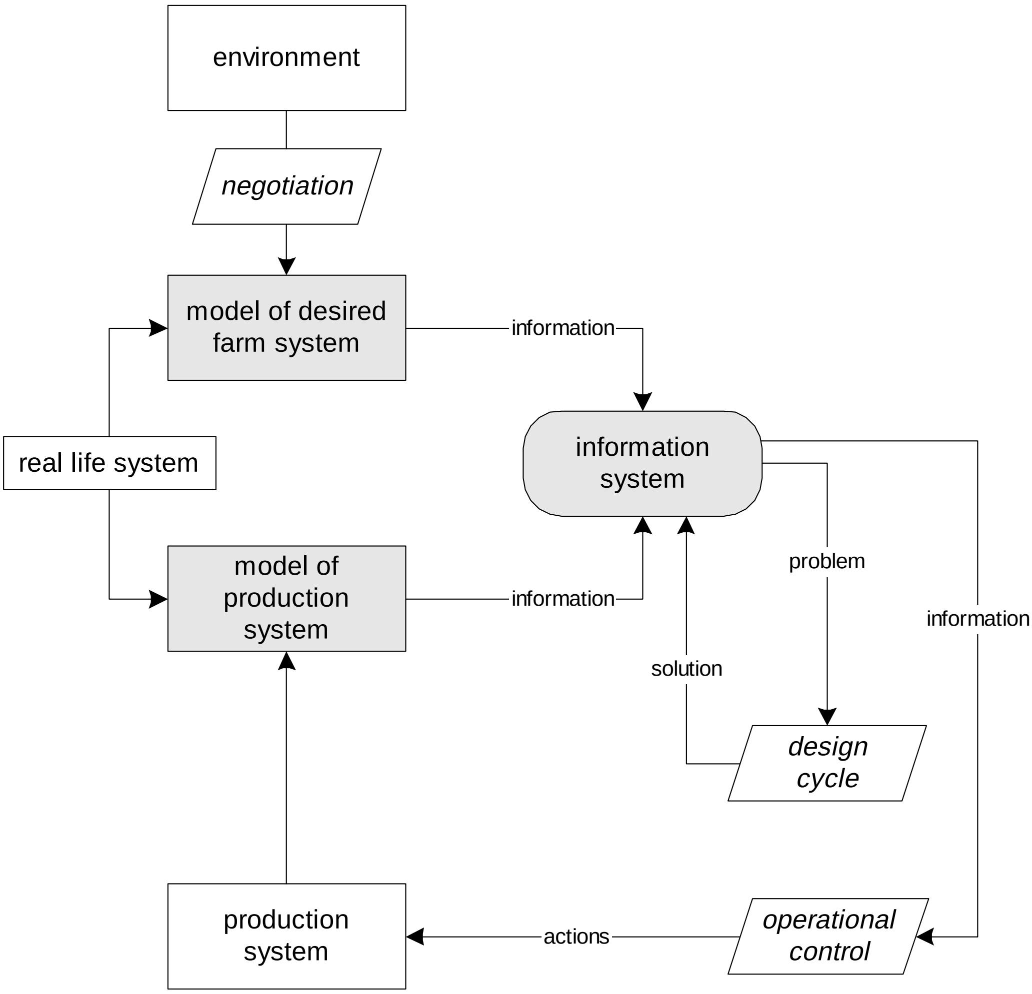


Fig. 4-3 General structure of the requirements of the model to be build as derived from Chapter 2. The gray blocks indicate what parts should be translated into an information model.

The environment is constantly changing and can be considered as the drive for farm system design. By negotiation, strategic goals are set, which are translated further by management control that finally results in operational control that changes the state of the production system. By providing feedback, the farmer is enabled to evaluate the progress of his farm system in relation to the environment and is triggered to improve management. Heuristic problem solving is considered to be an important mechanism for this improvement. In this way, a regulative management cycle can be distinguished, aiming at adapting the farm system to the changing environment, which can be characterized as a dynamic steady state. In Chapter 2, this was considered to be the most important notion of sustainability.

So, it can be concluded that the information model can be split up into several submodels:

- a model of the desired farm system
- a model of the production system
- an information system that
  - connects the information from the first two submodels and
  - further translates this to operational control

The real life system of the farmer, i.e. his personal view, will determine the model of the desired farm system and this will also determine what information from the production system is relevant, i.e. the model of the production system.
Below, a list of specifications that were defined in Chapters 2 and 3 are summarized for each submodel.

Model of desired farm system
The model of the desired farm system should:
- enable the farmer to define goals and means in a hierarchical way so that they are dependent on each other and make up a logical whole.
  - each means can become a goal when means at a lower level can be distinguished.
  - the goal at the highest level in the hierarchy should be 'a sustainable farm', which is a very unstructured goal.
  - descending the hierarchy, goals and means should become more structured.
- be flexible so that goals and means can be easily changed.
- enable the farmer to make visions, intentions and values explicit.

Model of production system
The model of the production system should:
- enable the farmer to look at the primary production system as a logistic chain or network of products that flow between production processes.
  - production processes should be modeled as delimited units of farm operations.
  - products can be be characterized by their properties.
- explicitly include the state of internal resources and relate them to the production processes.
- model the production system in such a way that information on import and export of products can be easily obtained.
- provide points of application for the model of the desired farm system.
- enable the farmer to define those components that are important in relation to his real life system.

- be able to provide actual data on products so that goals can be evaluated.

Information system

The <u>connection part</u> of the information system should:

- enable the farmer to connect goals from the model of the desired farm system with information from the model of the production system.
- enable the farmer to aggregate information from the production system so that cycles or chains of processes and intermediate products can be identified.
  - this aggregation should be connected with goals that were defined in the model of the desired farm system.
  - it should be possible to include natural resources in these cycles or chains.
- provide the farmer with information on import and export and enable him to gain insight in how this balance can be positively influenced; this influencing should be connected with the product cycles that are defined.

The <u>translation part</u> of the information system should:

- enable the farmer to define instructions for operational management, related to production processes that were defined in the model of the production system.
  - instructions should be aiming at steering properties of intermediate products into a desired direction.
- enable the farmer to detect progress in reaching his goals.

Mind Map 8 in Appendix VI provides an overview of the specifications. These specifications are further translated into a concise ontology in Section 4.5. Before that, current farm modeling approaches are reviewed in order to see if an existing approach possible already meets these requirements.

4.4 Current farm modeling approaches: why is a new approach needed?

The reason why this thesis was written is that it was felt that a new approach for modeling farm systems was required. The question that can then be asked is: what is wrong with current approaches? For that reason, a quick scan for searching existing approaches through recent literature was made. Results are discussed and success and failure factors are identified. It is then argued why current approaches do not satisfy the requirements that were listed in the previous section.

4.4.1 Whole farm management models – a quick scan

A quick scan was carried out using the search string ‘whole farm AND management AND model*’, because that is the scope of the model in this thesis. The used bibliographical databases were Agricola, Agris, CAB, Current Contents, Econlit and Sociological Abstracts over the last 10 years. After a further manual selection, about 80 articles remained that somehow dealt with modeling management within the context of a whole farm. These will be further evaluated for their application to whole farm management modeling.

First, it became clear that the term ‘whole farm’ is not equal to ‘mixed farm’ in the sense of integration of arable and animal production. It seemed that many models are only applicable to either arable farming or animal farming or horticulture (see Table 4-2).

Moreover, a further specialization within these categories could be distinguished. Some models are only applicable to a few specific crops (e.g. wheat, sugar beet), animals (e.g. cows, sheep) or types of animal production (e.g. dairy farming, beef production). Only a few models deal with mixed crop-livestock systems. It is also noted that only few models are dealing with ecological production (or organic farming).

Table 4-2 A classification of farms management models according to their application to a specific farm type.

farm type	references
arable farming specific crops	Barry et al., 1993; Swinton and King, 1994a; Swinton and King, 1994b; McCown et al., 1996; Schoney, 1996; Shewry, 1997; Deer Ascough et al., 1998; Shaffer and Brodahl, 1998; Smeulders et al., 1998; Thornton, 1998; Armstrong et al., 2000; Shaffer et al., 2000; Rotz et al., 2001
animal farming specific animals dairy farming beef production forage production	Grieve, 1989; Olney and Standing, 1989; Olney, 1989; Olney and Kirk, 1989; Warren and Johnston, 1989; Westphal et al., 1989; Abadi Ghadim et al., 1991; Knutson, 1991b; Knutson, 1991c; Knutson, 1991a; Horn et al., 1992; Knutson, 1992; Van de Ven, 1992; Barry et al., 1993; Kingwell et al., 1993; Bhende and Venkataram, 1994; Kouka et al., 1994; Cacho et al., 1995; Knutson et al., 1995; Darmody, 1996; Fleury et al., 1996; Hack ten Broeke et al., 1996; Hacker et al., 1996; Herrero, 1996; Hutchings et al., 1996; Sibbald, 1996b; Sibbald, 1996a; Uribe et al., 1996; Velthof and Oenema, 1997; Smeulders et al., 1998; Herrero et al., 1999; Pionke et al., 1999; Rotz et al., 1999a; Rotz et al., 1999b; Rotz et al., 1999c; Rotz et al., 1999d; Salinas et al., 1999; Shomo et al., 1999; Watson and Atkinson, 1999; Wang et al., 2000
horticulture specific crops vegetables fruits flowers	Blaise, 1996
mixed farming	Abadi Ghadim et al., 1991; Knutson, 1991a; Knutson, 1992; Barry et al., 1993; Kouka et al., 1994; Deer Ascough et al., 1997; Deer Ascough et al., 1998; Oomen and Habets, 1998; Shomo et al., 1999

Secondly, often one or few aspects of farm management are taken into account as shown in Table 4-3. The risk of these approaches is that optimal solutions are found with regard to that specific management aspect, resulting in sub-optimal solutions for other aspects. This does not correspond to the daily reality of farm management in which the farmer has to deal with more aspects at the same time.

Finally, the modeling method or technique is considered. From Table 4-4, it is clear that most models are based on simulation of ecological processes, ranging from models with complex differential equations to models that are merely a simple set of calculations (often a spreadsheet model). They usually originate from science and were developed with the purpose of better understanding ecological processes and therefore it is questionable if they are suitable for management support. The next section will come back to this issue.

Table 4-3 A classification of whole farm management models for different management aspects.

management aspect	references
production water nutrients nitrogen weeds grazing	Ghadim and Pannell, 1989; Abadi Ghadim et al., 1991; Knutson, 1991b; Knutson, 1991a; Horn et al., 1992; Van de Ven, 1992; Kingwell et al., 1993; Swinton and King, 1994a; Swinton and King, 1994b; Hacker et al., 1996; Herrero, 1996; Smith et al., 1996; Stonehouse et al., 1996; Uribe et al., 1996; Deer Ascough et al., 1997; Gray et al., 1997; Shewry, 1997; Smith et al., 1997; Shaffer and Brodahl, 1998; Thompson and Powell, 1998; Pionke et al., 1999; Rotz et al., 1999a; Rotz et al., 1999b; Rotz et al., 1999c; Watson and Atkinson, 1999; Shaffer et al., 2000; Wang et al., 2000
economics risk	Olney and Standing, 1989; Olney and Kirk, 1989; Warren and Johnston, 1989; Abadi Ghadim et al., 1991; Knutson, 1991b; Knutson, 1991c; Knutson, 1991a; Bottcher, 1992; Horn et al., 1992; Knutson, 1992; Ellis et al., 1993; Krisna and Pathak, 1993; Kubicki et al., 1993; Bhende and Venkataram, 1994; Knutson et al., 1995; Blaise, 1996; Hacker et al., 1996; Jones, 1996; Schoney, 1996; Stonehouse et al., 1996; Uribe et al., 1996; Gray et al., 1997; Schilizzi and Boulier, 1997; Thompson, 1997; Brennan and Gooday, 1998; Ghadim et al., 1998; Milham, 1998; Thompson and Powell, 1998; Thornton, 1998; Xin, 1998; Rotz et al., 1999a; Salinas et al., 1999; Shomo et al., 1999; Rotz et al., 2001
environment pesticides herbicides volatilization nature & landscape	McSweeny and Shortle, 1990; Abadi Ghadim et al., 1991; Kubicki et al., 1993; Swinton and King, 1994b; Blaise, 1996; Hutchings et al., 1996; Jones, 1996; Deer Ascough et al., 1997; Rotz et al., 1999c; Sells, 1999; Watson and Atkinson, 1999; Armstrong et al., 2000; Shaffer et al., 2000
machinery	Harvard et al., 1994

Two models that catch the eye are GPFARM (Shaffer et al., 2000) and APSIM (McCown et al., 1996). They provide an elegant framework within which the different modules can be easily combined so that, in theory, different specific farm systems can be designed. APSIM can only be used for arable farming while GPFARM can also be used for mixed farming. GPFARM uses an object-oriented software technology that makes it possible to evaluate management decisions dynamically. This means that parameters can be changed during a simulation run. However, the different modules consist of scientific simulation models, like crop growth models. A special issue of the Agronomy Journal, entitled ‘Use and abuse of crop simulation models’, concludes that these models are not suitable for these purposes, mainly because it is very difficult to validate each model for each specific situation (Baker, 1996). Besides, the scope of management aspects of the systems is very limited. They focus mainly on production parameters and a few environmental parameters, but hardly on any product quality parameter.

Table 4-4 A classification of whole farm management models for different modeling techniques.

modeling method	references
simulation ‘scientific models’ calculations	Abadi Ghadim et al., 1991; Knutson, 1991c; Knutson, 1991a; Bottcher, 1992; Van de Ven, 1992; Barry et al., 1993; Ellis et al., 1993; Kingwell et al., 1993; Swinton and King, 1994a; Swinton and King, 1994b; Cacho et al., 1995; Knutson et al., 1995; Blaise, 1996; Hack ten Broeke et al., 1996; Hacker et al., 1996; Hutchings et al., 1996; Schoney, 1996; Sibbald, 1996b; Smith et al., 1996; Uribe et al., 1996; Deer Ascough et al., 1997; Gray et al., 1997; Shewry, 1997; Smith et al., 1997; Velthof and Oenema, 1997; Brennan and Gooday, 1998; Deer Ascough et al., 1998; Ghadim et al., 1998; Milham, 1998; Oomen and Habets, 1998; Shaffer and Brodahl, 1998; Smeulders et al., 1998; Thompson and Powell, 1998; Thornton, 1998; Herrero et al., 1999; Pionke et al., 1999; Rotz et al., 1999a; Rotz et al., 1999b; Rotz et al., 1999c; Rotz et al., 1999d; Salinas et al., 1999; Watson and Atkinson, 1999; Armstrong et al., 2000; Shaffer et al., 2000; Wang et al., 2000; Rotz et al., 2001
optimization linear programming dynamic programming	Olney and Kirk, 1989; Westphal et al., 1989; Abadi Ghadim et al., 1991; Horn et al., 1992; Ellis et al., 1993; Kingwell et al., 1993; Bhende and Venkataram, 1994; Kouka et al., 1994; Stonehouse et al., 1996; Shewry, 1997; Brennan and Gooday, 1998; Ghadim et al., 1998; Oomen and Habets, 1998; Xin, 1998; Salinas et al., 1999; Sells, 1999; Shomo et al., 1999; Wang et al., 2000
budgeting nutrients	Barry et al., 1993; Velthof and Oenema, 1997; Milham, 1998; Pionke et al., 1999; Watson and Atkinson, 1999
evaluation diagnosis monitoring	Hack ten Broeke et al., 1996; Dalsgaard and Oficial, 1998; Rotz et al., 1999b; Rotz et al., 1999d; Armstrong et al., 2000
decision -making -support learning	Kristensen et al., 1997; Schilizzi and Boulier, 1997; Ohlmer et al., 1998; Shaffer and Brodahl, 1998; Thornton, 1998

Optimization models are mainly used for economic purposes and are often based on some linear or dynamic programming technique. In Chapter 2, it was already explained that this method is based on the *homo economicus*-view that does not correspond to the reality of management practice. Several budgeting models exist, mainly in the area of nutrient management. They are suitable to compare farm systems but do not really provide management support. Usually, they are designed for evaluating options for policy making. Some evaluation models are developed with special attention to environmental aspects. Such a model supports systematical diagnosing and monitoring certain parameters and in this way provides ideas for management improvement. This partly corresponds to the requirements that were described in Section 4.3

Finally, there are some recent models that focus on decision making and learning, which is also important for the requirements in this thesis. However, the approach of Shaffer and Brodahl (1998) relies heavily on simulation models. Moreover, Thornton (1998) attempts to simulate the decision-making behavior itself. This results in groups of management styles, which is suitable for descriptive purposes, but cannot be applied to the dynamics and diversity of everyday management practice. The same holds for the approaches of Schilizzi and Boulier (1997) and Ohlmer *et al.* (1998) that focus on the rationale of decision-making and are therefore more descriptive than that they are actually suitable for management support. However, it should be noted that they in line with the theory that was described in Chapter 2. The same holds for Kristensen *et al.* (1997) that emphasize the aspects of learning and the normative dimension of sustainability. They deal with the negotiation phase as described in Chapter 2, but do not show how this could be translated further into operational management.

In conclusion, many whole farm management models have a narrow, specialized focus on either farm type or management aspect. Hence, they are not applicable to the full range of management practices of mixed ecological farming, which deals with various crops and animals of which the variety is not fixed in advance and covers the whole range of management aspects in practice. This requires a much more generic approach because of the diversity in processes, and the interactions between them, that occur. Furthermore, it is questionable if the underlying modeling techniques correspond to the reality of farm management. In this respect, it should always be clear who are the final stakeholders of the model. If they are policy makers, then it is enough to distinguish general groups of farms and farmers. In the opposite, if stakeholders are farmers, a model should account for the specific, individual differences between farms and farmers and leave room for normative dimensions. Scientists can also be stakeholders of models with the purpose to explain biological or social phenomena. This results in usable knowledge, but this knowledge should be incorporated into a design-oriented approach before it becomes useful for management support. There are a few recent examples that try to develop models from the perspective of decision-making, but their number illustrates that this is still a largely undeveloped area that can be explored further.

4.4.2 Successes and failures of current and past agricultural decision support systems

The success of decision support systems in agriculture is often measured in terms of adoption rate. Several review articles conclude that, in this respect, successes are scarce and failures are plenty (Cox, 1996; Pannell, 1996; Parker, 1999; Keating and McCown, 2001). The success and failure factors they mention are summarized in the next subsections with the purpose to benefit from these lessons for the model development in this thesis.

4.4.2.1 Failures

Many decision support systems were developed without enough involvement of actual stakeholders. Frequently, the underlying models were originally developed for scientific research purposes and then, in second instance, it was thought that they could also be used for supporting farm management. This often has resulted in systems that were very complex in use and therefore required an extensive helpdesk that appeared to be too expensive afterwards. It was tried to sell a product without thinking about marketing. Sometimes, many data needed to be collected to feed the model in order for it to be reliable enough. This is usually the case when complex simulation models, which focus on prediction of ecological processes, form the basis. Then, it often appeared that the cost/benefit ratio was not small enough for successful use in practice. The same holds for systems that were developed for routine actions (structured problem situations) in which the farmer actually does not need any support from models. As mentioned in the previous section, many different models and systems were developed for different aspects of farming. In practice, it seemed that there was a poor integration between various systems, which is another failure factor.

Another important problem with 'scientific models' that are too directly applied to practice is that they usually are based on an objectivist approach (see Fig. 4-2). Their starting point is that there is only one view on reality and there is only one best solution to management problems. They fit into the biophysical view that was described in Chapter 2 of which was concluded that it did not correspond to the reality of farm system design. These systems often result in prescriptive rules a farmer has to apply in order to get an optimal solution to his problem. Often, the underlying models are complex and not transparent so that the reasons for advice that is generated is not clear and this leads to non-acceptance of the manager (see also Ackoff, 1967).

It can be concluded that many decision support systems failed, because they were not developed for farm systems design. They did not start with a farmer-centered approach and little energy was put into a study of how farm decision-making actually takes place.

4.4.2.2 Successes

Successes of decision support systems, mentioned in literature, are mostly connected with a participatory approach that focuses on interaction, communication improvement, sharing experiences and cultural embedding. The decision support system should not be considered as an end product, but as a process tool that facilitates decision-making. Models should play a modest role in decision-making (Hofstede, 1992).

There are a few models, based on simulation or calculations, that were successful, but these were simple and transparent models, that usually made themselves obsolete as a computer system, when farmers understood the underlying principles (Sinclair and Seligman, 1996). This emphasizes that decision support systems should not be viewed as an end product but as a process tool. Other models that were successful could be characterized by a generic modeling approach, which means that they were not very specific for a certain crop or animal. This corresponds to the requirements for the model in this thesis.

A final successful aspect mentioned is the broker role that models can play between research and practice. Use of models can elucidate white spots for research.

4.4.3 A new approach

In general, it can be concluded that despite several decades of modeling, the success of decision support systems in agriculture is not so large. The question is in which direction more successful pathways should be sought. Keating and McCown (2001) put this as (author's underlining):

> the biggest challenge facing the practitioners of farming systems modeling over the next 10 years, is not to build more accurate or more comprehensive models, but to <u>discover new ways of achieving relevance to real world decision making and management practice</u>

This corresponds to the philosophy and viewpoint that was described in Chapter 2 that puts the farmer in the center as a designer of his farm system. He should define his goals and means and evaluate the consequences. From the requirements, listed in Section 4.3, it can also be derived that no choice is made for one specific management aspect, specific crop or type of animal production; they support a generic approach. The farmer himself is optimizing the system and not any prescriptive, mathematical kind of model. This does not mean that these models are completely excluded. The farmer can still use them to support the heuristic problem solving process.

A modeling approach, which satisfies these requirements, will be relevant to the real world decision making of designing sustainable farm systems. The next section will describe how a model like that should look like.

4.5 Modeling the object system

According to Section 4.3, three model components can be distinguished of which the third one can be split up into two submodels. They are also dependent on each other as is as shown in Fig. 4-4. The model of the production system is called the *Product Flow Model*, indicating its logistic nature. The model of the desired farm system is called the *Sustainability Map*, because it maps the sustainability goals. The connection part of the information system is called *Sustainability Function Deployment*, indicating that sustainability as a main function is implemented further. The translation part of the information system is called the *Sustainability Management Handbook*, because it will contain instructions for operational management.

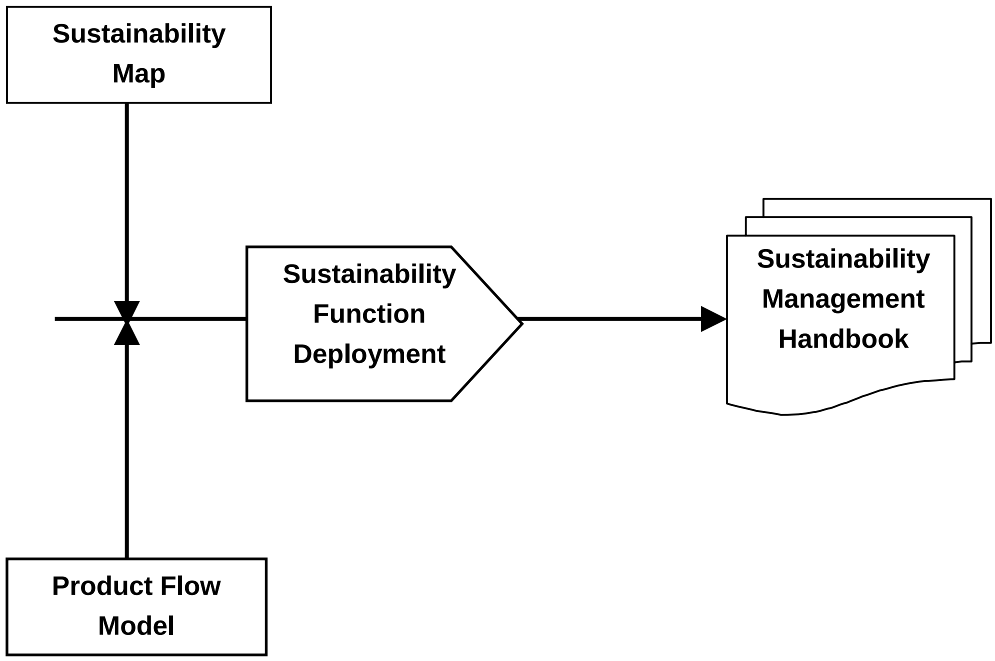


Fig. 4-4 System architecture of the model components. Information from the Sustainability Map and Product Flow Model is connected with each other and further elaborated by Sustainability Function Deployment, finally resulting in the Sustainability Management Handbook.

The model components will be separately described in the next subsections. Each of these subsections starts with a description of underlying ideas or existing concepts that were used: they constitute the model base (see Fig. 4-1). Then the ontology of the model is described, followed by a description of the entity-relationship diagram of the model. In this description, references to fields of an entity are written in `Courier` font type. All entity-relationship diagrams are combined in one entity-relationship diagram that is shown in Fig. 4-5. Finally, some software tools are described that support instantiation of the template. These are part of the database application of the IS-template and can also be used after first instantiation to view or edit the database.

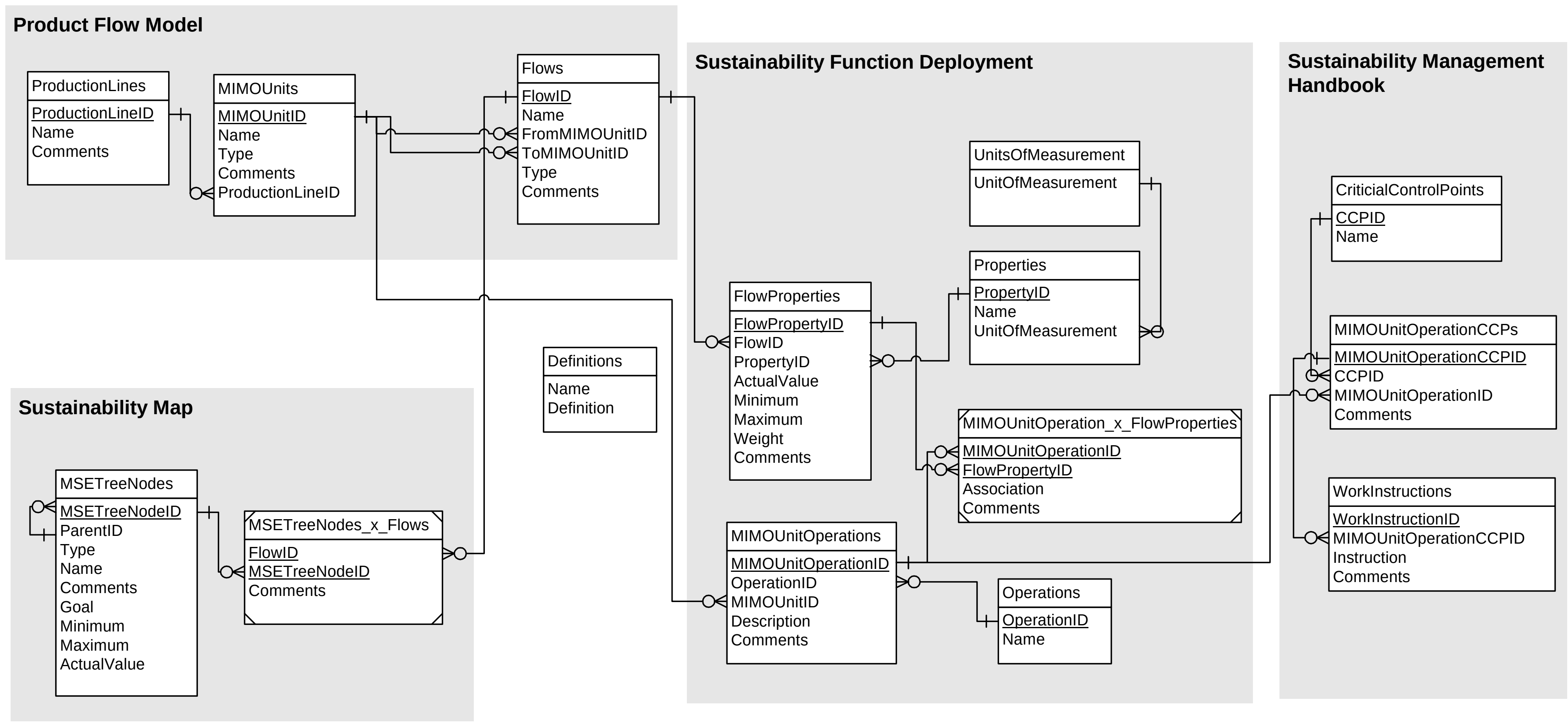


Fig. 4-5 Entity-relationship diagram of the whole information system. Some details, only useful for technical purposes, are left out. The entity `Definitions` has relationships with all other entities that have a `Name`-field so that every term with the same name has always the same definition. For clarity's sake the relationship lines for this entity are left out. A data dictionary is provided in Appendix III. Further description in text.

4.5.1 Product Flow Model

The main requirement for the model of the production system is that it provides a logistic representation. Generally, in a logistic model, managed units and flows of products between them are distinguished (Bertrand et al., 1990). For every specific farm system, the chain or network of units and flows can be quite different. Hence, one should look for a generic model that consists of basic building blocks that can be re-used to build every possible logistic chain. This kind of approach is referred to by Beers et al. (1994) as the 'minimal model approach'. First, this approach will be further described.

4.5.1.1 Minimal model approach

In the modeling approach of this thesis, the focus is on management, in particular operational control, of the production system. In connection with this, an important starting point of the minimal model approach is provided by Beers et al. (1994):

> …management is not primarily interested in the contents of processes, but rather in their behavior of transforming input to output.

This contrasts with models that were developed from scientific research, which are primarily interested in the processes themselves (e.g. crop growth, metabolisms, nitrate leaching). Hence, these models represent processes by simulation.
In the minimal model approach, the focus is on the primary processes. Miller and Rice (cited by De Leeuw (2000)) provide some useful definitions concerning primary processes:

> A system of activities is that complex of activities which is required to complete the process of transforming an input to an output. (…) An activity is a unit of work. Activities may be carried out by people or by mechanical or other means (…) A task system is a system of activities plus the human and physical resources required to perform the activities.

The primary process concerns the basic transformation of input to output and activities are related to them. These activities can be seen as secondary processes. In the minimal model approach only those secondary processes are taken into account, which are directly related to the primary processes. These type of secondary processes are referred to by Miller and Rice as operating activities (or abbreviated: operations):

> Operating activities are those activities that directly contribute to the import, conversion and export processes, which define the nature of the enterprise or unit and differentiate it from other enterprises or units.

In a farm system, examples of operations are sowing, plowing and feeding that are related to primary processes like potato production or milk production. Examples of secondary processes that are not taken into account are personnel management and financial management. Operations will be returned to in the description of the Sustainability Function Deployment model.

Now, the basic building block or minimal model can be described as a *production unit* as is shown in Fig. 4-6. Usually, input and output are not unique; a distinction can be made between different input and output of a production unit. For example, as input, a cow requires different kinds of feed, drinks water, etc. and as output, produces milk and manure. Therefore, one can speak of multi-input-multi-output (MIMO) production units (Jansen, 1998). This concept will also be applied in the Product Flow Model.

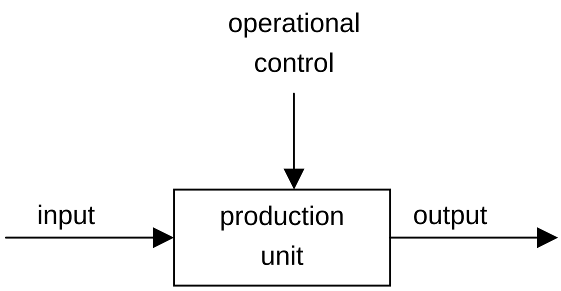


Fig. 4-6 The production unit as basic building block of the minimal model approach, slightly modified from Beers et al. (1994).

The next section formally describes how the minimal model and MIMO-approach is worked out in the product flow model.

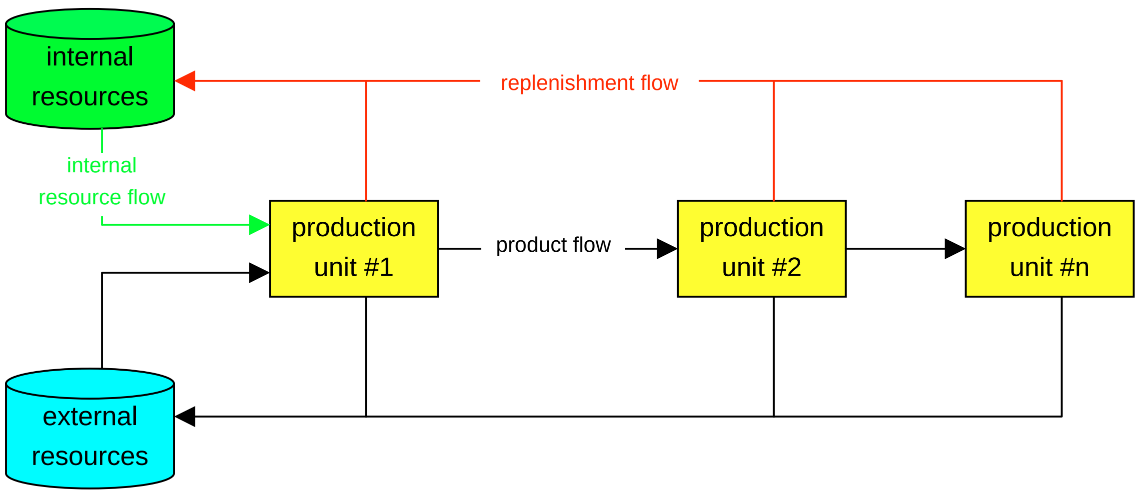
4.5.1.2 Ontology

Basically, the Product Flow Model is a connected network of minimal models or production units with preceding relationships. However, to distinguish between different kinds of input and output, in accordance with the MIMO-concept, some specializations are defined. Fig. 4-7a provides a schematic representation of this. All components are described in the next paragraphs.

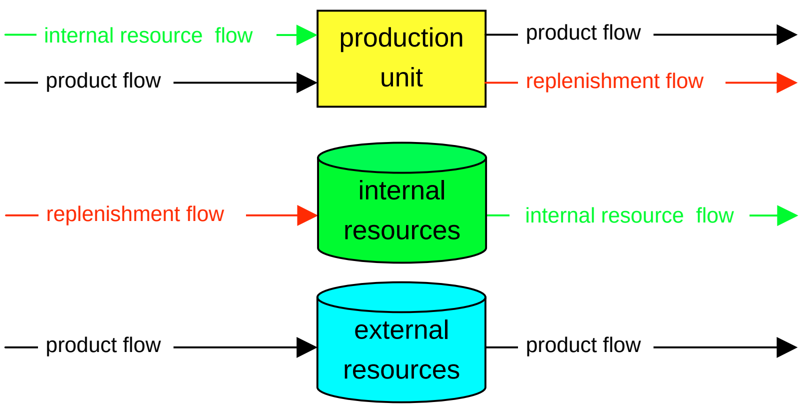
In the first place, *production units* are distinguished. These are directly managed units using input from other units and produce output that can be input for other units. In this way, a kind of *added value chain* can be distinguished. This chain, which is a sub-chain in the whole network of processes, can be identified as a *production line* like in industrial factories. Production units are usually connected with a certain site, e.g. a field, store or cow herd. In the latter example, the site is mobile: cows can be situated in a stable or a field.

To monitor import and export of products, *external resources* are distinguished. The external resources themselves are not important in the model. They usually represent suppliers as well as sales markets.

The main reason for distinguishing *internal resources* is to monitor procurement and replenishment of them, so that they are maintained in a dynamic steady state. Internal resources are distinguished as the most basic means for production and will usually represent natural resources like soil, water and air. Basically, they are also considered as multi-input-multi-output units, but in contrast with production units, they are not directly managed by operations. They are indirectly influenced by their input and output flows.



a) Generic product flow model



b) Distinguished multi-input-multi-output units and their flows

Fig. 4-7 Schematic representation of the product flow model: a) basic generic product flow model that shows all possible types of multi-input-multi-output-units, flows and their relations; b) the basic building blocks of the product flow model.

Distinguishing these special types of MIMO-units, several types of flows can be discerned. First, there are *product flows* between several production units or between a production unit and external resources. The procurement flow from an internal resource to a production unit is called the *internal resource flow*. The flow from a production unit to an internal resource is called the *replenishment flow*.
Now, various MIMO-units can be identified as shown in Fig. 4-7b. All definitions and rules for connections are described in Table 4-5. Besides, some concrete examples are provided.

Table 4-5 Types of multi-input-multi-output (MIMO) units and flows of the product flow model, their definitions and some examples.

MIMO-unit types	definition	examples
production unit	represents a primary process	potato growing, ensilaging, straw storage
external resource	resource outside the farm system	concentrates factory, fuel company, seed supplier, milk market
internal resource	resource that exists within the farm system	soil, water, atmosphere
Flow types		
product flow	material flow between two production units or between an external resource and a production unit	wheat, mown grass, manure
internal resource flow	material flow from an internal resource to a production unit	soil as starting material for growing, air containing nitrogen than can be fixated
replenishment flow	material flow from a production unit to an internal resource	soil as material left after growing, crop residues

4.5.1.3 Entity-relationship diagram

In the upper left part of Fig. 4-5, the entity-relationship diagram of the Product Flow Model is shown. The Entities `MIMOUnits` and `Flows` form the basis. The attributes `FromMIMOUnitID` and `ToMIMOUnitID` determine the originating and destination MIMO-unit of a flow. The field `Type` of the entity `MIMOunits` determines the type of MIMO-unit: a production unit, external resource or internal resource. According to the ontology of the Product Flow Model, it would not be necessary to include a field `Type` for a flow, because two connected MIMO-units already determine the type of flow. However, it was included for reasons of efficiency. If, for example you want to know the flow type in a certain query, you always would have to include a sub-query that identifies the from- and to-MIMO-unit. This construction could possibly lead to inconsistencies in the model. Applying consistency rules in the database application that was used to instantiate the data model solved this.

MIMO-units are appointed to `ProductionLines`, so that added value chains can be easily selected. This could be useful in practice, because usually a certain production line has one manager that is responsible for that specific line.

4.5.1.4 Software tools

For instantiating the Product Flow Model, it would be possible to edit the related database tables directly. Usually, this is done more conveniently by data entry forms. However, in this way you would never get a clear overview of what flows are connected with what MIMO-units. What one should want, is to look at the Product Flow Model as it is represented in Fig. 4-7a. Hence, a diagramming tool was searched for that satisfies this need. A first prerequisite for such a tool is that you can flexibly create and change network diagrams. There are numerous applications with which you can do this, however the diagram must also fulfill the requirements of the described ontology. Besides, it is also not very useful when you have to update both the diagram and database manually; this will certainly lead to inconsistencies. A diagramming tool that satisfies these needs was found in Visio. A description of how this software was used is provided in Chapter 5.
In this way, a flexible tool can be used to create and update the Product Flow Model quickly. It offers possibilities to overview the whole production system and to gain insight in it. Therefore, it is also an excellent tool for communication purposes.

4.5.2 Sustainability Map

Next to a model of the production system, a model of the desired system is required. The main requirement is that it should be a goals-means-hierarchy and it should be connectable with the Product Flow Model. Multifaceted Structured Entity (MSE) modeling (Zeigler, 1984) was found as an existing approach that could be used. In this section, this will be further explained and translated to a formal ontology and entity-relationship diagram.

4.5.2.1 A Multifaceted Structured Entity decomposition

There are several reasons to represent the model of the desired system as a hierarchical decomposition. In a hierarchy, goals and means are made concrete in a systematic way, so that it is clear how they were established. It results in a consistent and cohesive whole.
The main goal, a sustainable farm, is not directly quantifiable and therefore not measurable and controllable, because it involves normative assessments (Simon, 1997; De Leeuw, 2000). These cannot always be set in advance. They can depend on circumstances of the actual situation. Papy (1994) nicely explains this as he says:

> The crop or livestock farmer knows from the start that his objectives are not certain to be reached. Since predicting future events concerning the climate, the economic situation or incidents of all kinds is impossible, the farmer tries to allow for this by setting himself *ex ante*

> certain rules that provide him with a degree of flexibility. However, it is impossible for him to imagine at any time an overall adjustment of his farm; for this he needs to break the problem down.
> (…) The farmer breaks down his end production objective into sub-objectives that he has a better chance of achieving at certain points in time

By putting this break-down or decomposition into a hierarchy, the farmer can focus on subgoals, without the risk that goals, higher in the hierarchy, get lost. This is fully in accordance with the universally accepted connection of the three management levels: strategic planning, management control and operational control (see also Table 4-1); they should be logically related to each other (Simon, 1977; Keen and Scott Morton, 1978; De Leeuw, 2000).
If a goal is not directly quantifiable, it has more dimensions or aspects (De Leeuw, 2000). For example, sustainability has economic, social and ecological aspects. Hence, a decomposition of goals will consist of aspects and descending subgoals. It also means that goals, higher in the hierarchy, cannot be simply evaluated. It depends on the aspects that are taken into account and what values the farmer attaches to them and to the underlying sub-goals. Variation in styles of farming occurs in this process.
Zeigler (1984)[1] described a methodology for decomposing that is called Multifaceted Structured Entity (MSE) modeling. The objective in this methodology is to make a structured decomposition of a system in reality, which is called the System Entity Structure (SES), It contains a decomposition for several facets, or aspects, of the system. An important starting point of MSE modeling is that a system in reality is never fully decomposable. This means that one entity can play a role in different aspects of the system. For example, the entity ‘animal welfare’ can be part of the ecological as well as the social dimension of sustainability. Animal welfare is important in ecological farming, but is also socially desired. MSE modeling results in a cohesive, well-balanced decomposition. Then, the SES serves as a model base to make several simulation models of the same system from, for different purposes, while in the meantime guaranteeing a consistent use of entities.
In the modeling approach in this thesis, the objective is not to make a simulation model of the farm system, but the MSE methodology will be used to make a decomposition of the goals of the farm. The unstructured goal ‘sustainable farm’ is decomposed into aspects and entities until entities can be quantified and can be connected with flows of the Product Flow Model. Entities are wholes that have a meaning in practice (e.g. crops, financial result, protein content). Connections identify the means of connection in the Product Flow Model that can be used to reach the goals. So, what products play a role in reaching a goal? Inherent to the

[1] Actually, it were M.S. Elzas, T.I. Ören and B.P. Zeigler that together developed this methodology. Much research with this methodology was carried out at the former Department of Computer Science of Wageningen Agricultural University.

structure of the Product Flow Model, these products will usually depend on each other. So, this is the point where appropriate cycles or chains of products have to be identified. What cycles or chains should be identified, is a matter of heuristic problem solving. This is not clear in advance. It depends on craftsmanship, insight and experience, of the farmer. Hence, the Sustainability Map must be flexible and easily updateable.

The idea of a Sustainability Map is schematically represented in Fig. 4-8. The goal ‘sustainable farm’ is taken as the root entity and is decomposed into a whole tree of aspects (a_1, a_2, .., a_n) and entities (E_1, E_2, .., E_n). A goal is set on each entity. As long as the goal is not quantifiable, the entity should be further decomposed into aspects and other entities until quantified goals can be defined. Then, a connection with flows of the Product Flow Model should be made. There are also cases in which a goal is quantifiable, but it cannot automatically be related to flows of the Product Flow Model. This typically is the case with aggregated goals like ‘farm results’ that depends on several other entities like ‘sold crops’, ‘sold milk’ and ‘sold meat’. Then, this entity should be further decomposed into these subentities. A connection with a flow from the Product Flow Model is indicated by a cross in the appropriate cell.

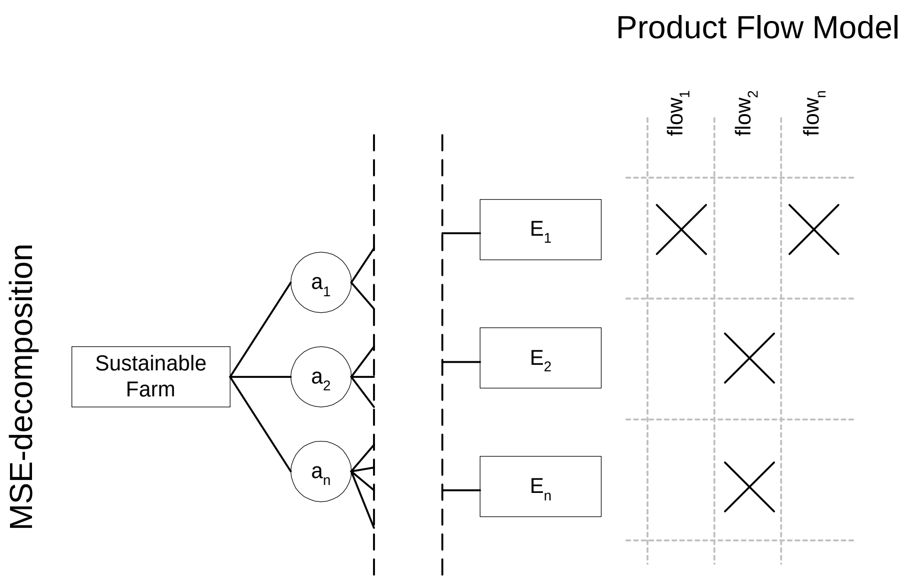


Fig. 4-8 The MSE decomposition of the main objective ‘sustainable farm’ and connection with flows from the product flow model. The vertical dashed lines indicate that usually more branches of aspects and entities are in between, but they are left out for clarity’s sake. A cross in a cell indicates a connection between an end entity and a flow.

The next section describes the ontology of MSE modeling as it is applied in the modeling approach in this thesis.

4.5.2.2 Ontology

A hierarchical tree decomposition consists of nodes. Table 4-6 describes the types of tree nodes that are possible in a MSE decomposition tree and the possible attributes they can

have. All nodes have a name with accompanying definition, and comments can be added for different purposes. For example, comments can be used to describe arguments why a node is split up into certain aspects or entities. The root entity in this thesis is fixed, namely ‘sustainable farm’. A goal, described in words can be added to an entity. For an end entity, this goal must be quantified into a ‘goal value’. This goal value must be specified by a minimum and/or maximum, because reaching a goal is always a matter of degree (Simon, 1997). The attribute ‘actual value’ should indicate the actual status of the goal that is monitored. Only end entities can have a connection with one or more flows.
Finally, there are two rules for building up an MSE-tree:

- an entity can be split up into one ore more aspects or one or more specializations;
- an aspect must be split up into one or more entities (so, an aspect can never be an end node).

Table 4-6 Types of tree nodes in a MSE decomposition: definitions and attributes. The x indicates if a tree node has this attribute or not; brackets [ ] indicate that this attribute is optional. Further description in text.

		attributes						
					goal value			
MSE tree node types	**definition**	definition	comments	goal	mimimum	maximum	actual value	flow connection
root entity	Entity at the highest level of the decomposition tree	x	x	x				
aspect	Describes a dimension of the parent entity; all aspects together describe its functionality	x	x					
branch-entity	Entity with a parent node and one or more child aspects or specializations	x	x	x	[x]	[x]	[x]	
end entity	Entity with a parent node but no child nodes	x	x	x	x	x	x	x
specialization	Branch- or end entity with an entity as parent and represents a specialization of this entity (e.g. nutrient can be specialized into nitrogen, phosphorus and potassium)	x	x	x	[x]	[x]	[x]	[x]

4.5.2.3 Entity-relationship diagram

The entity-relationship diagram of the Sustainability Map is shown in the lower left corner of

Fig 4-5. The whole MSE-tree can be represented by one entity, namely `MSETreeNodes` with a recursive relationship between the fields `MSETreeNodeID` and `ParentID`. The type of MSE-tree node is determined by the field `Type`. A software tool takes care of consistency of ontology rules.
The associative entity `MSETreeNodes_x_Flows` defines the connections between end entities and flows of the Product Flow Model. An end entity can be connected with one or more flows and a flow can be connected with one or more leaf entities. This highlights the multi-faceted aspect, because in this way, a flow can play a role in more than one goal. The field `Comments` can be used to describe arguments why a certain flow is connected with a certain goal.

4.5.2.4 Software tools

Like in the case of the Product Flow Model, transparency would be enhanced, and thus insight and communication, if the Sustainability Map can be created and edited in a more graphical way like shown in Fig. 4-8 with the aid of a software tool. The MSE-tree should then be represented as a tree of which the branches can be collapsed and expanded. This tool should also take care of consistency, according to the defined ontology. Furthermore, it should be possible that one can easily pick the flows that have to be connected with an end entity from a list of existing flows that is automatically generated from the database. This software was developed and called ‘Sustainability Mapper’. It will be further illustrated in Chapter 5.

4.5.3 Sustainability Function Deployment

In the Sustainability Map, goals, that can be quantified, are connected with flows of the Product Flow Model. The farmer thinks they form the means in order to reach the related goal. So, you could say that the unstructured goal ‘sustainable farm’ is broken down into semi-structured goals or in other words: the strategic planning level is translated to the management control level. Logically, the next step should involve the translation of semi-structured goals into structured ones or in other words: the translation from the management control level to the operational control level. This translation was called Sustainability Function Deployment (SFD) that was taken from the existing concept of Quality Function Deployment. This will first be explained.

4.5.3.1 House of sustainability

The connection of a goal with a flow must be further worked out by indicating what properties of a flow contribute to this goal. In other words: what are the critical properties of a flow that should be managed? Therefore, goals should also be set on these flow properties. For the same reasons as in the Sustainability Map, a goal should be defined using a certain bandwidth with a minimum and/or a maximum. The next question is: how can the flow property be kept within this desired bandwidth? The answer is: by the operations of the production unit, with which the particular flow is connected. Not all operations will influence a certain flow property in the same way; some of them will not influence the property at all. Therefore, a method was looked for that relates flow properties with operations also indicating the strength of the relation. An existing method, often applied in the assembly industry, that satisfies these requirements to a large extent, is Quality Function Deployment.

Quality Function Deployment is a concept and mechanism for translating customer requirements, often referred to as the ‘voice of the customer’, through the various stages of product planning, engineering and manufacturing into a final product (Kim et al., 2000). It is usually applied to the design and production of a new product, but sometimes it can also be applied to redesign an existing product. It involves a cascade of association matrices in which requirements (‘whats’) are associated with activities (‘hows’). All matrices are not always used. The last one, the production planning matrix, is used most frequently. The principle of this final matrix will also be used in Sustainability Function Deployment. The preceding matrices can be compared with what is done in the Sustainability Map, which basically could also be represented as a cascade of association matrices. The association matrix is called the ‘House of Quality’ and is schematically shown in Fig. 4-9. The name comes from the similarity with a saddle-roof house. The rows list the requirements (whats) that have to be fulfilled and the columns the activities (hows) that are involved. The requirements can be given a certain weight (e.g. ranging from 1 = less important to 5 = very important) in order to prioritize between them. The association matrix is the main part of the house. The associations are put in the crossing cells between the requirements and activities. They are often represented by a number: 1 = weak, 3 = medium, 9 = strong. This classification results in a stronger and clearer identification of critical points, instead of that numbers 1, 2 and 3 were used. The sum of multiplications of weights and associations results in scores, which gives the opportunity to rank the importance of activities. At the right, a comparison can be made with competitors for the requirements that can help to identify the requirements that should possibly get more attention. In the ‘roof’, conflicting trade-offs between activities can be identified. If there is trade-off, the scores can be used to make a choice.

One of the strongest points of Quality Function Deployment is that not only product properties in relation to quality are taken into account, but that they are linked with management control (Maas and Becking, 1996). Besides, it helps to gain more insight into the whole design process and improves communication between people of several departments of a firm. Quality Function Deployment can be seen as a guiding instrument for systematically translating objectives into operational control. It is also a rather time-consuming instrument. Time could be reduced by using the weights and scores to work out the most critical points first.

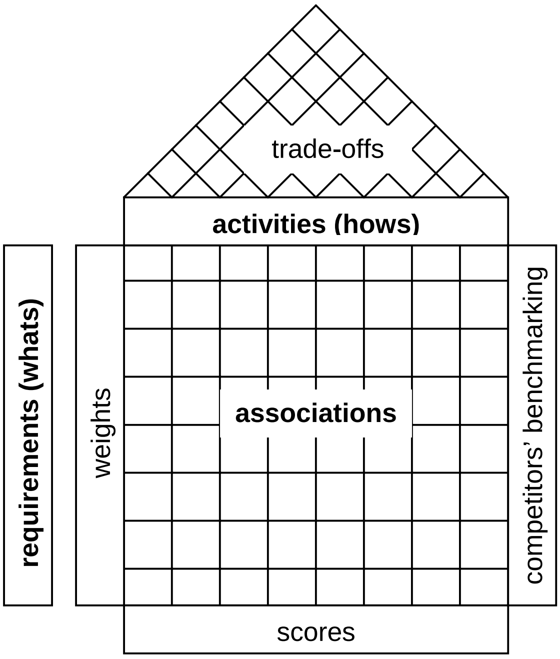


Fig. 4-9 The house of quality (adapted from Maas and Becking (1996)). Further description in text.

As mentioned before, Quality Function Deployment is mostly applied for assembly industries (e.g. cars, computers). Some authors have shown that the concept is also applicable for the agri-food chain (Jongen et al., 1996; Van Trijp and Steenkamp, 1998). One problem in this case is the higher variability in the product properties. For example, it is relatively much easier to reduce the variability of the shape of bolts and nuts than the starch content of potatoes, because in the latter case the influencing factor is less controllable.

The focus in this thesis is not on quality, but on sustainability. Therefore the name of the method was adapted to Sustainability Function Deployment (SFD) and the matrix can be called the 'House of Sustainability'. The principle basically remains the same, namely translating goals (requirements or whats) into operations (hows). The model will be described more precisely in the next section.

4.5.3.2 Ontology

Fig. 4-10 shows the framework of the Sustainability Function Deployment-matrix for an arbitrary flow. Flow properties ($p_1..p_i$) are listed in rows. A bandwidth for a goal is set by a minimum and/or maximum value, accompanied by the appropriate unit of measurement. A property is weighted by a factor, with a domain [1,2,3,4,5]; 1 = low importance and 5 = high importance. This factor indicates a *relative* importance between the properties in a Sustainability Function Deployment matrix. A weight of 1 indicates that this property is less important than others, but it is important, because otherwise it would not appear in the matrix at all.

The last columns list the operations ($o_1..o_j$) of the production unit of which the particular flow is output. Within the bounds of a production unit, the number and kind of operations can be chosen freely, but in most cases they will consist of the general defined agricultural operations like sowing, weeding, fertilizing, harvesting, etc. However, if a farmer wants to include a specific operation that only he himself applies in his specific farm system, he is free to do so.

Associations ($p_i \cdot o_j$) can be made between flow properties and operations within the following value domain:

0	no association
1	weak
3	medium
9	strong

In case of 0, the cell can also be left blank. There are no official rules that tell what associations should be made and how strong they should be. This relies on expert knowledge and experience of the farmer and is a matter of heuristic learning. It means that they can also change in time.

						operations			
		goal		unit	weight	o_1	o_2		o_j
flow properties	p_1	min_1	max_1	u_1	w_1	$p_1 \cdot o_1$	$p_1 \cdot o_2$		$p_1 \cdot o_j$
	p_2	min_2	max_2	u_2	w_2	$p_2 \cdot o_1$	$p_2 \cdot o_2$		$p_2 \cdot o_j$
	p_i	min_i	max_i	u_i	w_i	$p_i \cdot o_1$	$p_i \cdot o_2$		$p_i \cdot o_j$
				score = $\Sigma (w_i \cdot p_i \cdot o_j)$					

Fig. 4-10 The general framework of the Sustainability Function Deployment matrix. Flow properties are listed in rows. In the first column, the name (p) is listed. In the second column a goal can be set on a property, ranging from a certain minimum (min) to a maximum (max). The third column defines the unit of measurement (u) of a property. In the fourth column a weight (w) can be attached to properties. The last column lists a range of operations (o) of the production unit concerned. In the crossing cells between operations and properties, associations (p·o) can be defined. The score in the bottom row is the weighted sum of these associations. Further description in text.

The score for the operations is the weighted sum of the associations and give an indication what operations should be worked out first.

For reasons of time, the part with competitors' benchmarking (at the right in the original house of quality) is left out. In this column, product properties could be compared with

properties of other farmers. At the moment, farmers are not considered to be each other's competitors, but as each other's colleagues. Hence, benchmarking is not seen as relevant in this respect. However, in the current trend of globalization, it might become more important.
The trade-off part (the roof of the house of quality) is also left out for reasons of time. This would offer possibilities to indicate if two operations conflict with each other based on a certain property. This can be very relevant and should be included in next versions of the model.

4.5.3.3 Entity-relationship diagram

In the center of Fig 4-5, the entity-relationship diagram for Sustainability Function Deployment is shown. The entity `FlowProperties` is related to the entity `Flows` and could be seen as an extension of the Product Flow Model. An additional entity `Properties` was added so that a particular property can be reused. For example 'protein content' can be a property of milk, grass/clover or concentrates. This construction promotes a consistent definition of properties. A similar construction was made for units of measurement.
The entity `MIMOUnitOperations` is related to the entity `MIMOUnits` and can also be viewed as an extension of the Product Flow Model. Again, for reasons of reuse, a general entity `Operations` was defined so that an operation will always have a consistent definition. However, a field `Description` was included in the `MIMOUnitOperations` entity, because an operation can be differently described within the context of a specific production unit. For example, sowing wheat or onions concern both the process of sowing: putting seeds into the soil, but the process itself and the kind of material used is different.
The associative entity `MIMOUnitOperations_x_FlowProperties` handles the association between operations and flow properties. The field `Association` indicates the strength of the association. `Comments` can be added to describe arguments about why this association was made.

4.5.3.4 Software tools

Like with the other model components, it would be useful if a piece of software was developed that allowed to fill in the data like the matrix in Fig. 4-10. It could be extended with several consistency checks and hyperlink functions. For example, when clicking on a property or operation more details would become visible. However, at the moment such a software tool is not yet developed and a more simple database entry form is used to fill in the data.

4.5.4 Sustainability Management Handbook

In the Sustainability Function Deployment model, goals are set at the lowest level, namely at the flow properties level and they are associated with operations of a production unit. In this way, the farmer can concentrate on a certain action that takes place in a limited time span (ranging from a few minutes to one or a few days) and will usually be related to a limited entity (e.g. field, cow, storage), while the goals at a higher level are still accounted for. The basis for the ecological production principles of prevention and recycling management is laid down in the Sustainability Map and Sustainability Function Deployment by identifying cycles or chains of product flows and setting goals on their properties. By managing intermediate products at the start of a chain, it is expected that the desired properties of products at the end of the chain are assured. This corresponds to the concept of Quality Assurance that is used in industry (Peratec, 1994). At the lowest level, operational control, this must be insured. This means that critical control points during operations should be identified. What moments, actions or parameters are determining goals that were set on product properties most? Next, instructions should be written and carried out in order to handle these critical control points.

This idea of identifying critical control points and writing accompanying work instructions was taken from existing systems like HACCP (Hazard Analysis of Critical Control Points) or ISO-9000. It would be possible to structure the critical control points and work instructions according to these standards, but this goes beyond the scope of this thesis. Hence, the ontology of this model component is quite simple and will be directly described by its entity-relationship diagram. Before that, some statements are made about different types of work instructions. Finally, some remarks are made about connections with the other model components.

4.5.4.1 Work instructions

A multi-input-multi-output-unit can be represented by the following function:

$$f(I \pm \Delta I) = O \pm \Delta O$$

I stands for a certain input property that may vary within a certain bandwidth, indicated by ΔI. The function of the unit is that it transforms input to output (*O*) that also may vary within a certain bandwidth (ΔO). Now, different types of work instructions can be distinguished:

- <u>Control instructions</u> concern input (e.g. seeds, manure) that is involved in a production unit. Does it satisfy the requirements (i.e. the flow property goals) and if not, what (corrective) measures should be taken? It is not always possible to check everything continuously, so usually <u>sampling instructions</u> should be included that describe a frequency, quantity and method of analysis. Results should be written down on (electronic) *registration forms*, so that it is always possible to trace possible sources of problems further up in a chain.

- Monitoring instructions concern output and are needed for monitoring goals that were set in order to be able to evaluate them. Again, these instructions can also involve sampling instructions and registration forms. In case of deviations, it should be described what corrective measures or other actions should be taken.
- Inspection instructions are related to the status of external circumstances (e.g. weather, markets) or internal entities (e.g soil, crop, machinery). For example, in case of soil, a specification of the status 'before' and 'after' can be defined. In many cases, 'if-then rules' will be involved, related to operating instructions (see next item).
- Operating instructions describe how to carry out continuous actions and will usually involve some machine or other tool. They can refer to certain adjustment *specifications* (e.g. of a plow, harrow, milking machine).

A set of chronological work instructions that are directed to the same goal is usually referred to as a *procedure*. Procedures are not defined in this model, but should be defined in next versions.

4.5.4.2 Entity-relationship diagram

The identification of critical control points follows from the associations that were made in the `MIMOUnitsOperation_x_FlowProperties` entity. So, each association that was defined in the Sustainability Function Deployment matrix, must be translated into one or more critical control points and accompanying work instruction(s). All critical control points and work instructions together form the Sustainability Management Handbook. As indicated in the right half of Fig 4-5, it is represented by three entities in the entity-relationship diagram: `CriticalControlPoints`, `MIMOUnitOperationCCPs` and `WorkInstructions`. The entity `CriticalControlPoints` is defined for reasons of reuse of the same critical control point in several operations. A critical control point is defined for a specific operation, which is determined by the field `MIMOUnitOperationID` in the entity `MIMOUnitOperationCCPs`. Every specific critical control point results in one or more work instructions as is determined by the field `MIMOUnitOperationCCPID` in the entity `WorkInstructions`.

4.5.4.3 A handbook with different views

Work instructions form the basis of the handbook. They can be considered to be the final result of breaking down the unstructured goal 'sustainable farm' into structured tasks. Because this was done in a hierarchical framework, these tasks or instructions are not isolated entities. Their context can be made visible, because they are logically related to other model components, united by one and the same relational database. Relational databases are generally augmented with a very powerful tool: Structured Query Language (SQL). SQL provides many possibilities to look at the data in many different ways. In this model, basically two important views can be distinguished:

1. top-down: from the goal ‘sustainable farm’ it is possible to drill down the whole model to see what you are actually doing at your farm in order to satisfy this goal. This helps to make the principles of preventive and recycling management transparent. It provides a ‘helicopter view’ on the farm system.
2. bottom-up: for each critical control point and work instruction you can make clear (e.g. to colleagues or certifying authorities) for what purposes you are doing this. The main benefit is that at the moment the farmer is carrying out a certain work instruction, he does not have to worry about the higher level goals.

Based on SQL queries, sophisticated software tools can be developed that facilitates these processes. However, at the moment this has not yet been elaborated further.

4.6 Farm system design: how to use the model?

So far, the information system design, as shown in the left part of Fig. 4-1, was described. This section returns to the question how the developed models should be used and function in practice of farm system design (right part of Fig. 4-1). Basically, this should be in line with the three-phase-methodology of designing sustainable farm systems as described in Chapter 2: negotiation, heuristic problem solving and operational control.

A first instantiation of the template has to be made for a specific farm, indicated as ‘object system farm x’. This is done in four steps, in parallel to the model components that were developed, namely:

- Product Flow Modeling,
- Sustainability Mapping,
- Sustainability Function Deployment,
- critical control point identification and writing work instructions.

For this first instantiation, these steps will be taken in sequential order. After first instantiation, the information system will be incrementally updated, because the object system changes and the farmer is learning, resulting in new goals, critical control points and work instructions. This incremental update can involve only parts of the whole information system, for example only the Sustainability Management Handbook, but not necessarily all steps have to be taken each time in the same order.

The first, basic instantiation will be described first and then how the internal learning phase is supported by the information system. Finally, some technological and organizational implications will be discussed.

4.6.1 First instantiation

First, the production system must be modeled as a Product Flow Model. This can be quickly done using the software application that was developed in interaction with the farmer. The basic rule for splitting up the production process into production units is that there should be a product flow from a certain site to another one and that there is a difference between input and output, influenced by the activities or operations of the corresponding production unit. However, this does not necessarily always have to result in exactly the same representation of a system. Like in all modeling methodologies, there are some degrees of freedom left to the creativity of the modeler (Avison and Fitzgerald, 1995). Thus, subjective choices can be made, while one result is not by definition better than the other one. The most important thing is that the farmer recognizes his own farm in the represented Product Flow Model of his farm system.

Secondly, the Sustainability Map and the connections with the Product Flow Model should be established. This can be done by using the software tool that was developed for this purpose: the Sustainability Mapper. Therefore, the farmer should negotiate with his socio-economic environment, implicitly taking into account his personal attitudes. In this step, it could be useful if some possible examples of a Sustainability Map are provided, although it should be avoided to influence the farmer’s personal view too much. Again, the rules to split up entities and aspects are not so strict that one will always end up with the same decomposition. However, the most important result is that concrete goals of end entities are connected with flows of the Product Flow Model. The exact decomposition pathways from the root entity ‘sustainable farm’ to certain end entities are less important. The pathways should be based on logical arguments and must be clearly described.

In the third step, Sustainability Function Deployment, the goal-flow connections that were identified in the previous step, must be translated further into specific goals that are set on flow properties. These must then be connected with operations of the corresponding production unit. At this stage, the production units of the Product Flow Model are split up into operations and the flows are extended with flow properties. Again, it might be useful if some predefined examples are already provided in the database.

In the last step, the associations that were made between flow properties and operations are further worked out into critical control points and accompanying work instructions. This will be the most time-consuming step and therefore one should start with the flow properties with the highest weight and the operations with the highest score.

So far, the farmer is supported in strategic planning, management control and operational control of his farm system. In this way, a first version of the information system for a specific farm is established. Now it can be updated as a result of the internal learning process.

4.6.2 Incremental updating by heuristic learning

Basically, the information system supports the farmer's decision-making process during operations. It was mentioned that monitoring instructions should be involved in the handbook for monitoring goals. Beside monitoring the object system, it is also important to report if work instructions were carried out in the appropriate way. This should be checked by inspecting if registration forms are filled in or not. This becomes more relevant when product traceability and certification become an important goal.

When goals are not reached, the farmer can use the information system to investigate or diagnose where the problem possibly lies. If it concerns a flow property goal he can start to evaluate the work instructions that are involved. Then he can move up higher in the Sustainability Map (the bottom-up view!) and try to think of other preceding flows that might influence the goal value. In other words: there could be other means involved that he did not identify yet or values of identified means were not estimated correctly. If it concerns a goal at a higher level in the Sustainability Map, he can drill down the decomposition (the top-down view!) and reconsider the identified sub-goals and means. When the farmer has thought about possible solutions, a heuristic problem solving procedure starts by defining alternatives that are tested and evaluated. At this point, it is important to define the right experiments that can be seen as the keys to heuristic problem solving (see Chapter 2). The farmer uses experience and external knowledge in order to find them. In this process, it will turn out if one farmer has better experience, knowledge, learning skills or perhaps 'a better nose' than another one.

The outcome of a heuristic search will result in a change of the information system, for example in updated work instructions. In this way, the internal learning loop (see Fig. 4-1) will result in a more and more farm- and farmer-specific information system.

4.6.3 The computer, the farmer and the consultant

Because an instantiated information system has a high data and information density, the computer becomes an indispensable tool. It is needed for generating the right, filtered view on this information.

The first instantiation will be time-consuming, depending on the size of the farm system and to what degree the farmer thinks and works already in a similar way. In principle, if the software environment is user-friendly enough, the farmer can instantiate the information system himself. However, especially for the first instantiation, it might be better to leave that to a consultant. Such a consultant can build up experience in using the computer system, while this is not primarily the work for a farmer. As he has implemented the system for many other farm systems, he will also be able to advise the farmer in his heuristic search process. After the first instantiation, it is possible that the farmer himself updates the information system further or he can also leave that completely to the consultant, while there is a whole range of possible combinations in between.

4.7 Conclusions

(Hint: while reading these conclusions, it is a good idea to glance back regularly to Fig. 4-1).

This chapter described a modeling approach that supports designing sustainable farm systems. The final result of the approach is an information system that supports the farmer in decision-making with respect to his operational management. However, a crucial difference with many other modeling approaches is that rules for decision-making are not prescribed, but have to be defined by the farmer himself. For this defining, the farmer is supported by a template that consists of an information model and some software applications for instantiation. This template works as an instrument that helps the farmer to model information concerning his desired system and his production system according to his own personal view. This mainly takes place by Sustainability Mapping and Product Flow Modeling. Next, the template helps the farmer to combine this information (Sustainability Function Deployment) and translate it to his operational management by defining critical control points and accompanying work instructions, resulting in a Sustainability Management Handbook. Thus, the farmer is supported in the management process of translating the strategic, but unstructured, goal of sustainability into his operational management.

Related to the management process model, the information model consists of a data model that, by means of entity-relationship diagramming, is instantiated into an actual database. This enables the farmer to evaluate his decisions and gain insight into his farm system, so that he can improve decision-making. This will be necessary, because the environment will constantly change. Thus, the farmer is supported by this instrument in adapting his farm system to the changing environment in line with the three-phase-methodology of negotiation, heuristic problem solving and operational control.

The modeling approach is a generic approach, so that the information system can be tailored to farm- and farmer-specific situations. Therefore, it can be applied to mixed farm systems that are characterized by heterogeneous processes. Besides, this generic approach makes it possible to include different aspects of managing sustainability. Hence, it is supposed to correspond to daily management practice a farmer is faced with in reality.

The production system of primary processes is modeled by means of a logistical network of multi-input-multi-output-units and product flows in the Product Flow Model. In this model, it is possible to identify chains and cycles of products, including internal and external resources. This makes it possible to implement the ecological production principles of prevention and recycling, as described in Chapter 3, in operational management.

However, the model description is still rather abstract and the question is how it will turn out to be, when it is applied to real practice. Therefore, the next chapters provide some case studies that illustrate how the model can be used in practice.

5 A general instantiation of the model - an introduction to the case studies

Take care that you can read the map if you want to explore the area

Tony Buzan (2000, p. 159)

Abstract

While the previous chapters provided the theoretical basis of the model and the methodology, the next chapters provide some concrete case studies that should be considered as a proof that sustainability can be implemented in operational farm management. This chapter serves as an introduction into the case studies. It describes the whole model and its subcomponents in a nutshell and shows how they should be used. The ecological farm system at the 'ir. A.P. Minderhoudhoeve' is used as a test in practice. Software tools that are used for instantiation are illustrated and explained. The case studies in the next chapters go into more detail with regard to several aspects of sustainability and ecological production.

5.1 Introduction

The Chapters 5 to 7 serve as an illustration of the model and its underlying methodological basis, as described in the previous chapters. In this way, they serve as a proof of principle that with this methodology all kinds of sustainability goals can be implemented in the operational management level of a farm system. The ecological farm system of the APMinderhoudhoeve (further abbreviated as APMeco) serves as the object of this illustration. Some general data on this farm are provided in Appendix I, while Chapters 5 to 7 will show some more details. The assumption is that the farm configuration (crop rotation, herd composition, stable type, etc.) is fixed.

Within the time scope of this thesis it was impossible to work out all possible goals for all possible production processes. Therefore, two case studies were chosen. By covering different aspects, it is made plausible that all kinds of sustainability goals can be implemented in a similar way. The first case deals with the economic aspect of sustainability focusing on product quality within potato production. It particularly illustrates the ecological production principle of preventive management as described in Chapter 3. The second case is about nutrient management in which recycling and the maintenance of internal resources plays an important role. It particularly illustrates the ecological production principle of recycling management as described in Chapter 3.

Because the case studies focus on a certain aspect of sustainability and the production process, this chapter will provide a general model instantiation[1], so that an overall picture can be kept in mind while reading the case studies. It provides a brief description of the model instantiation as applied in both case studies and in this way serves as an introduction to the case studies. The instantiation process can be subdivided in several steps. Each individual development step will be described in more detail, starting with a concise description of its goal. A problem is, that the model illustrations are described by text on plain paper, while they were generated using several software tools, in which data can be viewed more dynamically using windows, hyperlinks and other useful techniques that enable the user to get a good overview and gain insight by intuitively browsing through the data. Hence, the software will be illustrated by a few examples so that an impression can be obtained of how it works in reality. Various software tools were used, but it is important to be aware that all data are stored in one and the same underlying database.

[1] In the previous chapters the design of a model template was described. A template is a framework that describes how data should be arranged and related, but contains no actual data by itself. An *instance* of the model template means that specific data are filled in; in this case for a specific farm system. The process of filling in data is called *instantiation*.

5.2 Overview of the whole model and its instantiation

The general idea is that the farmer is supported in implementing sustainability in his operational management. This support takes place by offering him an instrument by way of a generic model template, with which he can model the information about his desired system and his production system. Next, he is enabled to combine this information and translate it to operational management. The instantiated model requires that the farmer monitors and evaluates goals so that the model is fed back with information and can be used to improve decision-making. In this way, the farmer is enabled to successfully adapt his system to the changing environment, which was considered to be the main prerequisite for sustainable development in Chapter 4.

Fig. 5-1 provides an outline of the model instantiation process and the resulting sub-components. The process starts with representing the primary production process in terms of a network of processes with product flows in between, resulting in a Product Flow Model. Then, the main goal ‘a sustainable farm’, which is too abstract and vague, is split up into more concrete goals resulting in a Sustainability Map. The Sustainability Map and the Product Flow Model are connected, by identifying the means of connection where sustainability goals could be involved in the production process. Sustainability Function Deployment, resulting in so-called Sustainability Function Deployment-matrices, further translates these connections to operational management.

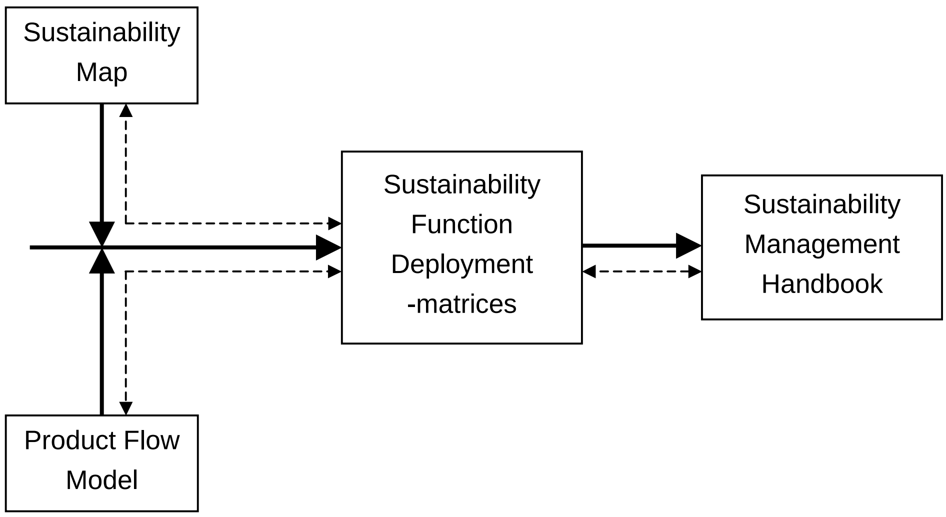


Fig. 5-1 Outline of the instantiation process (indicated by the arrows) resulting in various sub-components of which the Sustainability Management Handbook is the ultimate result. Because all components are related to each other, it is possible to trace how and why data are defined (indicated by the dotted arrows).

Finally, the Sustainability Function Deployment-matrices are elaborated further by identifying critical control points and writing accompanying work instructions for each operation. These critical control points and work instructions constitute the Sustainability Management Handbook.

In this way, a handbook for operational management is developed that describes what should be done and what critical points should be controlled while carrying out each operation. Each instruction and control point is related to the goal ‘a sustainable farm’, but at the moment of execution, the farmer does not need to bother about that and he can focus on the operation itself: sustainability is made manageable.
After an initial instantiation, the model must be constantly updated because:

- the environment and the farmer’s attitude changes, so other sustainability goals are set;
- the farm configuration changes;
- the farmer learns by experience and he will be more able to translate goals into the operational management.

The work instructions in the handbook should also contain instructions to write down actual values of goals that were set, so that the farmer is enabled to see in how far he reaches these goals.
In conclusion, the model can be seen as an instrument for diagnosing, monitoring, developing, evaluating and improving farm management. Because a generic approach, which provides a lead for farmer’s personal values, is followed, it is the idea that the model will become more and more farm- and farmer-specific in time.
The following sections will describe the individual modeling steps in more detail.

5.3 Product flow modeling

GOAL: Represent the primary production process in terms of a network of production units, internal and external resources and intermediate flows between them. In this way, chains and cycles of products can be distinguished and flows are preceding other flows, so that recycling and preventive management can be applied.

A global Product Flow Model was made of the complete farm system (see the enclosed folded map). Production units are the main processes, between which products flow. Product input is transformed into product output by these production units. The most important production units are the crop growing units and cattle units. External resources supply or take products. This is where products cross the virtual border of the farm system. Product flows are real, concrete products. Internal resources and their corresponding internal resource and replenishment flows are less concrete. The soil is considered as the most important internal resource. It is divided according to the crop rotation of APMeco. So, for example, the internal resource *winter wheat soil* is the soil where the winter wheat crop is grown. The red replenishment flow *soil* is the soil that is left behind after winter wheat growing. The idea is that the properties of this 'flow' can be influenced by operations (e.g. plowing) of the winter wheat growing process. The green internal resource flow *soil* from that same internal resource is the soil that is input for the next crop i.e. silage grain. Properties of this flow can be influenced by operations of silage grain growing (e.g. seed bed preparation).

The Product Flow Model was constructed with the aid of a graphical software tool. By double-clicking an element in the drawing, more detailed information can be viewed and edited. Fig. 5-2 provides an example of the form that is shown when double-clicking the production unit *temporary pasture growing*. In this form, the name can be changed. The ID-number and unit type are shown, but cannot be edited because they should be handled only by the software itself for reasons of consistency. A unit can be assigned to a certain production line that can be chosen from the following list of options:

0	non-specific	5	spring wheat production
1	milk production	6	winter carrot production
2	potato production	7	sheep production
3	white cabbage production	8	sugar maize production
4	onions production	9	ecological infrastructure

This list was developed according to the products that are produced for the market. A definition of the unit can be entered and comments can be added to provide additional relevant information.

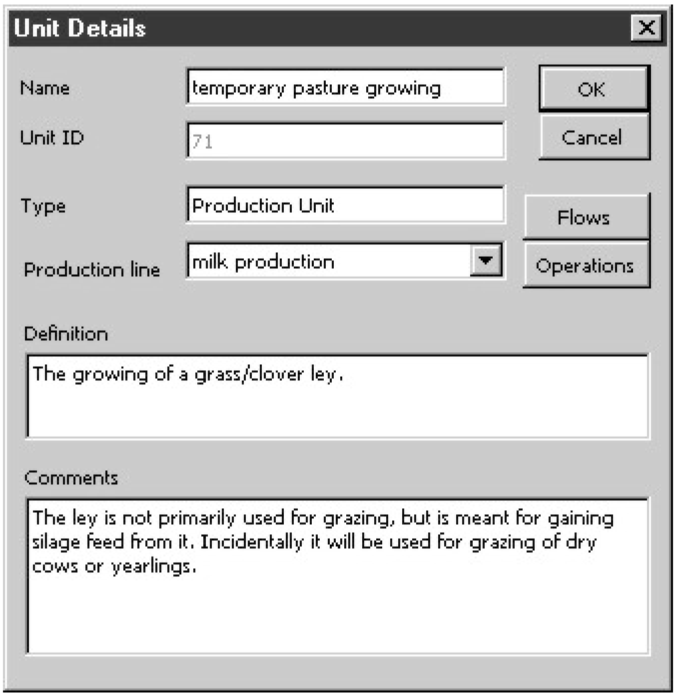


Fig. 5-2 An example of a Unit Details form that is popped-up when double-clicking the production unit 'temporary pasture growing'.

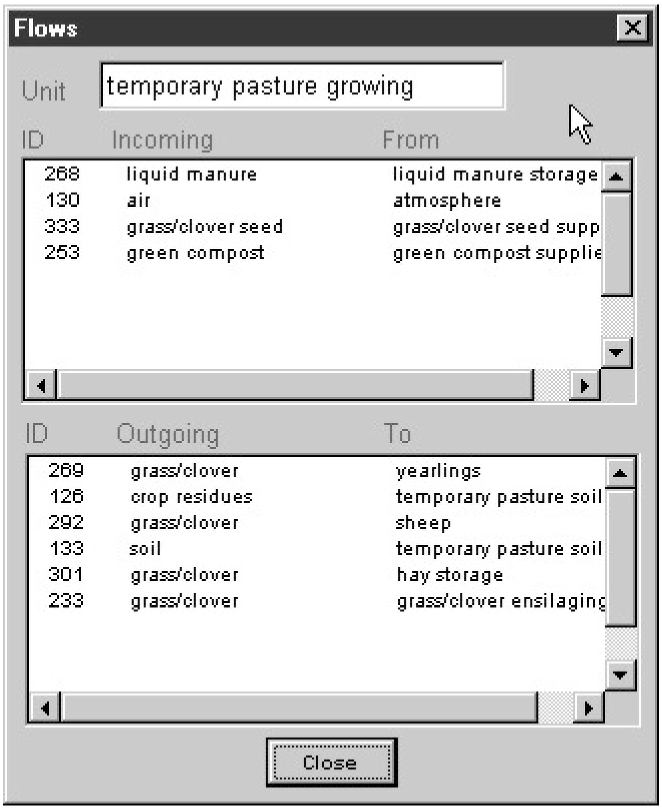


Fig. 5-3 An example of a Flows form that is shown when pushing the 'Flows button' in the Unit Details form. A list is provided of all incoming an outgoing flows with their corresponding originating and destination unit.

Especially in the milk production line, many flows are involved, so it can be difficult to distinguish all flows of a certain production unit. Therefore the 'Flows button' can be pushed, which provides a list of all incoming and outgoing flows with their corresponding unit. An example is shown in Fig. 5-3. The 'Operations button' on the Unit Details form will be discussed later.

Fig. 5-4 shows an example of a form that is shown when the flow *ware potatoes* is double-clicked. In this form, the name, definition and comments can be entered and the flow type, origin and destination can be viewed. When the 'Properties button' is pushed, properties of that flow can be added or removed and edited. A Flow Properties form appears as shown in Fig. 5-5. At the left a list of all properties is shown of which one can be selected. At the right the relevant details of the currently selected property are shown and can be edited. Properties can be added and removed by pushing the corresponding buttons.

In this way, an initial product flow model was constructed that can easily be extended or changed later. The names of the production units, external and internal resources are unique. The names of the flows can be used more than once, but their corresponding originating and destination unit uniquely identify them. This will cause no confusion when using the described software tool.

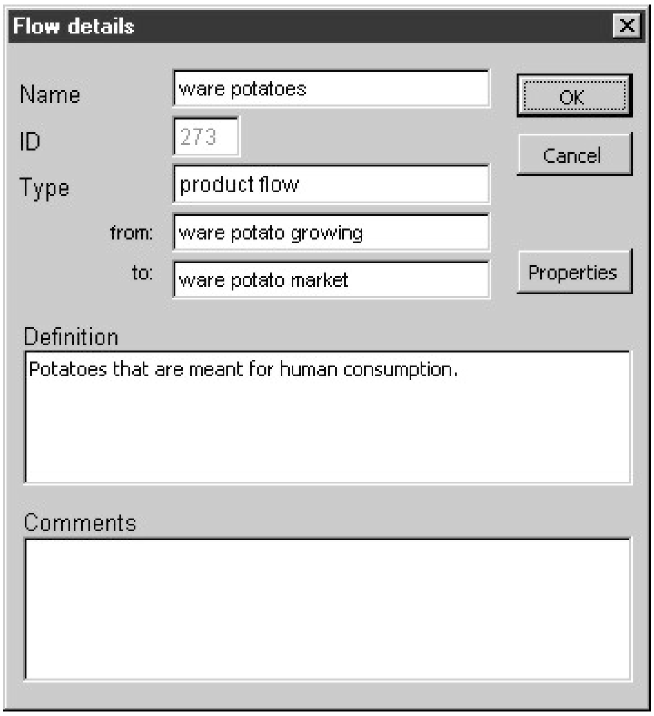


Fig. 5-4 An example of a Flow Details form that is shown when double-clicking the flow 'ware potatoes'.

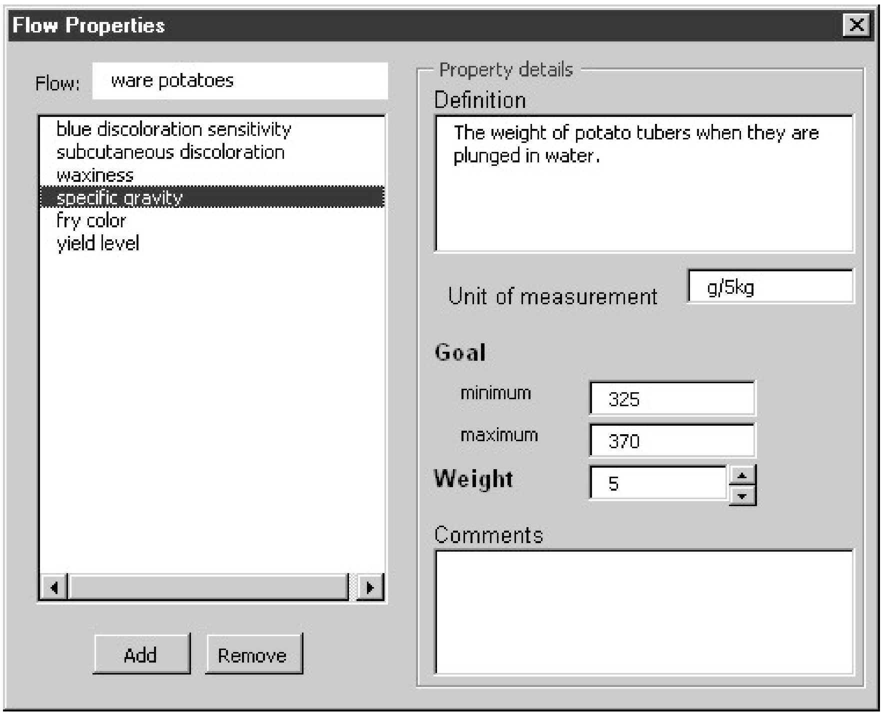


Fig. 5-5 An example of a Flow Properties form that is shown when pushing the 'Properties button' in the Flow Details form. A list is provided of all properties of the particular flow. At the right, details of the currently selected property are shown and can be edited.

5.4 Sustainability Mapping

GOAL: Split up the fuzzy goal ‘sustainable farm’ into a hierarchy of more concrete goals and means until the final subgoals can be quantified and connected with the Product Flow Model. In this process, normative values are attached to goals and means. This process actually is a negotiation process between the farmer and his environment.

Fig. 5-6 provides a screenshot of the used software application, called ‘Sustainability Mapper’. It provides a representative impression of a possible Sustainability Map. Goals are attached to entities (red rectangular folder icons). Entities are wholes that have a meaning in practice. Entities are alternated by one ore more aspects (blue ball icons). Entities and aspects are connected to each other in a hierarchical tree that can easily be collapsed and also edited. When a branch is selected, the right windowpane shows the details of that branch. What information is shown, depends on the type of branch that is selected. If a so-called end entity (at the lowest level, without any child entities) is selected, all possible fields are shown. A definition, comments and goal can be entered. Via a special dialog window, connections with flows from the Product Flow Model can be made. By double-clicking a connected flow, a window is popped-up in which the reason can be entered why this flow was connected with this specific goal.
Fig. 5-6 contains an example of a small case, namely *butyric acid bacteria spores* in milk (the selected end entity) that will be briefly discussed. The tree shows that the entity *sustainable farm* is split up into an *economic*, *ecological* and *social* aspect. An important entity of this economic aspect is *farm results* on which a certain goal can be set. Farm results depend on revenues in the *arable* and *animal* subsystem, the two aspects of this entity. The entity *milk revenue* has a *gross return* and *allocated costs* aspect. The gross return depends on *price* and *yield*. An aspect of the price is *quality*. Quality can be translated into several properties of milk that are entities. Now a stage is reached at which quantitative goals can be set on entities and they can be connected with the product flow model. For example, *butyric acid bacteria spores* are related to the flow milk that goes from ‘milking cows’ to the ‘milk market’ (see Product Flow Model). Practical knowledge learns that butyric acid bacteria produce these spores during the ensilaging process. These bacteria are mainly attached to sand particles. Butyric acid bacteria spores in the silage feed are taken up by the cows and excreted in the milk. Especially for cheese making, milk should not contain any butyric acid bacteria spores. This mechanism shows that a chain of preceding flows is connected with this goal.

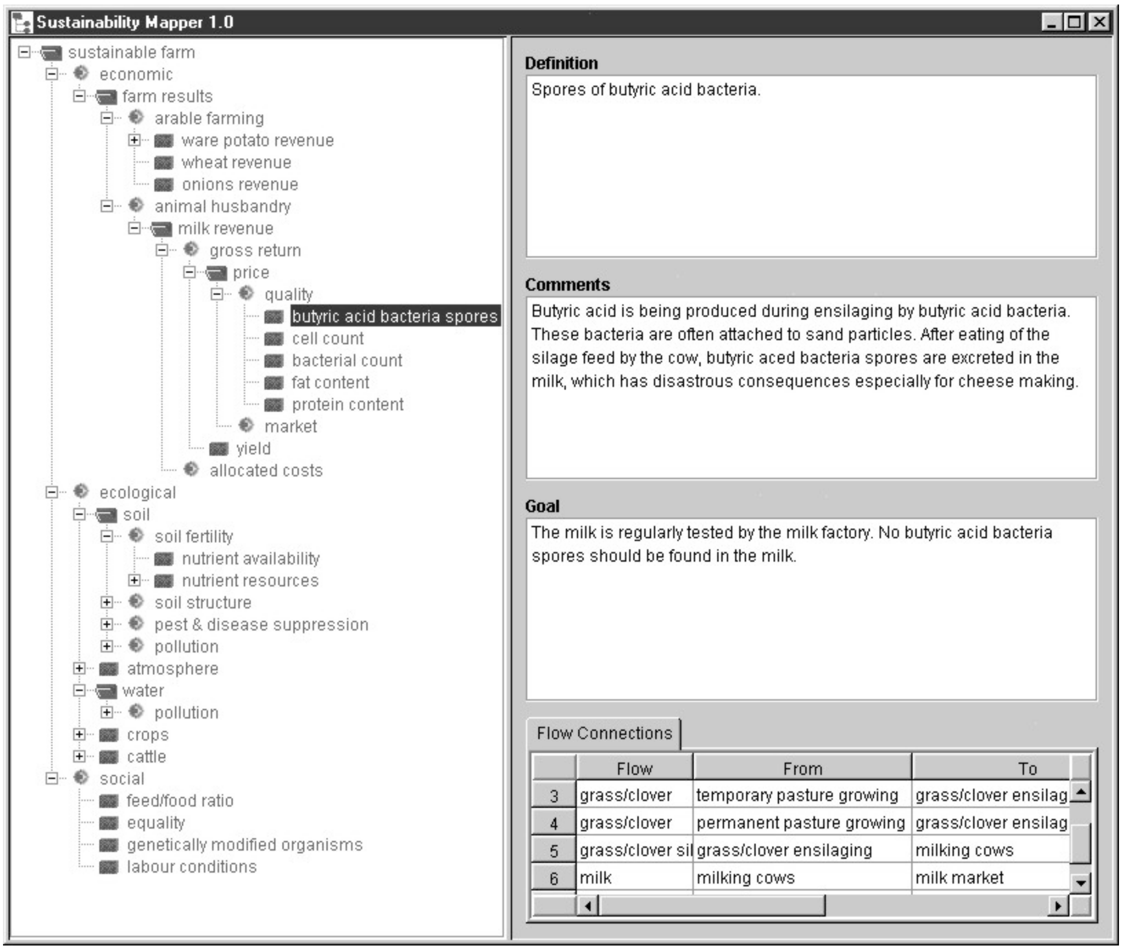


Fig. 5-6 Screenshot of the Sustainability Mapper application with a representative example of a possible Sustainability Map. Further explanation in text.

This final goal can be connected with the flow *grass/clover* coming from the *temporary pasture growing* production unit, with the flow *grass/clover silage feed* coming from the *grass/clover ensilaging* production unit and finally with the flow *milk* itself coming from the *milking cows* and goes to the *milk market*. The same mechanism may be relevant for other feed flows like *grain silage feed*.

In the description of the case studies, it would be too complicated to show a screenshot for every relevant selected branch of the Sustainability Map. Hence, the relevant part of the Sustainability Map will be shown and described in a text that describes the branches and explains why the goals are split up in that particular way.

5.5 Defining operations

GOAL: identify and define the operations of each production unit in the product flow model.

Before the identified flow connections can be translated to operational management, the operations need to be identified first. They can be considered as an extension of the product flow model: operations are one level of processes deeper than the production units. Typical examples of operations are sowing, milking and plowing. They should be identified in interaction with the farmer.

By using the software tool, operations can be added by pushing the 'Operations button' in the Unit Details form (see Fig. 5-2). Fig. 5-7 shows an example when the Operations button of the production unit 'ware potato growing' is pushed. At the left, a list of operations of that production unit is shown and one operation can be selected. The right windowpane shows the details of the currently selected operation and they can be edited. The list of operations can be changed by using add- and remove buttons.

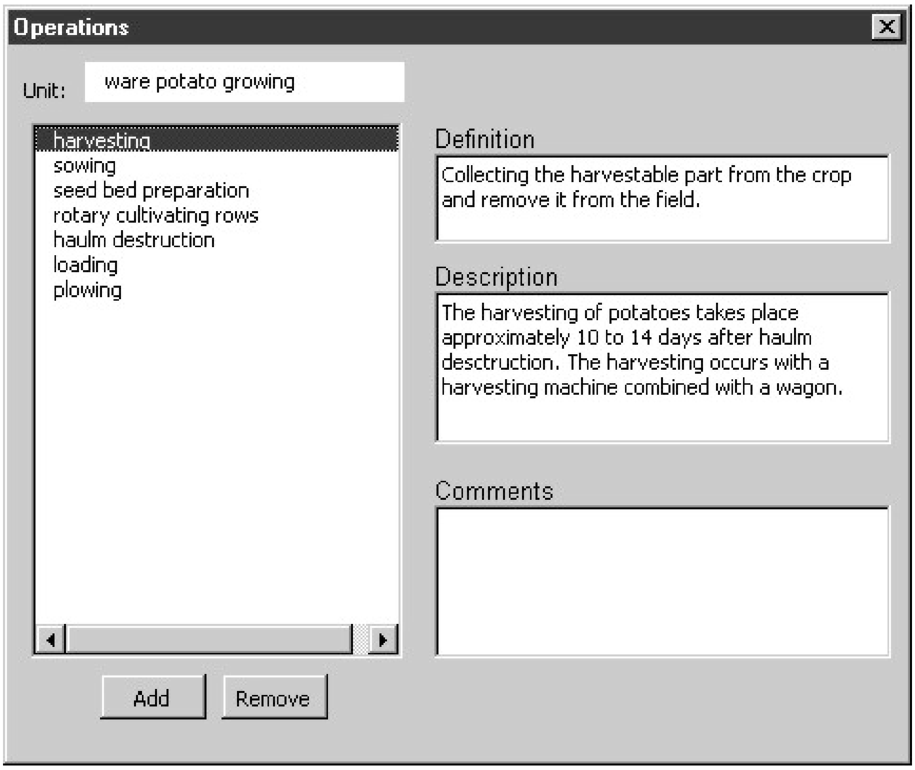


Fig. 5-7 An example of an Operations form that is shown when pushing the 'Operations-button' in the unit details form (see Fig. 5-2). A list is provided of all operations of that particular production unit. At the right, details of the currently selected operation 'harvesting' are shown and can be edited.

5.6 Sustainability Function Deployment

GOAL: Based on the connection of a sustainability goal and a flow, identify the relevant properties of that flow and identify the operations of the corresponding production unit that have a possible influence on these properties.

The main vehicle for Sustainability Function Deployment is the Sustainability Function Deployment-matrix of which an example for the production unit *temporary pasture growing* is shown in Fig. 5-8.

1. temporary pasture growing	**goal**				**operations**									
	min	**max**	**unit**	**weight**	seed purchase	soil tillage	sowing	fertilization	compost purchase	compost application	mowing	tedding	side raking	loading
1. grass clover (to grass/clover ensilaging)														
sand content		2	%	5		3					9	9	9	9
dry matter content	40	45	%	4	3	3	9	9		3	9			
grass/clover ratio			-	3	9	3	1	3						
2. grass/clover (to yearlings)														
protein content	180	200	g/kg ds	4	3			9						
3. grass/clover (to hay storage)														
structure value	0.9		-	4	3			3				9	9	
9. grass/clover (to sheep)														
12. green compost (from green compost supplier)														
N-content	8	9.5	kg/1000 kg	3					9					
P_2O_5-content	3	4	kg/1000 kg	4					9					
13. liquid manure (from liquid manure storage)														
16. grass/clover seed (from grass/clover seed supplier)														
grass/clover ratio	60	70	-	5	9									
				score	108	36	39	93	63	12	81	81	81	45

Fig. 5-8 Example of a sustainability function deployment matrix for the production unit ‘temporary pasture growing’. Further explanation in text.

In the rows, flow properties are listed per possible input or output flow. (Also flows that do not (yet) have properties assigned are listed.) On each flow property, a goal is set as a range between a minimum and maximum value. The weight-column indicates the relative importance (1 = low, …, 5 = high) of a certain property. In the other columns, the operations of the production unit are listed. In the crossing cells an association between a flow property and an operation can be made, indicated by a number (0 = none, 1 = weak, 3 = medium, 9 = strong). So, for example, it can be concluded from the arguments of the butyric acid bacteria spores goal in the Sustainability Map that sand content of the grass/clover that is ensilaged is a very important property to watch. It can be strongly associated with the operations mowing,

tedding, side raking and loading. It should be prevented that the mown grass/clover becomes polluted with sand particles by e.g. appropriate machine adjustments. Soil tillage is also important (but less than the aforementioned operations, so it gets a medium association), because it is important that a smooth field area without holes or heaps is created.
It can be seen that other goals are set on flow properties originating from different goals of the Sustainability Map. Most associations will be made with properties of outgoing flows, because these can be influenced by the operations. Incoming flow properties are usually involved when a purchase operation from an external supplier is involved. For example, green compost is bought and it is checked during the purchase operation whether it satisfies the specified requirements (e.g. nitrogen or phosphate content). Similar properties are surely important for liquid manure that is applied, but these cannot be influenced by the operations of this production unit. The preceding production units like *liquid manure storage* and *loose/tie up cow house* determine them.
In the bottom row of the matrix, a score is calculated, which is the weighted sum of the associations for each operation. This score can be used to prioritize between the different operations. Operations with a high score get a high priority when writing the handbook.
At this moment, a convenient software tool to enter the association values for Sustainability Function Deployment does not yet exist. The case studies will provide the matrices like shown in Fig. 5-8.

5.7 Sustainability Management Handbook

GOAL: Based on the associations that were defined in Sustainability Function Deployment, identify the critical control points for each operation and define accompanying work instructions that should help to reach the goal for that particular flow property.

Operations form the basic building block of the handbook, because an operation consists of a set of harmonized actions concerted to one or more practical goals. From the previous steps, several flow properties were derived that are important to have in mind while carrying out a particular operation. It is tried to define what should be done (work instructions) in order to keep the flow properties within the desired bandwidth. These can be grouped around control points. Critical control points are defined as crucial moments during an operation where specific things need to be checked. The identification of critical control points and the definition of work instructions is based on logical thinking, knowledge and experience. As knowledge and experience will always be changing, the handbook is also always open for changes, extensions and updates.
Fig. 5-9 shows an example of an operation elaborating on the butyric acid bacteria spores problem. It focuses on the operation *mowing* of the production unit *temporary pasture growing*. Associations were made with the two flow properties *sand content* and *dry matter*

content of the *grass/clover* flow going to the next production unit *grass/clover ensilaging*. By thinking logically, it can be concluded that the mower should be adjusted properly, so that the knives will never go too deep and touch the soil. From this fact, work instruction 1 can be derived. The stubble length of 5 to 6 cm can have been obtained by knowledge from literature, colleagues, etc., or it can be based on experience.

production unit: 1. temporary pasture growing **operation:** 1.7 mowing	
flow properties *1. grass/clover (to grass/clover ensilaging)* ▪ sand content ▪ dry matter content	**instructions** 1. Take care of a 'plane' adjusted mowing machine (see mower adjustment instructions). The average stubble length should be 5 to 6 cm. Check this after the first meters of mowing and regularly afterwards. Re-adjust if necessary. Write down the results at the mowing control form. 2. Start mowing at an average grass length of 18 to 25 cm. Write down the results at the mowing control form. 3. Start mowing if the weather forecast is good, which means that there should be a high chance of dry weather for the next 3 days.
critical control points 1. mower adjustment 2. timing 3. weather	

Fig. 5-9 Example of a description of the operation 'mowing' as it occurs in the Sustainability Management Handbook.

It is important that critical control points and work instructions are verifiable. Therefore, results of control instructions should be written down, so that they can be checked afterwards. This is very important for tracing possible causes of trouble, occurring in a product chain. These data can also become a source for learning to improve the production system. For that reason, comments about particularities can sometimes be valuable. To make the whole really auditable, a certification system like ISO[1] or HACCP[2] should be implemented. However, this goes beyond the scope of this thesis.

A software tool was developed to edit the handbook of which a screenshot is shown in Fig. 5-10. At the same time, it provides an overview of other relations. This overview can be shown per production line. This example shows the *potato production* line. At the upper left, the units that are involved in potato production line are provided. Beside it, the incoming and outgoing flows of the selected unit (*ware potato growing*) are shown. In the next column, the

[1] ISO is a worldwide system that provides standards for all kind of business processes. For example ISO-9000 provides all kind of standard guidelines for quality management.

[2] HACCP (Hazard Analysis of Critical Control Points) is a standard hygiene code mainly applied in food processing industry.

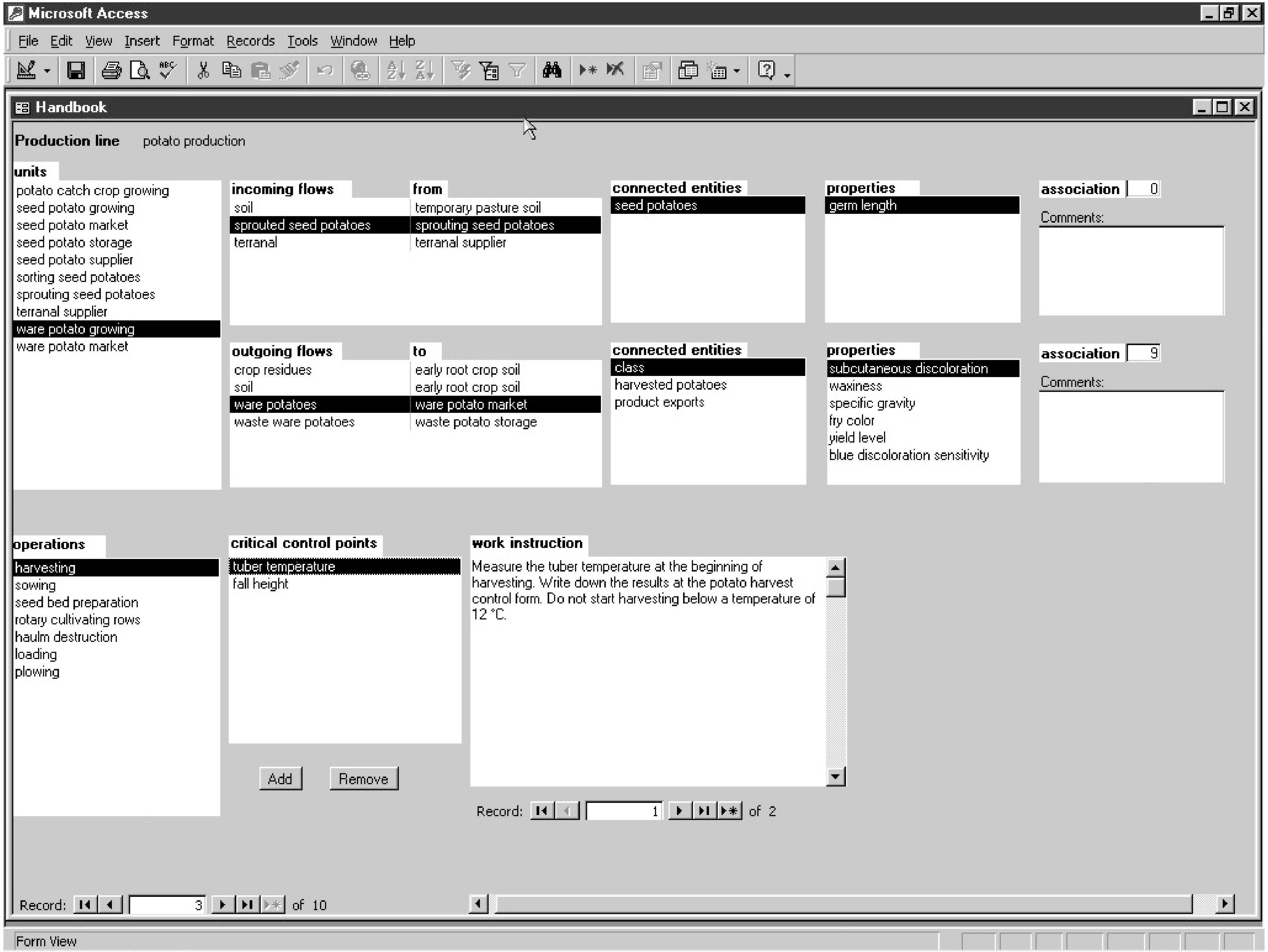


Fig. 5-10 Screenshot of the software application to edit the handbook.

entities of the Sustainability Map that are connected with the selected flows are shown. Next to it, the properties of the selected flows are shown. In the most right column, the association value, which was set by Sustainability Function Deployment, is shown. It shows the association between the currently selected property and the currently selected operation. So, in this example the association value between the operation *harvesting* and property *subcutaneous discoloration* is 9. The list of operations is shown per unit. Beside it, the critical control points for the selected operation are shown. This list can be changed by using the add- and remove buttons. Finally, at the lower right, work instructions can be entered and viewed for each critical control point. All items that are shown in lists can be double-clicked in order to view and edit more details of that particular item.

By using this software tool, insight into the whole production process can be enhanced. In the description of the case studies, it would be too complicated to show a screenshot for every operation. Hence, they will provide the descriptions like shown in Fig. 5-9.

5.8 Conclusions

In a nutshell, the whole model and how it should be instantiated was described. An initial Product Flow Model for APMeco was instantiated. Furthermore, software tools were described that are very useful to enter, view and edit data in the database. Without these tools, it would be very difficult to obtain the right view on data and to relate data in the appropriate way. It could not be shown how a farmer can further improve decision-making by evaluating and redesigning management. For that purpose, the model must be tried out on a farm for a certain period of time. This was beyond the scope of this thesis. However, it was made plausible that it is possible.

It was also not possible to work out the model for every possible sustainability goal. In the case studies, some specific sustainability goals are worked out in detail. However, it should be kept in mind that the goals and their implications for operational management are always part of an integrated whole. It means that a goal can have implications for one ore more operations and the other way around, critical control points and work instructions can be related to one or more different goals. For example, from some production goal’s perspective it is derived that soil tillage depth should be between 10 and 15 cm, while from a nutrient management’s perspective the depth should not exceed 12 cm, which puts a further constraint on the related work instruction.

While this chapter provided an overview and some small illustrations, the next two chapters will provide some more substantial real world examples. They will also provide a broader illustration of the ecological production principles of preventive and recycling management.

6 Economic aspects and quality management of potato production at the mixed ecological farm system at the ir. A.P. Minderhoudhoeve

Boeren schrijven lang niet genoeg, en er zijn veel te weinig die schrijven[1]

farmer Hoeksma cited by Van der Ploeg (1999, p. 222)

Abstract

This chapter provides a case study that illustrates the model and methodology that was developed in this thesis, focusing on the economic aspect of sustainability as applied to potato production. The study shows how several goals, with regard to farm economics and quality production could be translated into the operational management level. It shows how unstructured goals could be translated into structured tasks. The Product Flow Model, in combination with Sustainability Mapping, shows how chains and cycles of products could be identified. Sustainability Function Deployment, in combination with the Sustainability Management Handbook, shows how goals can be concretized further and assured during production. The final result is an example of a handbook, which describes several critical control points and work instructions concerning the operations of potato production. The handbook shows how various goals come together in one operation. Especially, the ecological production principle of preventive management is illustrated, but also some examples of recycling management can be distinguished. It is illustrated that implementing sustainability goals is a matter of common sense and that room is left for personal values and choices.

Keywords: potato; quality management; sustainability; operational management

[1] Translation from Dutch: Farmers do not write (register) enough by far, and there are far too few that write.

6.1 Introduction

This chapter describes a case study of potato production that focuses on economic aspects and related quality management. Its objective is to illustrate the model and methodology, laid out in the previous chapters. Besides, it wants to provide an example of preventive management, which was described in Chapter 3 as a basic management principle in ecological production. For a good understanding of this chapter, the reader is expected to have read Chapter 5 at least.
Being an illustration, this case study does not provide a complete example of all possible goals and aspects of potato production. Furthermore, it should be regarded as a model of a specific farm and farmer who sets his own goals and means and therefore should not be read as a scientific discourse on potato production.
Potato production, as practiced at the ecological farm system of the ir. A.P. Minderhoudhoeve (further abbreviated as APMeco), was chosen as object for this case study. First, the construction of the Product Flow Model will be described. Secondly, some relevant sustainability goals are identified by using Sustainability Mapping. After setting sustainability goals, these goals are connected with flows from the Product Flow Model. Thirdly, these connections are elaborated by Sustainability Function Deployment.
Before applying Sustainability Function Deployment, operations of the production units are defined. Next, the Sustainability Function Deployment-matrices are translated into critical control points and accompanying work instructions that are integrated in the Sustainability Management Handbook. Finally some conclusions will be reached.

6.2 Product flow modeling

A Product Flow Model for the potato production line was constructed and is shown in Fig. 6-1. This was done in interaction with the farm managers of APMeco. Table 6-1 provides definitions of all defined components. The main objective of potato production is to produce potatoes for the ware potato market, using farmer’s own seed potatoes. Occasionally, a small amount of seed potatoes is purchased from external resources if the amount of farmer’s own seed potatoes is not enough or for reasons of renewal. After growing, ware potatoes are delivered instantly to the market. Seed potatoes are stored during winter and sorted in spring. Seed potatoes that are not needed for the farm’s own ware potato production are sold to the market. After sorting, seed potatoes are sprouted and used for ware potato and seed potato growing. Several processes result in a flow of waste potatoes that is stored and used as feed for the cows. According to the crop rotation scheme, potatoes are grown after a 2-year old temporary pasture, so the soil of that field serves as a starting point for potato growing. Potato is followed by a catch crop in order to retain nutrients in the soil that has after plowing in early winter a positive effect on soil structure.

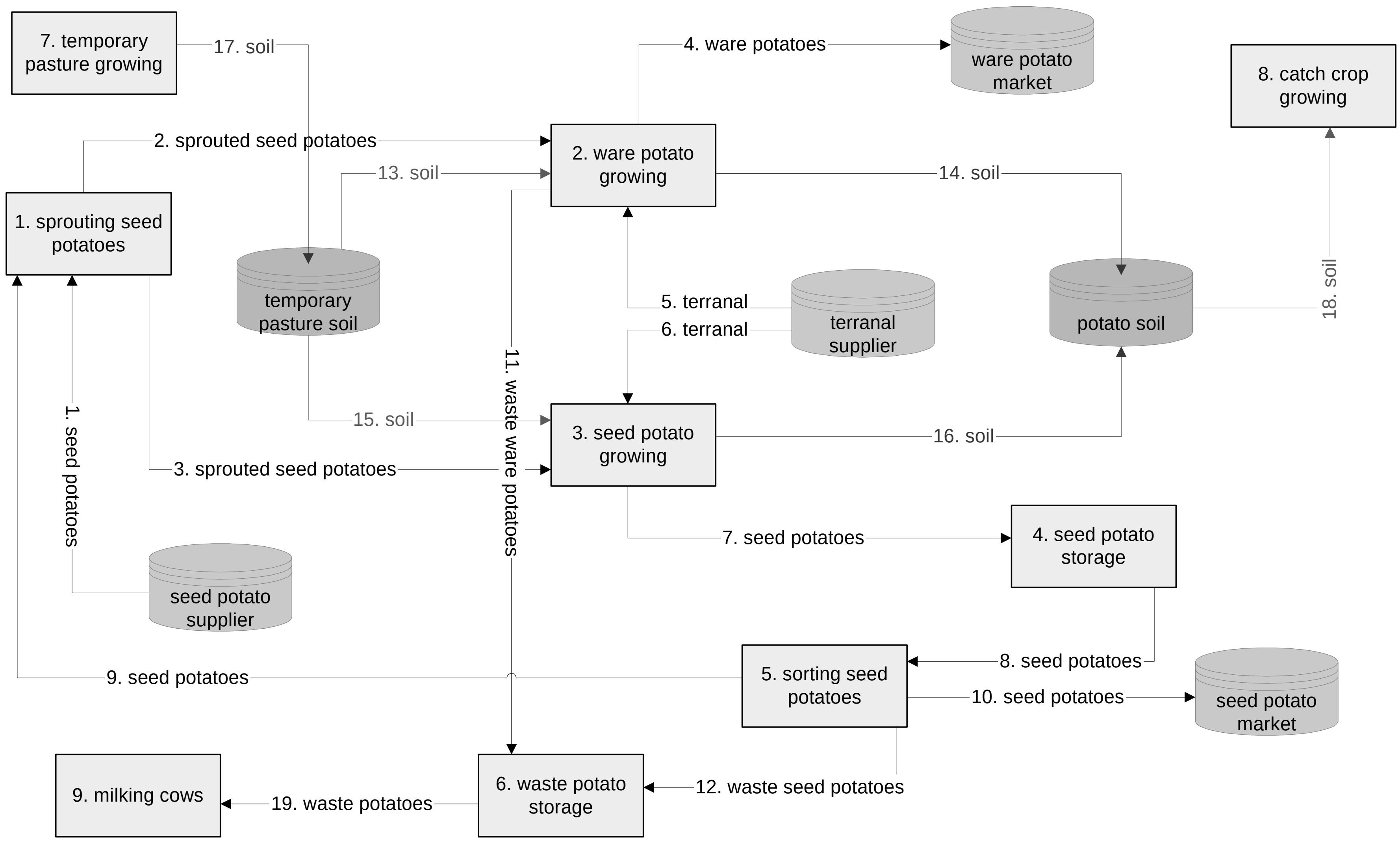


Fig. 6-1 Product Flow Model of potato production at the ecological farm system. For definitions see Table 6-1.

Table 6-1 Descriptions of used elements in the product flow model for potato production

production units	
1. sprouting seed potatoes	Sprouting and multiplication of seed potatoes.
2. ware potato growing	The growing of ware potatoes in the field.
3. seed potato growing	The growing of seed potatoes in the field.
4. seed potato storage	The storage of seed potatoes.
5. sorting seed potatoes	The sorting of seed potatoes for size and quality and eventually preparation for the market.
6. waste potato storage	The storage of waste potatoes.
7. temporary pasture growing	The growing of a temporary pasture.
8. catch crop growing	The growing of a catch crop, grown after the main crop, with the main purpose to prevent nutrient leaching and improvement of the soil structure.
9. milking cows	The cow herd that produces milk.
external resources	
ware potato market	The place where ware potatoes are sold.
seed potato market	The place where seed potatoes are sold.
seed potato supplier	The supplier of seed potatoes.
terranal supplier	The supplier of terranal.
internal resources	
temporary pasture soil	The soil that is left at the field after temporary pasture growing.
potato soil	The soil that is left at the field after potato growing.
product flows	
1. seed potatoes	External seed potatoes that are used as starting material for potato growing.
2. sprouted seed potatoes	Seed potatoes that are sprouted and used for ware potato growing.
3. sprouted seed potatoes	Seed potatoes that are sprouted and used for seed potato growing.
4. ware potatoes	Potatoes that are meant for human consumption and sold to the market.
5. terranal	A crop protection product that enhances the natural resistance of the crop
6. terranal	A crop protection product that enhances the natural resistance of the crop
7. seed potatoes	Seed potatoes that, after growing, are stored at the farm during winter.
8. seed potatoes	Seed potatoes that were stored and are going to be sorted.
9. seed potatoes	Seed potatoes that are sorted and selected and are going to be sprouted.
10. seed potatoes	Seed potatoes that are sorted and selected and are sold to the market.
11. waste ware potatoes	Ware potatoes that appeared not to be suitable for human consumption.
12. waste seed potatoes	Seed potatoes that appear not to be suitable for further production, because they do not fit to the internal quality requirements.
19. waste potatoes	Potatoes that for several reasons are not used for the potato production anymore.

Internal resource flows	
13. soil	The soil that serves as input for ware potato growing.
15. soil	The soil that serves as input for seed potato growing.
18. soil	The soil that serves as input for catch crop growing.
Replenishment flows	
14. soil	The soil that is output of ware potato growing
16. soil	The soil that is output of seed potato growing
17. soil	The soil that is output of temporary pasture growing

6.3 Sustainability Mapping

The Sustainability Map was created on the basis of existing business-plan-like documents and several sessions, formal and less formal, with farm managers and researchers were held. The following main goals were identified:

- high physical yield of ware potatoes;
- good quality of ware potatoes;
- high degree of self-sufficiency concerning seed potatoes;
- low cost level.

These goals are still vague and it is also unclear how to reach them. Hence, they need to be split up further and quantified by Sustainability Mapping. The resulting Sustainability Map is shown in Fig. 6-2. First, the development of the tree will be discussed and then the connections that were made between end entities and product flows. Literal references to aspects and entities are written in italics.

6.3.1 Description of the tree

The entity *farm results* is identified as an important entity with respect to the *economic* aspect of a *sustainable farm*. It is defined as the difference between total return and total costs. As APMeco is a mixed farm, the entity farm results is split up into two aspects: *arable farming* and *animal husbandry*. Several revenues can be distinguished for those crops that are grown for the market. *Ware potato revenue* (usually expressed per hectare) is one of them. The revenue is defined as the net return or the difference between *gross return* and the *allocated costs*, the next two aspects.
Gross return is defined as the multiplication of *yield* and *price*, the next two underlying entities. The price is difficult to influence, because it largely depends on *market* mechanisms of demand and supply. However, *quality* is an aspect that influences the price and it can be managed. The quality of ware potatoes is expressed in *classes*. More than 90% of the ware potato yield should belong to class I. Classification depends on several physical properties of ware potatoes. Starting material and growing conditions determine quality. One of the most

important aspects of growing is *soil treatment* that influences the soil status with regard to *structure* and nutrient availability often closely related. The end entities *class*, *starting material* and *soil structure* are not split up further, because a concrete goal can be attached to and they can be related to flows of the Product Flow Model. This will be worked out further in Section 6.3.2.

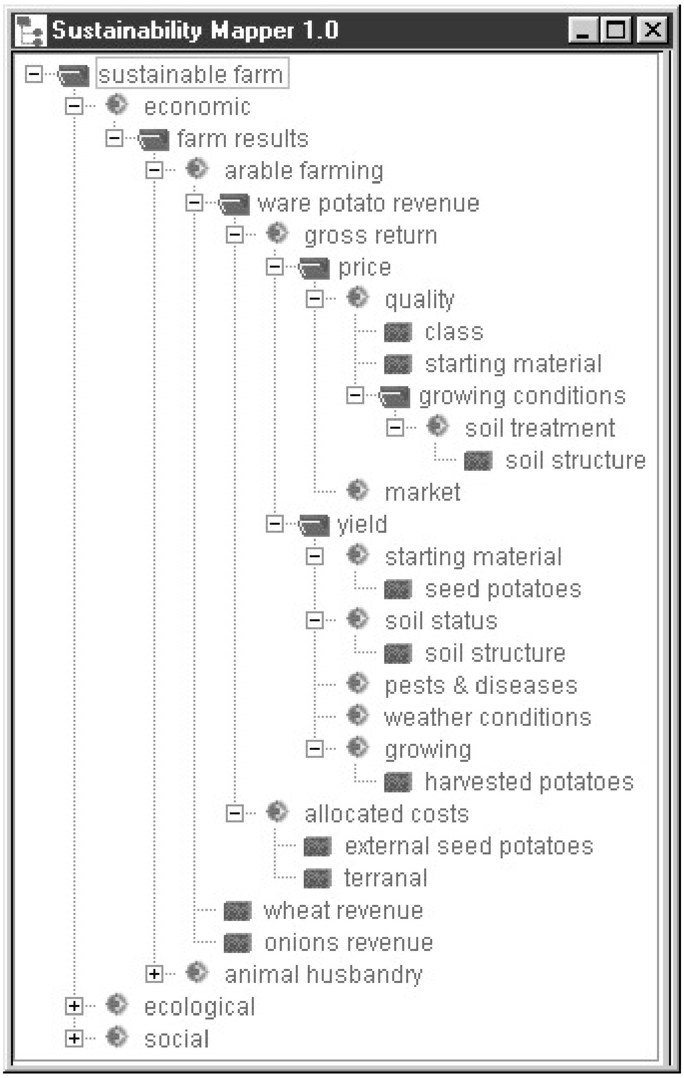


Fig. 6-2 The Sustainability Map focusing on the economic aspect for potato production.

The yield level, defined as *harvested potatoes*, depends on how ware potatoes are grown in general (*growing*), the quality of *starting material* (i.e. *seed potatoes*), *weather conditions*, *pests and diseases* and *soil status*. Some of these factors, like weather and pests and diseases, are hard to influence although their effect on yield can be influenced indirectly. For example, a healthy crop status reduces the effect of pests and diseases and a good soil status reduces the effect of extreme weather conditions. *Soil structure* is considered as a factor that can be managed in order to reach a good soil status. The end entities *seed potatoes*, *soil structure* and *harvested potatoes* are not split up any further, because a concrete goal can be attached to them at this level and they can be easily related to flows of the Product Flow Model.

Some of the allocated costs, like insurances, can be hardly influenced and are therefore not taken into account. Two cost entities that are manageable are the amount of *external seed potatoes* and *terranal*, a crop protection product that enhances the natural resistance of the crop. Terranal is an external input, so a goal is set on the maximum amount of terranal that should be used. Because the price of external seed potatoes is higher than the internal price of farmer's own seed potatoes, a goal is set on the maximum allowable amount of purchased seed potatoes. However, for reasons of renewal, a certain minimum amount needs to be purchased. The end entities *external seed potatoes* and *terranal* are not split up further, because a concrete goal can be attached to them and they can be related easily to flows of the Product Flow Model.

6.3.2 Description of connections with the product flow model

Table 6-2 provides an overview of the connections between end entities, accompanying goals and flows of the Product Flow Model. The following text explains how connections were identified. This explanation follows the order of the rows in Table 6-2. Numbers between parentheses refer to the numbers of the flows in the Product Flow Model.

class
The quality class is directly determined by several physical properties of the ware potatoes that are marketed (4). This flow is the measuring point to evaluate the goal.

starting material
The quality of the externally bought seed potatoes should be checked carefully (1). It is very important to obtain a high quality of seed potatoes after growing (7). It is also important that quality of seed potatoes is retained during storage (8). The selection process determines the quality of seed potatoes that are input for sprouting and thus the quality of ware potatoes (9).

soil structure (quality)
The soil status influences several quality properties of potatoes (13). The soil structure of seed potatoes grown (15) determines their quality and therefore indirectly influences quality of ware potatoes.

Table 6-2 Connections between goals attached to end entities in the Sustainability Map and flows from the Product Flow Model. The end entities are listed in rows and are categorized per aspect. A cross (x) marks a connection.

	goal			flows															
end entity	**min**	**max**	**unit**	1. seed potatoes	2. pregerminated seed potatoes	3. pregerminated seed potatoes	4. ware potatoes	5. terranal	6. terranal	7. seed potatoes	8. seed potatoes	9. seed potatoes	10. seed potatoes	11. waste ware potatoes	12. waste seed potatoes	13. soil	14. soil	15. soil	16. soil
price → quality																			
class	90		%				x												
starting material	S		index	x						x	x	x							
soil structure	7		index													x		x	
yield																			
seed potatoes	S		index	x	x	x				x	x	x							
soil structure	7		index													x		x	
harvested potatoes	40,000		$kg.ha^{-1}$				x												
costs																			
external seed potatoes	5	10	%	x		x				x	x		x					x	
terranal	180	220	$g.ha^{-1}$					x	x										

seed potatoes
Quality of externally bought seed potatoes will influence the ware potato yield and should be checked carefully (1). Sprouting is very important for initial growth and final yield of ware potatoes (2). To obtain a good quality of seed potatoes as starting material for ware potato growing, it is important that starting material for seed potato growing itself is also good (3). Seed potatoes that leave the field after growing form the main starting material for ware potato growing next year (7). It is important that quality is reduced as little as possible during storage (8). It is important that the right size of seed potatoes is obtained and the selection process determines quality of seed potatoes that are input for sprouting (9).

soil structure (yield)
For a high yield level of ware potatoes, a good soil structure (13) is important. Soil structure (15) determines quality of grown seed potatoes and therefore indirectly influences the yield of ware potatoes.

harvested potatoes
The marketed ware potatoes (4) represent the harvested yield. This flow is a measuring point that indicates whether the goal, which depends on many subgoals, is reached.

external seed potatoes
When purchasing external seed potatoes (1), the purchased amount has to be calculated. A goal should be set on the maximum and minimum amount. The quality of sprouted seed potatoes (3) is important for the amount of farmer’s own seed potatoes. The growing process highly influences the final amount of seed potatoes (7) that is harvested. The soil status influences the amount of harvested seed potatoes (15). During storage, as little as possible seed potatoes should be lost (8). If there are enough seed potatoes, it has to be determined how many seed potatoes can be sold to the market (10).

terranal
To reduce costs, the amount of terranal used has to be kept as small as possible. This goal is connected with flows 5 and 6.

6.4 Definition of operations

Before a goal-flow connection can be associated with the operations of the production units, they should be defined first. All operations are listed and described in Table 6-3.

Table 6-3 Description of the operations per production unit

1	**sprouting seed potatoes**	
1.1	purchase	buying seed potatoes from an external seed potato supplier
1.2	boxing	putting the seed potatoes in boxes, that are especially designed for sprouting potatoes
1.3	storing	putting the boxes with seed potatoes in a special barn in which the climate is controlled in an appropriate way
2	**ware potato growing**	
2.1	seed bed preparation	loosing and crumbling the top soil layer and making the appropriate seed beds or ridges, in which the seed potatoes can be sown.
2.2	sowing	putting the seed potatoes in the prepared seedbed at an appropriate plant distance.
2.3	rotary cultivating rows	rebuilding the ridges using a rotary cultivator
2.4	haulm destruction	destruction of the potato haulm either by pulling, slashing or burning
2.5	harvesting	lifting the ware potato tubers from the soil and transporting them into wagons that move the tubers from the field
2.6	loading	transshipping the ware potatoes from the wagons to a trailer in which they are removed from the farm.
2.7	plowing	tearing and reversing the top layer of the soil
3	**seed potato growing**	
3.1	seed bed preparation	loosing and crumbling the top soil layer and making the appropriate seed beds or ridges, in which the seed potatoes can be sown.
3.2	sowing	putting the seed potatoes in the prepared seedbed at an appropriate plant distance.
3.3	rotary cultivating rows	rebuilding the ridges using a rotary cultivator
3.4	selecting	removing the sick or abnormal plants from the field at the final stage of growth
3.5	haulm destruction	destruction of the potato haulm either by pulling, slashing or burning
3.6	harvesting	lifting the seed potato tubers from the soil and transporting them into wagons that move the tubers from the field
3.7	boxing	transshipping the seed potatoes from the wagons to boxes in which they are stored.
3.8	plowing	tearing and reversing the top layer of the soil
4	**seed potato storage**	
4.1	storing	putting the boxes with seed potatoes in a special barn in which the climate is controlled in an appropriate way
5	**sorting seed potatoes**	
5.1	sorting & selecting	sorting the seed potatoes by size and remove abnormal seed potatoes
5.2	packaging	putting the seed potatoes that are sold to the market in bags

6.5 Sustainability Function Deployment

From the columns of Table 6-2 it can be derived that several flows are involved in one or more sustainability goals. These connections need to be translated further into particular properties of that flow, related to that goal. Next, operations of the corresponding production unit that influence these properties should be identified. This is done by the Sustainability Function Deployment method. The results are shown in Table 6-4 to Table 6-8. The associations between flow property goals and operations are shown per production unit. The text in this section describes why flow properties are identified and why associations with certain operations were made. Flow properties, listed in rows, are categorized by possible input and output flows of the production unit. The description follows this categorization. Literal references to flow properties or operations are written in italics.

Table 6-4 Sustainability Function Deployment-matrix for the production unit sprouting seed potatoes

1. sprouting seed potatoes	**goal**				**operations**		
	min	**max**	**unit**	**weight**	purchase	boxing	storing
1. seed potatoes							
Phytophtora		0	%	4	9		
Rhizoctonia		10	%	4	9		
size	45	65	mm	3	9		
physiological age	100	300	°C.d	4	9		
tuber defects		10	%	4	9		
external seed potatoes		10	%	3	9		
2. sprouted seed potatoes							
sprout length	1	2	cm	4			9
3. sprouted seed potatoes							
sprout length	1	2	cm	4			9
9. seed potatoes							
				score	198	0	72

1. sprouting seed potatoes (Table 6-4)

Although the amount of externally purchased seed potatoes is small, it matters for the final quality and yield of ware potatoes. As to yield level, especially *size* and *physiological age* are important. For quality, percentage of *Phytophtora*, *Rhizoctonia* and various *tuber defects* are important, as they effect yield level. All these properties should be checked during the operation *purchase*. Because a maximum was set on the amount of external seed potatoes, this percentage should also be checked.

The *sprout length* is a very important property of sprouted seed potatoes that are input for ware potato growing and seed potato growing. The operation *storing* mainly controls this property.

2. ware potato growing (Table 6-5)

The properties *blue discoloration sensitivity*, *subcutaneous discoloration*, *waxiness*, *specific gravity* and *fry color* determine ware potato quality. Temperature is a determining factor for blue discoloration sensitivity during the operations *harvesting* and *loading*. Subcutaneous discoloration is the actual discoloration as a result of physical damage caused by fall heights. Hence, the operations *harvesting* and *loading* are strongly related to this. Waxiness depends on cultivar and water and nutrient availability of the soil. With regard to this production unit, the operation *seed bed preparation* is related to this, because it highly determines soil status. Specific gravity, correlated to dry matter content, is determined by growing season conditions. Again, soil is the only manageable factor, so the operation *seed bed preparation* is related to this. The same is true for the property fry color, but for this property, also timing of *haulm destruction* is important. The *yield level* depends on all operations before harvesting of which *seed bed preparation* and *sowing* are most important.

The *dose* of terranal is determined during the operation *sowing*.

Soil structure determines yield level and tuber quality, because it largely influences water and nutrient status during the growing season. *Seed bed preparation* is most related to this property.

Table 6-5 Sustainability Function Deployment-matrix for the production unit ware potato growing

2. ware potato growing	**goal**				**operations**						
	min	**max**	**unit**	**weight**	seed bed preparation	sowing	rotary cultivating rows	haulm destruction	harvesting	loading	plowing
2. sprouted seed potatoes											
4. ware potatoes											
blue discoloration sensitivity		40	index	5					9	9	
subcutaneous discoloration		5	%	5					9	9	
waxiness		5	%	5	3						
specific gravity	325	370	g/5kg	5	3						
fry color	4	6	index	4	3			9			
yield level	40000		$kg.ha^{-1}$	4	9	9	3	3			
5. terranal											
dose	180	220	$g.ha^{-1}$	3		9					
11. waste ware potatoes											
13. soil											
soil structure	7		index	5	9						
14. soil											
				score	123	63	12	48	90	90	0

3. seed potato growing (Table 6-6)

The *dose* of terranal matters as to reducing costs for this input and is related to the operation *sowing*.

For the quality of ware potatoes as well as the amount, the *quality* of seed potatoes is important. As with ware potatoes, several quality parameters are related to *soil status* and thus with the operation *seed bed preparation*. In this special case of seed potatoes, the *selecting* operation is very important. Furthermore, *harvesting* and *boxing* are related to quality. For physical yield level, the operations *seed bed preparation* and *sowing* are very important, while the operations *rotary cultivating rows* and *haulm destruction* are less important.

For several reasons that were mentioned previously, *soil structure* after *seed bed preparation* is important.

Table 6-6 Sustainability Function Deployment-matrix for the production unit seed potato growing

3. seed potato growing	**goal**				**operations**							
	min	**max**	**unit**	**weight**	seed bed preparation	sowing	rotary cultivating rows	selecting	haulm destruction	harvesting	boxing	plowing
3. sprouted seed potatoes												
6. terranal												
dose	180	220	$g.ha^{-1}$	3		9						
7. seed potatoes												
quality	SE		index	4	9			9		9	9	
yield level	25000		$kg.ha^{-1}$	4	9	9	3		3			
15. soil												
soil structure	7		index	5	9							
16. soil												
score					117	63	12	36	12	36	36	0

4. seed potato storage (Table 6-7)

The *physiological age* of seed potatoes determines final yield level of ware potatoes and is largely determined by the *storing* operation.

Table 6-7 Sustainability Function Deployment-matrix for the production unit seed potato storage

4. seed potato storage	**goal**				**operations**		
	min	**max**	**unit**	**weight**	storing		
7. seed potatoes							
8. seed potatoes							
physiological age	100	300	°C.d	3	9		
score					27	0	0

5. sorting seed potatoes (Table 6-8)

For production of ware potatoes as well as for seed potatoes that are marketed, several quality properties matter, namely *Phytophtora*, *Rhizoctonia* and various *tuber defects*. Concerning farmer's own production, *size* is also important. All properties are related to the *sorting & selecting* operation. For the *packaging* operation, the *amount* of seed potatoes that can be sold should be determined in order to keep the right amount for farmer's own production.

Table 6-8 Sustainability Function Deployment-matrix for the production unit sorting seed potatoes

5. sorting seed potatoes	goal				operations		
	min	**max**	**unit**	**weight**	sorting & selecting	packaging	
8. seed potatoes							
9. seed potatoes							
Phytophtora		0	%	4	9		
Rhizoctonia		10	%	4	9		
size	45	65	mm	3	9		
tuber defects		5	%	3	9		
10. seed potatoes							
Phytophtora		0	%	4	9		
Rhizoctonia		10	%	4	9		
tuber defects		5	%	3	9		
amount	100	200	ton	3		9	
12. waste seed potatoes							
				score	225	27	0

6.6 Sustainability Management Handbook

Appendix IV provides the handbook for potato production. To be clear, the associated flow properties that were derived from Sustainability Function Deployment are listed again. Critical control points and work instructions are logically derived from the descriptions of the Sustainability Function Deployment matrices in the previous section.

6.7 Conclusions and discussion

This chapter provided a concrete example of how the model could be implemented. It illustrated how the Product Flow Model represents the system in such a way that manageable product chains or cycles can be identified. It also illustrated that by distinguishing external resources product import and export can be identified. In the first place, this has provided possibilities for carefully checking products that were imported. In this way, the farmer prevents his farm system from acquiring unwanted material. Secondly, the balance between purchased and sold seed potatoes can be maintained. Two internal resources, the soil before and after growing, were identified. It was shown that soil, as input for growing, played an important role and how this could be managed by operations. However, the aspect of maintaining internal resources by balanced procurement and replenishment was not considered. This can be explained, because this case study focused only on quantitative and qualitative production in the context of one production line. The case study on nutrient management in the next chapter will focus more on maintenance of internal resources. In this respect, it should be noted that results from that case study are added to these results. So, this means that the handbook is extended with critical control points and work instructions. This could imply that further constraints are imposed on the goals that were identified in this case study. This highlights the model's validity for farmer's decision-making, because in reality, he will also face several goals and constraints at the same time when executing an operation.

Sustainability Mapping illustrated how unstructured goals could be made more structured by identifying a hierarchy of goals and means. This was done on basis of logical reasoning, but because the farmer is doing this himself, room is left for personal priorities and choices with regard to goals that are set and means that are identified. Of course, in this rather trivial goal of farm results, the Sustainability Map farmers will not vary much between different farmers, but the principle of diversity and variation remains. Variation will increase when other goals and aspects are also worked out.

It was shown that several goals involved a chain or cycle of flows (see Table 6-2). They determined the quality or quantity of the final potato yields. This illustrates the principle of preventive management. The yield is not only determined by the potato growing process, but also depends on several preceding product flows. With regard to farmer's own seed potato production, a type of recycling management can also be distinguished. However, this is not a kind of recycling that concerns the basic material cycle of uptake, degradation and mineralization. This principle of recycling management will be illustrated in more detail in the case study in the next chapter.

After connections between goals and flows were made, Sustainability Function Deployment took care of a further concretization by identifying flow properties and associating them with operations. The principles of preventive and recycling management were defined at the previous level of Sustainability Mapping and in this step they are implemented to a further extent. It means that, at this point, the farmer can focus on setting goals on flow properties, without constantly thinking about chains and cycles. So, the scope of management is demarcated further. As with Sustainability Mapping, identifying flow properties and defining goals is mainly a matter of logical thinking, but room is left for personal values and choices, so it will also result in diversity and variation between farmers.

In the last step of writing the Sustainability Management Handbook, the management scope is limited again by focusing on operations. Several types of work instructions were defined. Monitoring instructions are important for evaluating goals. Although it was not really worked out, it was suggested that results are written down on forms, so that these can be verified. This is important when you really want to assure goals and it is obligatory when certification is involved. This pleads for using certification as a tool for sustainability management. If these registration forms were also available in electronic form, connected to the database, it would be possible to generate automatic warnings when goals are not reached. However, the threshold for data entry should then be very low and user-friendly. Otherwise, the farmer will be discouraged too much to do this.

In conclusion, this case study illustrated how the model supports implementing sustainability in daily, operational management. The examples might have been trivial, but it is expected that they will become less trivial after heuristic problem solving. At least, it was shown that many different goals can be taken into account and that the model leaves room for personal values and choices. This case study focused on the economic aspect of sustainability and mainly illustrated the ecological production principle of preventive management although a type of recycling management could also be identified. The case study in the next chapter will deal with the ecological aspect of sustainability and mainly focus on the ecological production principle of recycling management. The most important facts of this case study are summarized in Mind Map 9 in Appendix VI.

7 Nutrient management at the mixed ecological farm system at the ir. A.P. Minderhoudhoeve

Soils are manageable by designing life processes.
Peter van der Werff[1]

Abstract
This case study illustrates the model and methodology that was developed in this thesis, focusing on nutrient management. The study shows what goals can be identified and how they can be connected with the primary production process by identifying chains or cycles of product flows in the entire Product Flow Model of the ecological farm system at the ir. A.P. Minderhoudhoeve. In this way, recycling management, but also preventive management, is being developed. Especially in nutrient management, the whole production process is involved and thus the idea of mixed farming becomes an important issue. It means that intermediate products, like manure and crop residues, become important for management. It should focus on getting a hold on properties of these products. Internal resources, in particular the soil, play an important role in this process. Biological processes, related to soil life, should be stimulated and can be used to reach goals. However, this case study also shows that a lack of knowledge exists for the desired type of nutrient management. In this respect, it was shown that the model and methodology could help the farmer to develop his own heuristics to resolve this. These heuristics could then be used in agricultural research to develop a sounder theoretical basis.

Keywords: nutrient management; soil management; soil fertility; soil structure; recycling

[1] Peter van der Werff was a renowned soil researcher and esteemed colleague at the department of Ecological Agriculture when this thesis research started. He hated it when the soil was merely considered as a physical-chemical substance and no attention was paid to the biological soil processes. Unfortunately, he suddenly died in 1996.

7.1 Introduction

This chapter describes a case study on nutrient management. It illustrates how the developed model deals with the principle of recycling management, one of the basics of ecological production as described in Chapter 3. However, also some examples of preventive management will be provided. For a good understanding of this chapter, the reader is expected to have at least read Chapter 5.

Nutrient management consists of many aspects and goals. It is not the objective of this case study to illustrate all of them, but just to provide some illustrative examples. As in the case in the previous chapter, the results must be seen from a specific farm' and farmer's point of view and therefore do not pretend to be completely science based and approved.

The production process, as practiced at the ecological farm system of the ir. A.P. Minderhoudhoeve (further abbreviated as APMeco), is object for this case study. First, the Product Flow Model, in relation to nutrient management, will be described. Secondly, some relevant sustainability goals will be described, using Sustainability Mapping. These goals will be connected with the Product Flow Model. Because nutrient management concerns the whole farm, a goal will usually be connected to many, often similar, flows. Hence, it would result in many Sustainability Function Deployment-matrices, in which many operations are involved, and many critical control points and work instructions can be defined. Therefore, the case study stops at the level of sustainability-goal-flow-connections. These are sufficient to illustrate the idea behind recycling management. As to the Sustainability Function Deployment and the Sustainability Management Handbook, these were sufficiently illustrated in the previous chapter. However, now and then, some brief examples of what could possibly be included in them with respect to nutrient management, will be provided. Finally, conclusions will be drawn.

7.2 Product flow modeling

In contrast to the previous case on potato production, described in Chapter 6, nutrient management is not connected with one production line only, but it involves the complete production process. Hence, the total Product Flow Model, as described in Chapter 5, forms the basis for this case study. Some parts of the Product Flow Model were particularly identified in relation to nutrient management. They will be discussed here.

7.2.1 Soil as an internal resource

It was concluded in Chapter 3 that the soil plays a crucial role in ecological production. Soil is characterized by chemical properties like nutrient contents and physical properties that constitute soil structure. It was also emphasized that processes, in which biological soil life is included, play an important role in determining these properties. In the Product Flow Model, soil is used for growing processes, indicated by the green internal resource flows *soil* that are input for a production unit that involves a crop growing process, which will further be indicated as ‘growing production units’. Soil tillaging operations, like *seedbed preparation*, influence the properties of this input flow. The red replenishment flows *soil* indicate the soil that is left after growing a crop. Soil tillaging operations, like *plowing*, but possibly also other ones like *harvesting*, influence the properties of this output flow. Although plowing itself has no direct connection with crop growing, a choice was made to include the operation plowing in these production units as an operation that comes chronologically after harvesting. Because the same internal resource *soil* is output of a growing process and input for another one, crop rotation is automatically included in the Product Flow Model.

7.2.2 Crop residues and green manure

Beside the more abstract replenishment flow *soil*, another flow *crop residues* is distinguished. Crop residues consist of leaves and stems (e.g. of potatoes, cabbage), but also the subterranean parts (roots and stems) are important. These crop residues compound a relevant amount of nutrients and are also important for soil life; as they provide energy for all kind of soil organisms. In case the residue consists of a complete crop that is plowed in, the term *green manure* is used. Especially when this crop is (partly) leguminous, the importance for nutrient management is high.

7.2.3 The atmosphere as internal resource - biological nitrogen fixation

Leguminous crops (e.g. clover) are able to fix the nitrogen from the air that is released after decomposition of crop residues. These crops play an important role in nutrient management in ecological agriculture. Hence the *atmosphere* is considered as an important internal resource. The internal resource flow *air* is input for growing processes in which leguminous plants are involved. The amount of nitrogen that is fixed in this way can be influenced by operations of the corresponding production unit.

7.2.4 Animal manure

Applying animal manure to the field is an important means for re-allocation of nutrients within the farm system. At APMeco, the manure is separated into two components: solid manure that is stored on a compost heap (indicated as *solid manure storage* in the Product Flow Model) and liquid manure that is stored in a pit (indicated as *liquid manure storage*). In ecological agriculture, solid manure is primarily used for nourishing soil life and not directly considered as crop nutrition. Hence, the flow *solid manure* could have been directed to the internal resources *soil* directly. However, just like with plowing, the choice was made to include the operation *manure application* in a crop growing production unit, so this flow is directed to a production unit and it is related to the internal resource *soil* via the outgoing replenishment flow *soil*. In this way this flow can be related to operational management.

So far, an explanation was provided of important choices that were made in instantiation of the Product Flow Model with regard to nutrient management. It is not the purpose of the Product Flow Model to provide a sound ecological process model of nutrient cycles (like dynamic simulation models), but it should provide means of connection for operational management. This does not exclude the option to use ecological simulation models in parallel to this model as an additional aid to decision support.

7.3 Sustainability Mapping

In order to establish the Sustainability Map, some existing business plan-like documents were examined and several sessions, formal and less formal, with farm managers and project researchers were held. With regard to nutrient management, the goal is:

> a highly self-regulating soil that supports
> - effective nutrient cycles in time and space;
> - soil structure-forming processes;
> - suppression of soil-borne pests and diseases;
>
> so that the grown crops are healthy and return a sufficient yield, while the current soil fertility is being maintained or improved.

Self-regulation means that an interaction exists between different subsystems in the soil that take care of internal regulating processes, in such a way that the soil as a living system can recover from disturbances without external intervention. Furthermore, the soil should not be polluted with certain products.
These goals are still rather vague and therefore they need to be further split up and quantified by Sustainability Mapping. The resulting Sustainability Map is shown in Fig. 7-1. The development of the tree and the connections that were made between end goal entities and product flows will be discussed. Names of aspects, entities and connected Product Flow Model elements will be written explicitly in italics. Flows that are connected to an entity will be listed in tables.

7.3.1 Description of the tree

Good nutrient management is indispensable for sufficient production and thus economic return. Good nutrient management is also important for societal acceptance of production, because bad management causes pollution and depletion of natural resources (like air and water) that can be considered as common public goods. However, the choice was made to consider nutrient management as mainly related to the *ecological* aspect of sustainability.

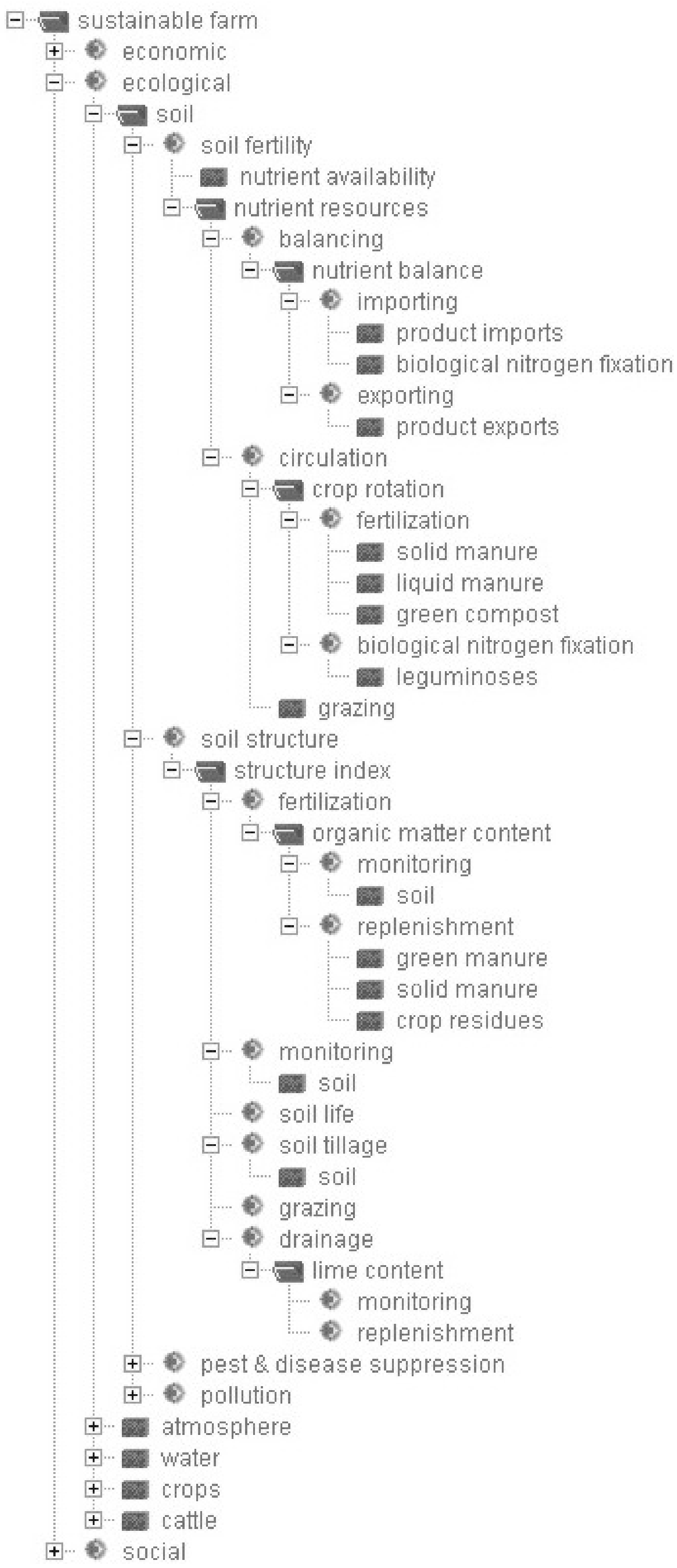


Fig. 7-1 The Sustainability Map, focusing on the ecological aspect of sustainability in relation with nutrient management.

In the first place, the ecological aspect concerns the interaction of ecological relations within the farm. This deals with the question of how far ecological processes are integrated in farm management. It is related to the basic attitude of the farmer towards nature. Hence, the subjacent entities *crops* and *cattle* are identified. In this case study, these entities are not elaborated further. Furthermore, it concerns the interaction of ecological relations between the farm system and its environment. This concerns burdening of the environment and depletion or pollution of natural resources. Related to this, but also with the first point, the entities *soil*, *water* and *atmosphere* are identified as entities of the ecological aspect of sustainability.

Water and atmosphere

The entities water and atmosphere both have the aspect of *pollution*. Pollution is defined as an unacceptable excess of product concentrations. This could be further worked out into entities like ammonia emission or nitrate leaching. However, the assumption was made that by a sound ecological soil, cattle and crop management, there will be no pollution of these natural resources (Oomen, pers. comm.). Hence, these aspects are not worked out further.

Soil

Soil is defined as the biologically active, porous medium that has developed in the uppermost layer of the Earth's crust (Encyclopædia Britannica). Opposite the natural resources atmosphere and water, soil is the ecological component, which can be mostly influenced by farm management. Starting from the overall goal for nutrient management that was described on page 158, the aspects *soil fertility*, *soil structure*, *pest & disease suppression* and *pollution* are distinguished. As the self-regulation principle already indicates, it is acknowledged that these aspects are mostly interrelated. For example, a bad soil structure will have a negative influence on soil fertility and probably also on pest and disease suppression. However, by identifying the right subentities and related goals, these relations will be assured in reality, when they are connected with operational management. In this case study, the aspects *pest & disease suppression* and *pollution* will not be further elaborated.

Soil fertility

Soil fertility is defined as the potential crop growth capacity of the soil that depends on the quantitative presence of nutrients and their availability in time. Hence, the subentities *nutrient availability* and *nutrient resources* are distinguished.

Nutrient availability

A goal is set on *nutrient availability*, namely that the main nutrients nitrogen, phosphorus and potassium must be sufficiently available during the growing season, so that crop growth is not limited. This goal can be directly connected to all internal resource flows *soil* that go from an internal resource *soil* to a growing production unit (see Fig. 7-2).

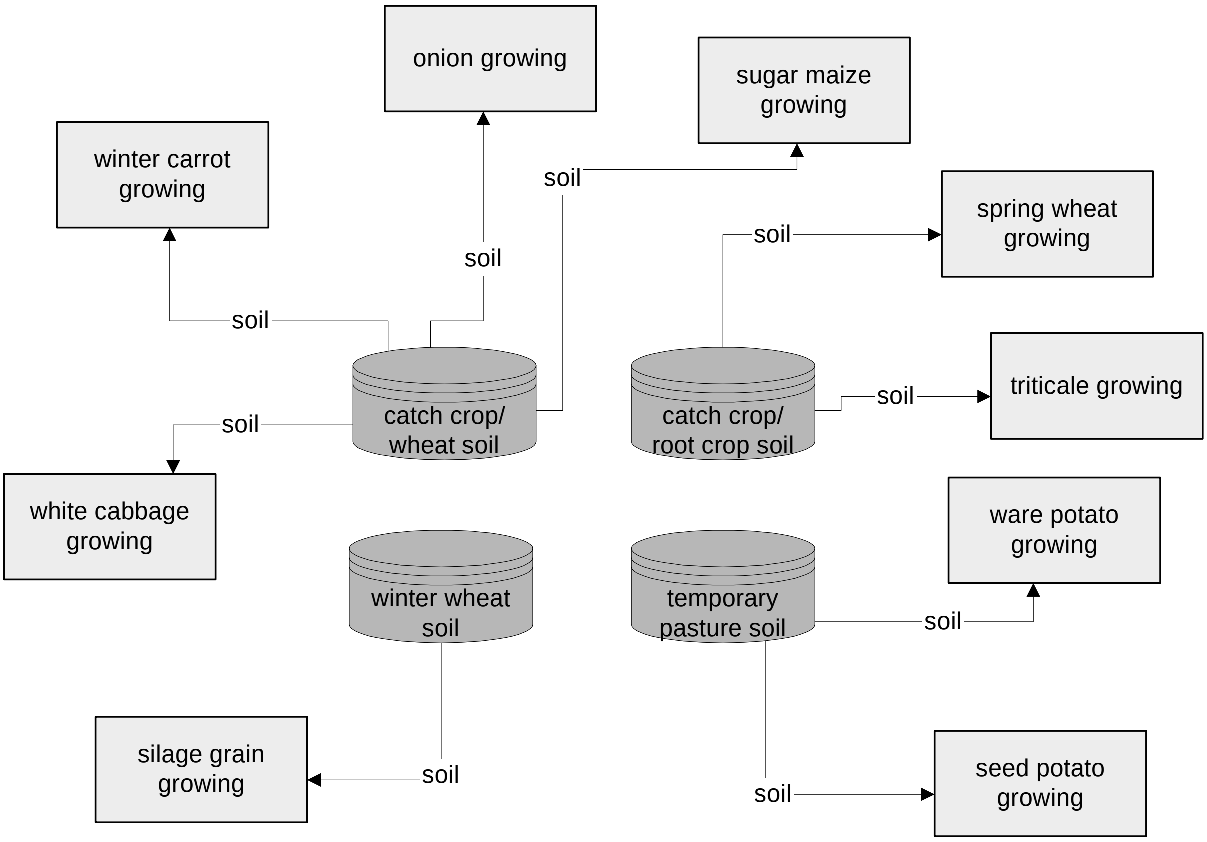


Fig. 7-2 Flows that are connected with the entity *nutrient availability*

Nutrient resources

A goal is set on *nutrient resources*, namely that in the long term nutrient resources in the soil should not be depleted and no accumulation of nutrients must take place within a time span of one crop rotation. So, for a particular field, there may be some fluctuation in time, but over a period of 7 years, nutrient resources must remain equal. This, in particular, holds for nitrogen and phosphorus; the potassium resource may slightly decrease, because the soil was impoldered relatively recently (ca. 30 years ago). The goal implies that there should be a balance between nutrient input and output at farm system level as much as possible. However, a good balance at farm system level can still imply that there locally is depletion or accumulation in certain fields. Therefore, *balancing* and *circulation* are considered as the two most important aspects.

Balancing

The entity *nutrient balance*, subentity of the aspect *balancing*, is defined as the balance of nutrients at farm system level. Assuming that there is a good circulation of nutrients within the farm system, it is sufficient to balance nutrients at this level. The output of nutrients at the farm system level should be compensated by input, without use of external synthetic inputs. Hence, the aspects *importing* and *exporting* are distinguished.

Importing concerns the purposeful transport of nutrients into the farm system. One entity concerning importing is *product imports*. Nutrient import by importing products must be equal to the nutrient export (for nitrogen this is minus the amount that is fixed by leguminous crops). Flow connections are made with all possible input product flows of the farm system (Fig. 7-3). It is assumed that product imports like seeds do not significantly contribute to the nutrient balance.

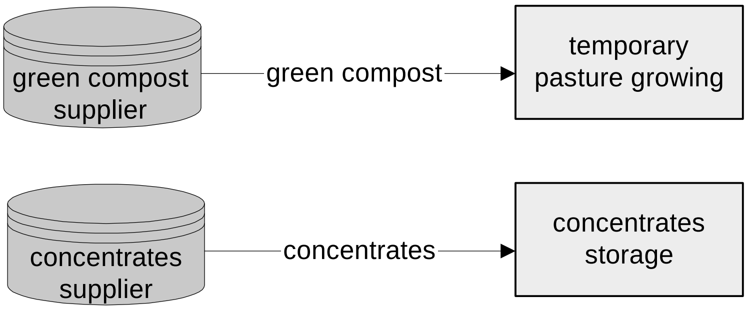


Fig. 7-3 Flows that are connected with the entity *product imports.*

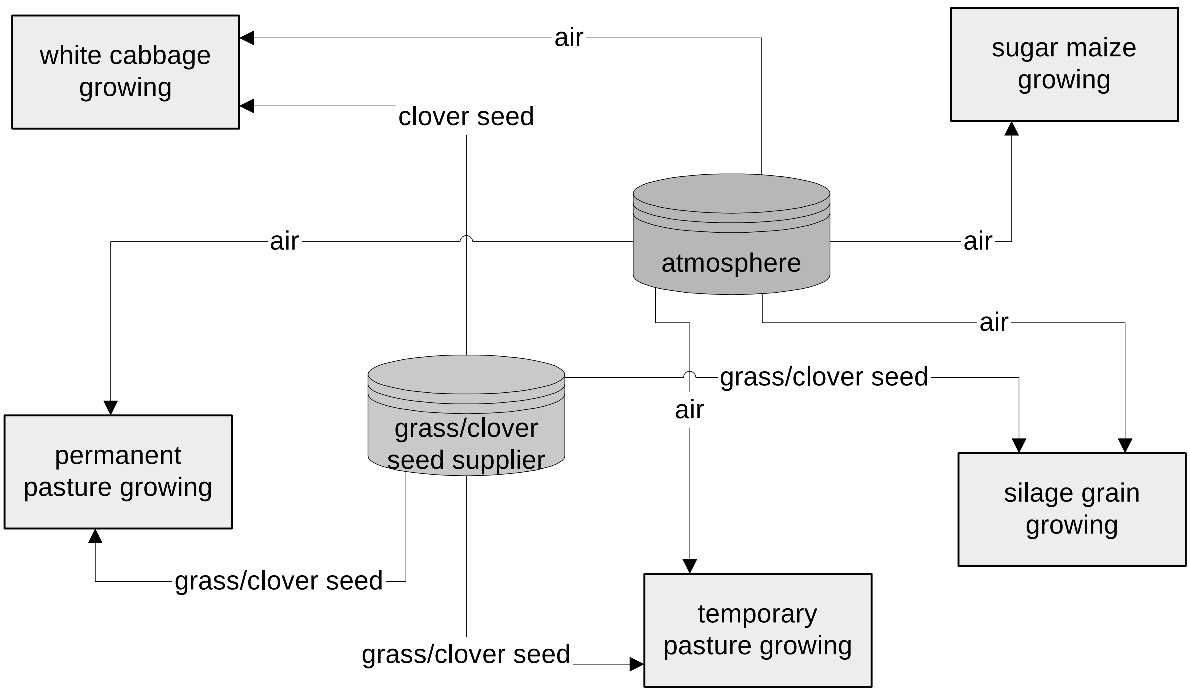


Fig. 7-4 Flows that are connected with the entity *biological nitrogen fixation.* The pastures consist of a grass/clover mixture and other grown crops use clover as an undercrop.

Another entity concerning import is *biological nitrogen fixation*. This is fixation of nitrogen in the air by a symbiosis of bacteria and (leguminous) plants. This is a less visible input, but it is imported purposefully. The amount of nitrogen fixed must compensate the export of nitrogen (minus the nitrogen that is imported by products). This goal is connected with the flow *air* (that contains nitrogen) from the internal resource *atmosphere* and the *grass/clover seed* flows (see Fig. 7-4). The seed mixture and several other operational management factors that influence growth will determine the amount of nitrogen fixed. Another less visible flow is deposition from the atmosphere but this input cannot be influenced and is therefore not taken into account.

Exporting deals with the purposeful transfer of products out of the farm system. The amount of nutrients that is exported by *product exports* must be replenished by import. This goal is connected with all possible product flows that go to an external resource and contain a significant amount of nutrients (Fig. 7-5).

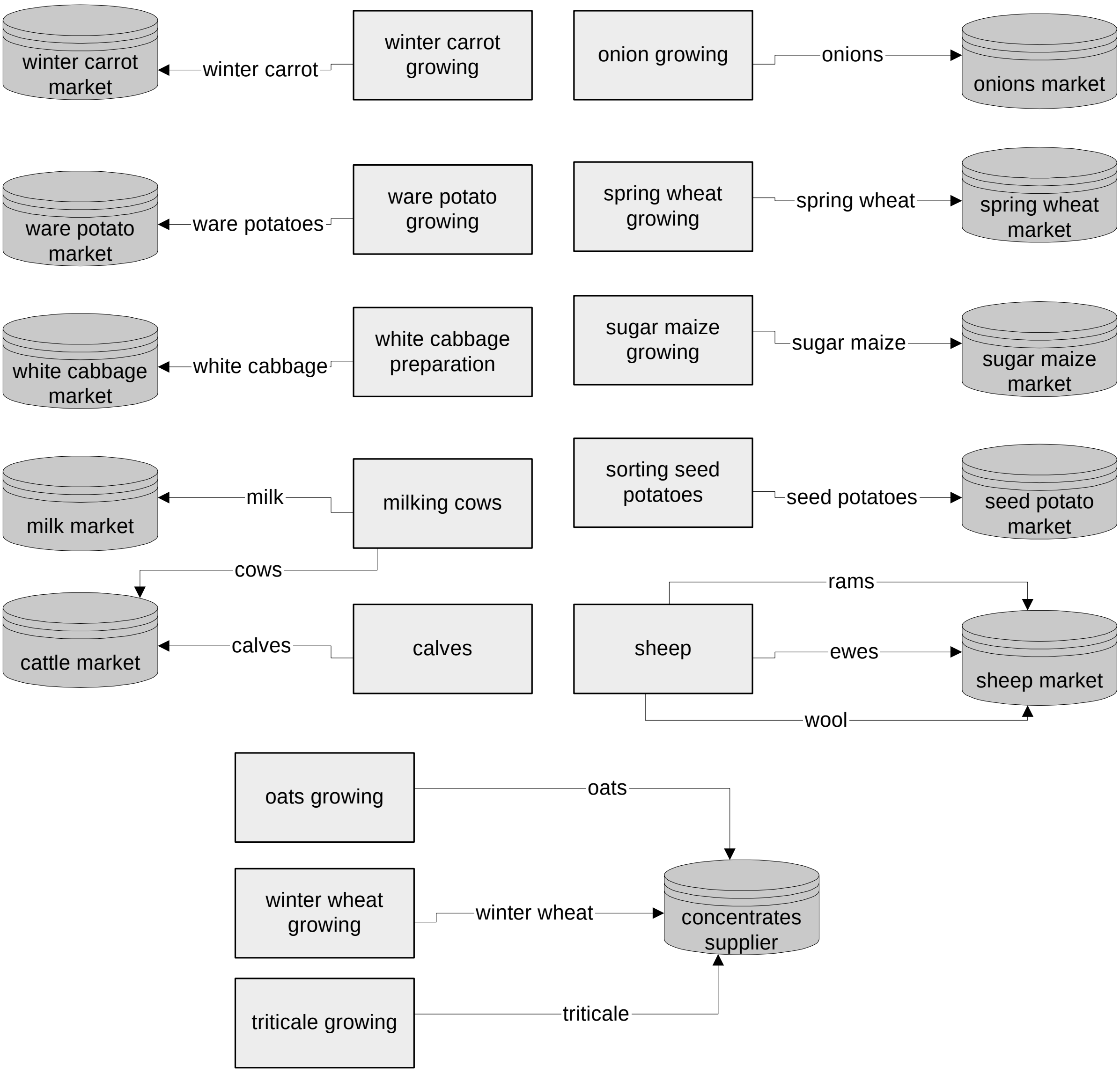


Fig. 7-5 Flows that are connected with the entity *product exports.*

There are also less visible output flows like volatilization and denitrification, but it is assumed that, if goals set on nutrient availability and nutrient resources are maintained in a proper way, these flows will only be slightly larger than in a ‘natural’ ecosystem.

Circulation

With fertilization, nutrients can be re-allocated within the system by farmer’s intervention. In a mixed ecological farm like APMeco, this is done by applying manure to crops. Because the crops rotate over the different fields, nutrients are automatically re-allocated in time and space. Because several crops are leguminous (sometimes in a mixture like grass/clover), the nitrogen that was fixed is also circulated in time and space. Hence, *crop rotation* is the next entity to be distinguished, with *fertilization* and *biological nitrogen fixation* as aspects. The permanent pasture is by definition not included in the rotation, but it is an important source of nitrogen input, because it consists of a mixture of grass and clover. The nitrogen that was fixed is circulated by cattle *grazing*. The entity grazing will not be further elaborated in this case study.

Fertilization

The goal, set on fertilization with manure can be described as: applying the manure in such a way that the nutrient cycle of the crop rotation is restored. In APMeco, the farmer has several types of fertilizer to his disposal: *solid manure, liquid manure* and *green compost.*

Solid manure consists of faeces of animals mixed with straw. *Solid manure* from the *solid manure storage* is applied to the stubble of the fields where oats, spring wheat and winter wheat have been grown. Hence, these flows are connected with this entity. For the circulation of nutrients, the nutrient content (nitrogen, phosphorus and potassium) of solid manure is important. This is determined by the preceding flows: *solid manure* from both cow houses to the solid manure storage, *faeces, straw,* all *feed intake flows* (e.g. *grass/clover silage feed, concentrates*) and the flows that precede this feed until the feed growing processes (e.g. *silage grain*, *grass/clover*). At the moment, only feed flows related to the milking cows are taken into account, because these will contribute most. All connected flows are shown in Fig. 7-6.

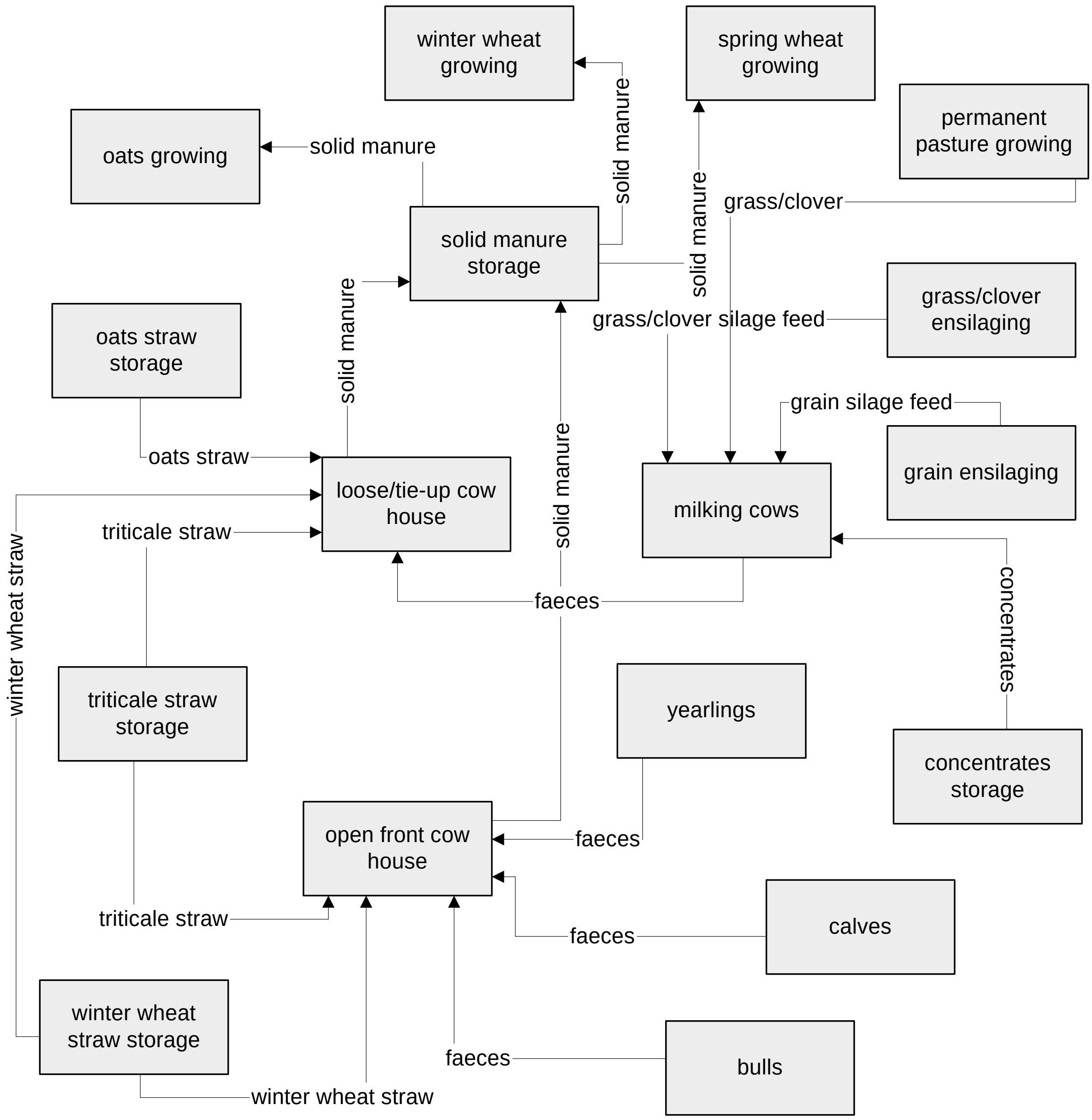


Fig. 7-6 Flows that are connected with the entity *solid manure.*

Liquid manure consists of the urine and a bit of faeces of the cattle. *Liquid manure*, from the *liquid manure storage*, is applied to the temporary and permanent pasture. Hence these flows are connected with this entity. Again, for the circulation of nutrients, the nutrient content (nitrogen, phosphorus and potassium) of liquid manure is important. This is determined by the preceding flows: *liquid manure* from both cow houses to the liquid manure storage, all *feed intake flows* (e.g. *grass/clover silage feed*, *concentrates*) and the flows that precede this feed till the feed growing processes (e.g. *silage grain*, *grass/clover*). At the moment, only feed flows related to the milking cows are taken into account, because these will contribute most. The flow connections are shown in Fig. 7-7.

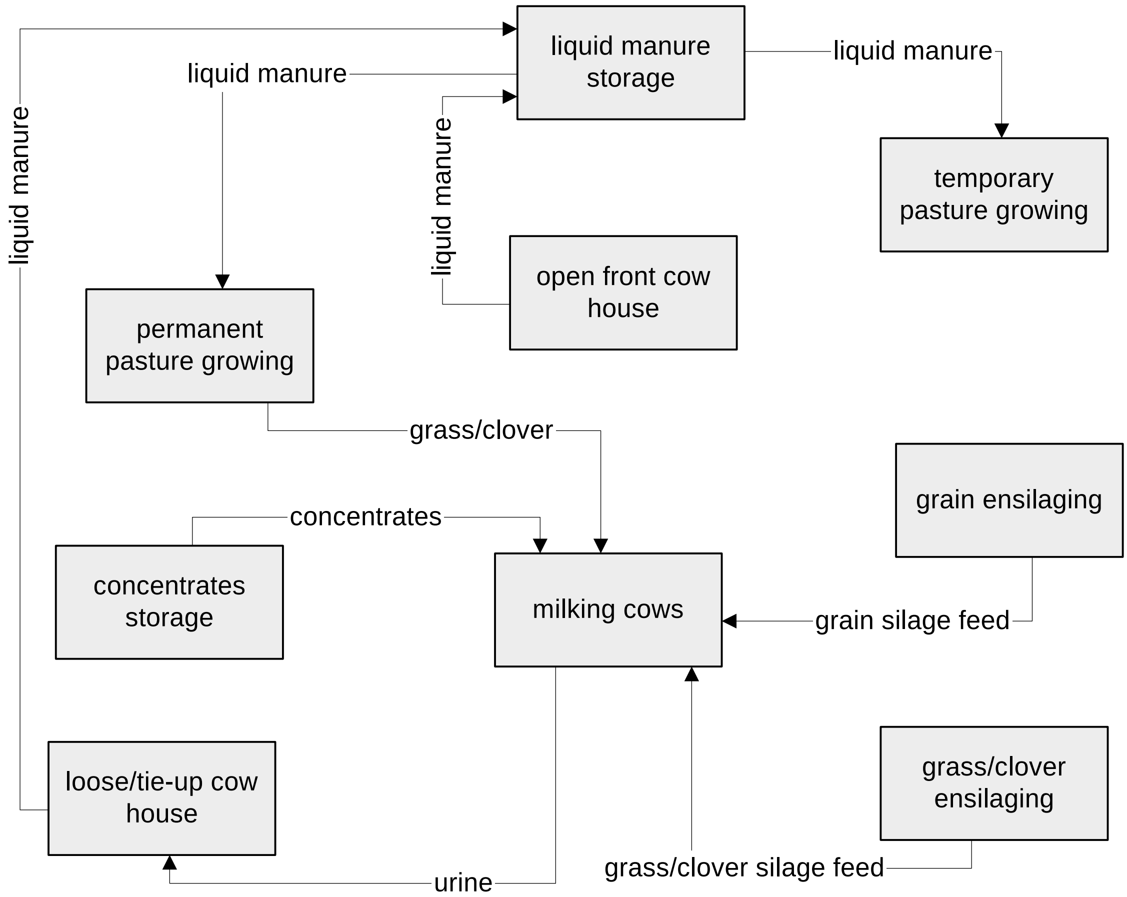


Fig. 7-7 Flows that are connected with the entity *liquid manure.*

Green compost is defined as composted vegetable-, fruit- and garden waste material from consumer households. In the Netherlands, this is collected on a rather large scale. By using this material, some of the nutrients exported by products sold, are recycled. The *green compost* is applied to the temporary pasture, and this is the only flow that is connected with this entity. It is purchased from an external resource, so it is important to include a strict work instruction in the Sustainability Management Handbook, to assure that no unwanted compounds are imported into the farm system. This goal can be connected with only one flow (Fig. 7-8).

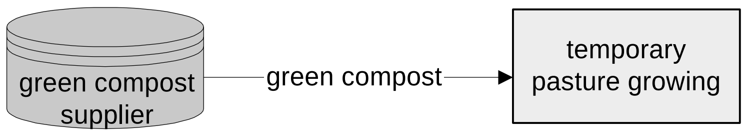


Fig. 7-8 Flows that are connected with the entity *green compost.*

Biological nitrogen fixation

Biological nitrogen fixation was already mentioned under the balancing aspect of nutrient resources. However, there is also a circulation aspect, because the crop mixtures containing *leguminoses* are part of the crop rotation. So, these crops rotate over different fields and it can be important for circulation to control the amount of nitrogen fixed. Hence, this goal entity is connected with the internal resource flows *air* that go from the internal resource atmosphere to the relevant growing production units. The *clover seed* flows are connected, because the amount and quality of seed influences the amount of nitrogen that is fixed. Besides, the grass/clover crops are also circulated by mowing and grazing. Therefore, the *grass/clover* flows and also the *silage grain* flow are connected with this goal entity. All connected flows are shown in Fig. 7-9.

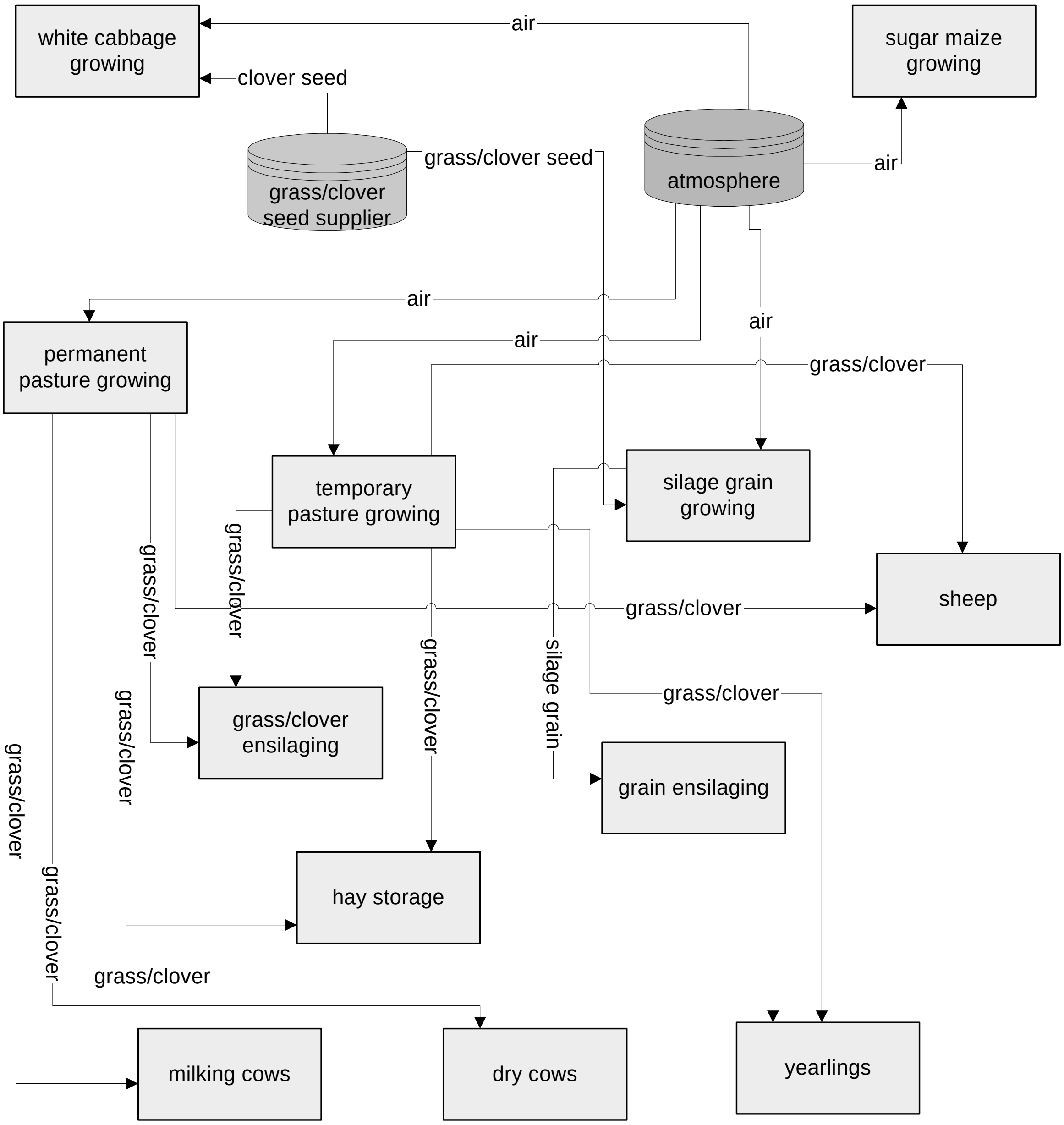


Fig. 7-9 Flows that are connected with the entity *leguminoses*

So far, some entities and aspects of soil fertility and their connections with product flows were described. Now, it is continued with the aspect of soil structure.

Soil structure

Soil structure is defined as the spatial arrangement, shape and size of elementary soil constituents and their eventual spatial aggregates, as well as the pores that occur in the soil (Boersma, 1989). Soil structure is a difficult subject. With regard to soil quality, there is as yet not a well-defined methodology to characterize soil quality and to define a set of clear indicators in general (Bouma, 2002)[1].

A visual *structure index* was defined ranging from 1 to 10 according to the spade analysis method (Van der Werff, 1995). In this case, farmers can typically use intuitive knowledge, to define what, to their opinion, is a good soil structure. Objectively, a good soil structure could be indicated by one that is featured by sufficient cohesion between soil particles, gradual transitions and sufficient large and small pores. This is still a rather abstract goal, but some aspects can be identified that influence soil structure.

Soil structure is a result of dynamic physical and biological processes. Physical processes partly consist of weather influences and cannot be influenced. *Soil tillage* is an important physical process that does fall within the scope of farm management. *Soil life* is an important biological factor. Indirectly, it can also be considered as a physical process, because many organisms - cooperating together - take care of decomposition of organic matter and creation of pores in the soil. These organisms must be fed somehow with food and energy, often represented by carbon/nitrogen ratios of organic matter, in which nitrogen stands for food and carbon for energy. Hence, *fertilization* is, beside of soil fertility, also an important aspect of soil structure. Concerning animal husbandry, *grazing* can also be important, because wrong grazing management (e.g. in wet weather conditions) can easily lead to a bad soil structure of the pastures. In this case study, this aspect is not worked out any further. Good *drainage* is one of the most important prerequisites for good soil structure. *Monitoring* is important in order to keep track of the soil structure.

Soil tillage

Soil tillage concerns all kinds of operations such as loosening the soil, incorporating manure into the soil, weed control, seedbed preparation and yielding (especially root crops). In different ways, they influence soil structure. Timing, in combination with soil and weather conditions, influences soil structure. Wrong timing can easily lead to disintegration of soil structure, leading to compaction, smearing or tracking. Dry soil is most favorable for soil

[1] This reference is taken from a special issue of the journal Agriculture, Ecosystems and Environment, which is dedicated to the 'soil health' and contains much recent information on this topic.

tillage. With respect to machines, light machines with low tire pressure or broad tires are favorable.
An entity *soil* was identified on which a rather abstract goal was set, namely that the soil must have a good structure after a soil tillage operation. This goal can be connected with all *soil* flows to and from growing production units (Fig. 7-10).

Soil life

Soil life can be defined as the whole of organisms living in the soil. Important processes, carried out by these organisms, are: decomposition of organic matter, converting organic matter into humus products, mixing and moving soil particles and transport of micro-organisms; processes, which are in their turn, very important for soil structure.
Soil life can be influenced by fertilization and soil tillage, two aspects that are already aspects of the structure index (see Fig. 7-1), so they are already accounted for.

Fertilization

In fertilization with respect to soil structure, *organic matter content* is an important entity. Organic matter is connected with soil life because of its carbon/nitrogen ratio. Hence, the organic matter content should be *monitored* and *replenished*. Monitoring is related to the soil and a common point for monitoring is in spring. Thus, flows *soil* that are input for a growing production unit can be connected to this goal (Fig. 7-11).

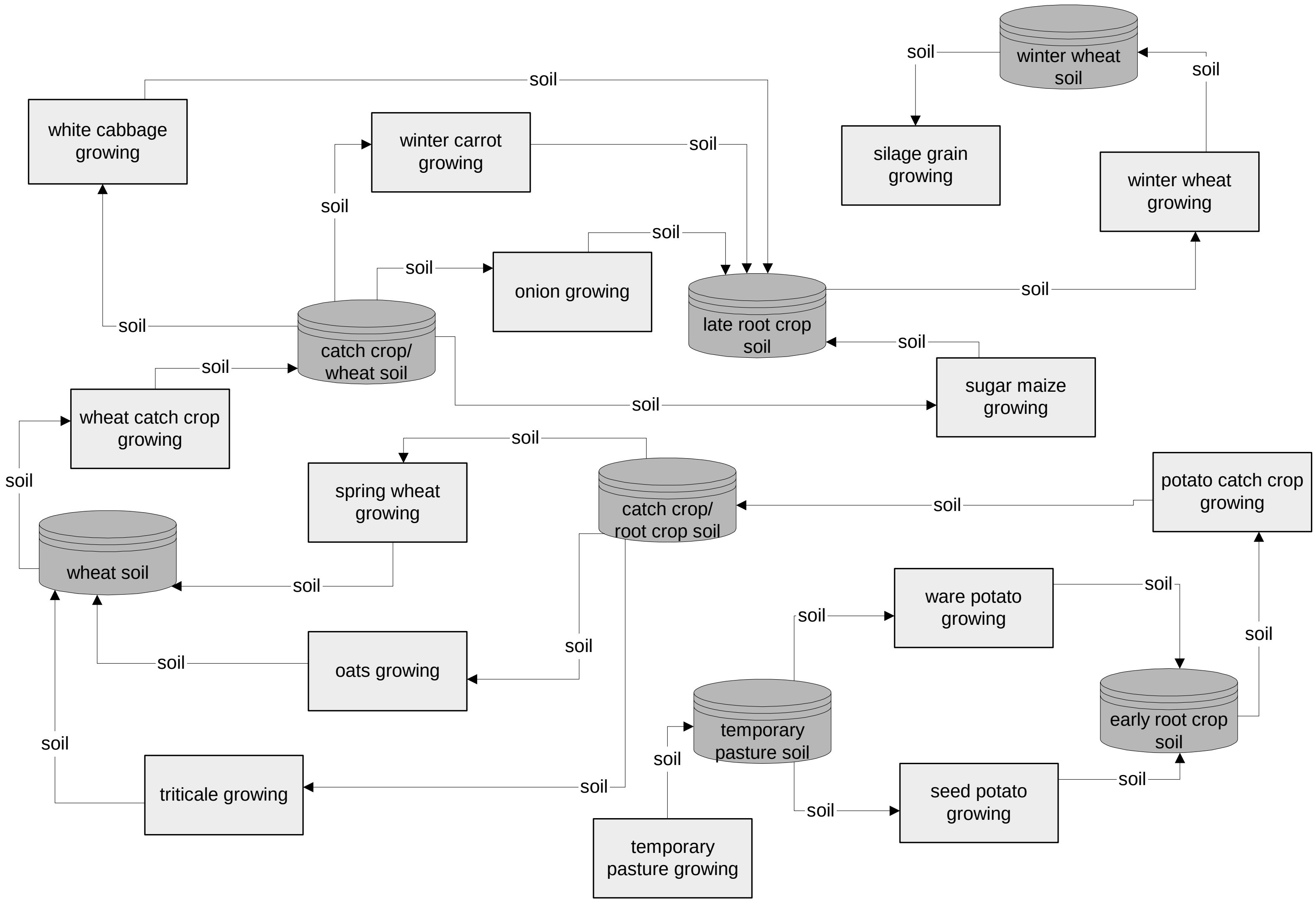


Fig. 7-10 Flows that are connected with the entity *soil*

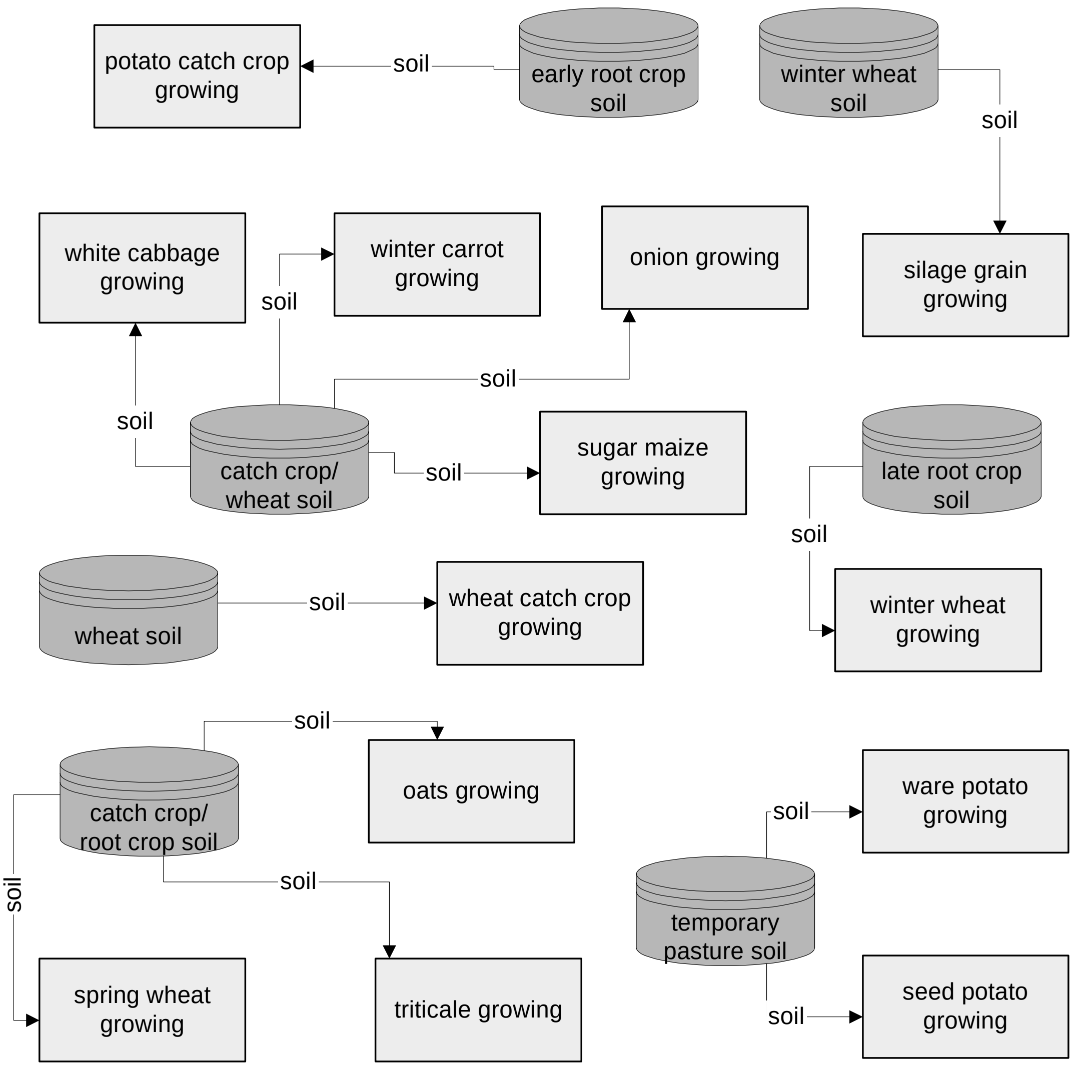


Fig. 7-11 Flows that are connected with the entity *soil.*

Replenishment takes place by *green manure*, *solid manure* and *crop residues*. Green manure and crop residues are directly connected with the relevant growing production units (Fig. 7-12 and Fig. 7-13). Timing of harvesting and plowing might be important.

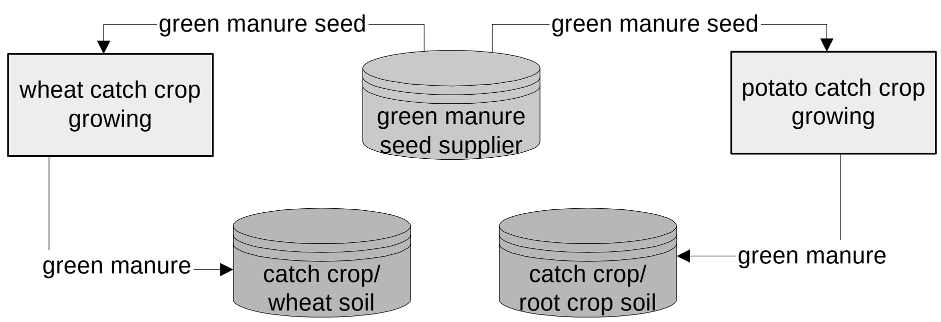


Fig. 7-12 Flows that are connected with the entity *green manure*

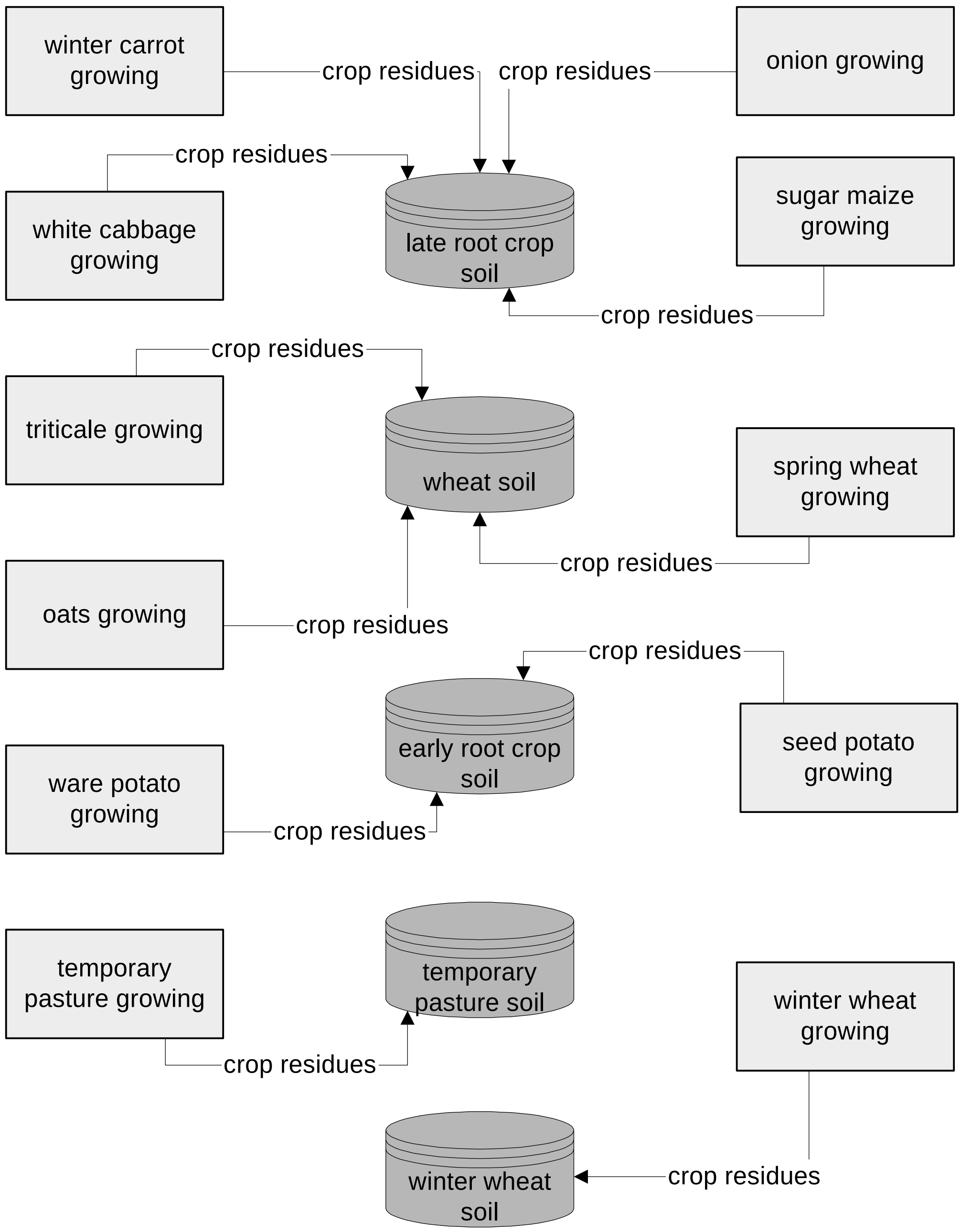


Fig. 7-13 Flows that are connected with the entity *crop residues*

The flow *solid manure* is applied to several crops. Its contribution to the organic matter content of the soil depends on its quality. This is especially determined by the solid manure storage production unit, but also by its input product flows, namely the *solid manure* from both cow houses. This, in its turn, is dependent on the *faeces* of the cows and the *straw* that is added. Thus, there are several flows involved in getting the appropriate quality of solid manure (Fig. 7-14).

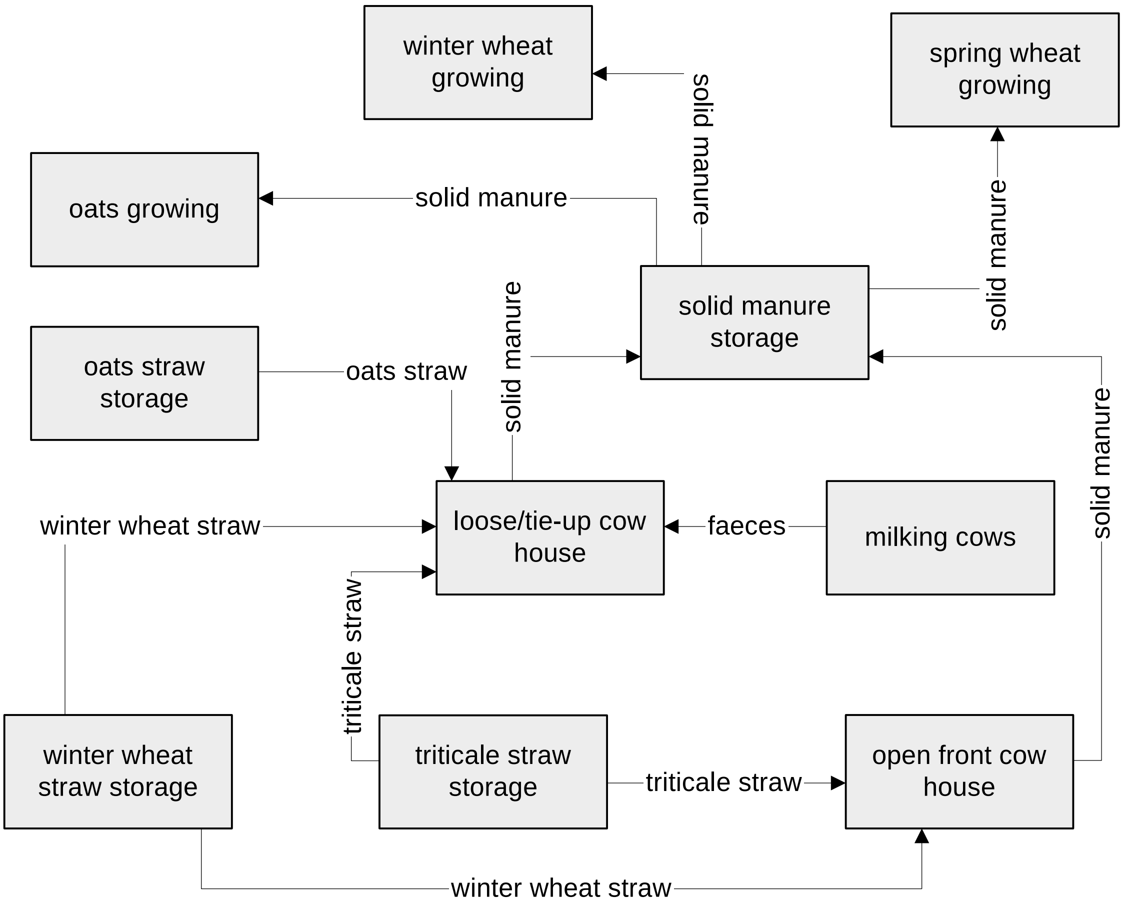


Fig. 7-14 Flows that are connected with the entity *solid manure*

Drainage

Drainage can be improved in a technological way by putting drainpipes into the soil. This can be very important, but it is not part of operational management, but merely a strategic decision. Hence, this aspect is not taken into account further.

A more biological and dynamic factor is the *lime content* that highly influences the drainage capabilities of the soil. An appropriate lime content determines the acidity of the soil and thus indirectly stimulates soil life and also plant root growth that helps to break up the soil in smaller aggregates and forms holes and channels. Furthermore, it has a direct effect on formation of soil aggregates like clay-humus complexes.

Like with organic matter, lime content should be *monitored* and *replenished*. Hence, it can be connected with the Product Flow Model in a similar way.

Monitoring

As already mentioned, the soil structure index is difficult to define and thus also to monitor. Still, it can be obtained from practice that farmers have many ideas about what is a good soil structure. These ideas are based on careful observations by looking and feeling. Rooting and

wormholes for example could be useful indicators. Crushing soil between the fingers is also something that most farmers use as in indicator for soil structure. Depending on the soil type, soil color and spottiness may say something about the water status. This looking and feeling can be extended using simple tools like a penetrometer or a spade. Good soil structure is also a dynamic and context-specific concept: it can be different for the time of the year and each crop requires a different soil structure.
It is obvious that this entity should be connected with all internal resource- and replenishment flows *soil*.

7.4 Discussion

From the results in the previous section two points for discussion can be derived. First, it is evaluated how nutrient management was implemented in the model. Secondly, it is discussed how the model provides support in situations where there is incomplete knowledge and information.

7.4.1 Nutrient Management

As to the aspect of soil fertility, the nutrient balance at farm system level was identified as an important entity. Many accounting models have already been developed for this purpose and, in the Netherlands for example, it has become an official governmental instrument (Mineral Accounting System, MINAS). However, most models are rather static and only calculate the balance over a certain time period, usually one year. They do not provide means of connection about how the balance can be actively influenced. The added value of the illustrated approach is that import and export is related to the whole production process and operational management. The inclusion of external resources in the Product Flow Model makes it easy to identify nutrient export and import. With respect to export, also preceding, intermediate product flows can be taken into account. With respect to import, purchase operations can be further defined in order to carefully check what is imported. Besides, goals were set on import to maintain the nutrient balance at farm system level. Although it was not extensively illustrated in this case study, these goals can be translated further into product flow properties that have to be kept within desired bandwidths. In this way, the nutrient balance is not a static accounting entity anymore, but becomes dynamic and manageable.
Crop rotation appeared to be a crucial, driving factor in nutrient management for both soil fertility and structure. In the Product Flow Model, the internal resource *soil* was modeled as an intermediate element that reflects the effects of crop rotation. These effects are included in the growing production units by its operations. The farmer is made aware of what soil quality is required for growing a specific crop, related to what soil quality is left after growing a crop. It was tried to translate soil quality into more concrete and manageable terms. By doing this, it also became clear that this is not always easy; Section 7.4.2 will come back to this.

Special attention was paid to biological nitrogen fixation that is part of the crop rotation. It became clear that the amount that is fixed should be managed with regard to several goals. Beside the input aspect, it was shown that circulation is very important. This can be managed by identifying the relevant product flows (often preceding each other) in the whole production process. Especially feed flows play an important role. Again, this can be related to product flow properties (e.g. nitrogen contents, clover shares) and thus with operational management.

Manure was considered as an important intermediate product that can be used for re-allocation of nutrients and for managing both soil fertility and structure. It was shown that manure quality is influenced by several preceding flows, that become manageable via the intermediate production units. Hence, there are many means of connection for influencing the desired quality of manure.

7.4.2 Incomplete knowledge and information

As already mentioned, goals were set, but it was not always clear how to monitor and manage them. This seems to be more the case for soil structure rather than for soil fertility. This is probably due to the fact that much more attention is paid to this topic in conventional agriculture. Hence, not much hard information and knowledge is available about soil structure. In the first place, the illustrated approach helps to identify knowledge and information gaps. Secondly, it was also shown that the model leaves room for including intuitive knowledge and qualitative information based on farmer’s experience. In this way, the model provides means of connection to make aspects like soil structure as manageable as possible.

7.5 Conclusions

From the results and discussion it can be concluded that the model is in line with the principle of recycling management of ecological agriculture and especially supports in implementing it in practice. This is done by connecting overall goals with flows and their properties. Management is improved by getting more grip on these properties. It was illustrated that in this way management co-operates with (ecological) processes.

Identification of natural resources, especially soils, in the Product Flow Model play a key role. It was also shown that recycling management is often tightly connected with preventive management, because product flows within a cycle or chain are closely related to each other. These relationships can be manipulated by the operations of a production unit. This case study also demonstrated that in topics like nutrient management an integrative approach of the whole production process is necessary.

Finally, it was illustrated how the model helps to support learning-by-doing or learning-by-experience and in this way helps to develop knowledge. Mind Map 10 in Appendix VI summarizes the most important facts of this case.

8 Expert validation

Wetenschap kan een zuiver parochiale aangelegenheid worden en de functie krijgen van zelfbevestiging en rechtvaardiging van een subgroep...[1]

Van Strien (1986, p. 185)

Abstract

This chapter evaluates the model and methodology by applying expert validation. During a half-day's session, a panel of experts was confronted with the model and some illustrative outcomes of the potato case study. They were asked to judge whether the model and methodology satisfied its main objective, namely if implementing sustainability in operational farm management in this way corresponds to the learning behavior of a farmer. This was done by questioning them and by group- and plenary discussion. Apart from discussing how the entire model is applied, each model component (Product Flow Model, Sustainability Mapping, Sustainability Function Deployment and Sustainability Management Handbook) was reviewed separately. The experts were asked for their opinion on relevance, feasibility and practicality of the approach. This has resulted in a list of strengths and weaknesses and also recommendations for future improvement. The main conclusion is that the model and methodology are adequate means of support for translating and implementing sustainability in operational farm management and that potentially, the approach corresponds to learning behavior, although this is hard to justify.

Keywords: model validation; expert validation; model assessment; expert panel

[1] Science can become a pure parochial affair and get the function of self-affirmation and justification of a sub-group.

8.1 Introduction

Every model must be validated (Lewandowski, 1982; Qureshi et al., 1999). Validation can be carried out in different ways. In this thesis, *expert validation* is applied. Section 8.2 briefly describes various types of validation, explains why expert validation was chosen and provides a definition for this activity. Next, Section 8.3 describes the aims of expert validation, specifically for this thesis. Section 8.4 describes how it was carried out. Section 8.5 provides the results of expert validation, while Section 8.6 discusses them. Finally, some main conclusions are drawn in Section 8.7.

8.2 What is validation?

In Chapter 4, it was concluded that agricultural management systems are hardly or not at all used. In connection with this, Harrison (1991) says that usually much effort is spent on model development and less on testing. Model validation can be considered as the first phase of testing and is therefore important. However, what exactly is model validation? Several papers from different fields of research are written about this specific subject (see e.g. Lewandowski, 1982; Preston White, 1989; Harrison, 1991; Andert, 1992; Sheng et al., 1993; Kleijnen, 1999; Qureshi et al., 1999). Sheng et al. (1993) conclude that the use of this term is rather ambiguous. Validation is often connected with simulation models or models that execute calculations, which is not the case in this thesis' model. Expert systems or knowledge-based systems come closer to it and several papers were found that specifically deal with validating these type of models (Harrison, 1991; Andert, 1992; Kerr et al., 1999). However, they refer to models that contain existing knowledge concerning content (e.g. management rules on plant protection or irrigation). In other words, they are still rather prescriptive. The model in this thesis is more descriptive and based on the idea that knowledge is put in by the farmer himself.

In conclusion, literature on validation is ambiguous and no method was found that is directly applicable to the model in this thesis. Hence, it is necessary to explain briefly what is understood by validation and what validation method is applied in the specific case of this thesis.

8.2.1 Definitions

In general terms, Harrison (1991) speaks of *evaluation* as all procedures applied to assure a model is appropriate for its intended purpose. Evaluation is often divided into verification, validation and sensitivity analysis (Preston White, 1989; Harrison, 1991; Qureshi et al., 1999).

Verification handles the question if the model performs as intended (Harrison, 1991) or 'am I building the product right?' (Andert, 1992). In other words: does the model satisfy the requirements that were set, or more formally, its specifications. In this thesis, this issue concentrates on specifications of management control and ecological production as described in Chapter 4, based on the general theory, described in Chapters 2 and 3.

Validation determines whether the model is an acceptable representation of the real system, given the purpose of the model (Kleijnen, 1999). It handles the question 'am I building the right product?' (Andert, 1992). A model will never be perfectly valid as is indicated by terms like 'acceptable', 'matter of degree' or 'sufficient confidence' (Qureshi et al., 1999). According to the Popper's philosophy, a model can never be proven to be valid, but only to be invalid (Sheng et al., 1993; Ebbing, 1995). The more the attempts to invalidate the model fail, the higher the degree of credibility that can be given to the assumption that the model is valid. Several types of validation can be distinguished. *Conceptual validation* is a static kind of validation (Andert, 1992) and looks if the model concepts that have been used correspond to the concepts recognizable in the system that is being studied in reality. This is usually closely related to verification. *Operational validation* (Preston White, 1989; Ebbing, 1995) tests whether the model is valid for its intended purpose, closely related to the intended potential users and their assumed way of utilizing the model. Therefore, the purpose and the users and their needs have to be carefully defined first. *Empirical validation* tests whether the model output sufficiently agrees with data of the system in reality, provided that these data were not used to develop the model. This is often considered as the best form of model behavior. It can be seen as the most objective type of validation. However, it is only applicable to simulation or calculation models of systems that allow replicable experiments or data collection (Qureshi et al., 1999). *Face validation* is a more subjective type of validation (Harrison, 1991). A model with face validity is one which appears to be reasonable (or does not appear to be unreasonable) to people who are knowledgeable about the system under study (Preston White, 1989). Face validation can be carried out by confronting (or facing) experts with model outcomes (provided a certain input) and ask them if they are reasonable (Kerr et al., 1999; Qureshi et al., 1999).

Sensitivity analysis searches for small changes of variables in the model or real system that have a large effect on the outcome. It is connected with the behavioral robustness of the model. This is also only relevant for simulation or calculation models.

This categorization of evaluation could be further extended with model assessment, which is related to reliable use of the model (Preston White, 1989). It deals with the questions to what systems the model can be applied and in which situations the model outcome is still reliable. It is related to activities like model maintenance, quality control and understanding model outcomes.

Finally, it is emphasized that validation is a continuous process. It can be carried out at several development stages and a model will also be regularly changed and updated, often after a validation session.

8.2.2 Expert validation

In theory, a validation method for the model in this thesis could be as follows: implement the model at a group of farms, measure the degree of sustainability and compare the outcomes with a control group that does not use the model. In practice, this would be hard to realize for several reasons. In Chapter 2, it was argued that an objective overall degree of sustainability is hard to define. Each individual farmer will set his own norms and priorities, based on his personal values. Perhaps, it would be possible to compare farms for goals at a lower level, like farm results, energy use or animal welfare. But then the question emerges how to account for natural differences between farm craftsmanship and stochastic factors. It would mean that a large group of farmers must be involved in order to obtain statistically valid results. Hence, at this stage of model development, a more subjective approach seems to be the most feasible.

Face validation seems to be most appropriate. However, at this moment the model and accompanying software is not yet developed far enough to apply it directly to a group of farm systems. Hence, a combination of face validation, conceptual validation and operational validation was made and called *expert validation*. It is defined as follows:

> Expert validation is confronting a group of experts (who are knowledgeable about the model domain) with the model itself and some illustrative outcomes of the model, and letting it judge to what extent the model fits for its intended purpose by questioning and plenary discussion.

The next sections will explain in detail how this was carried out.

8.3 Aims of this expert validation

Aims of expert validation, as described in this chapter, are:

- a general assessment of the whole model, its subcomponents (Product Flow Model, Sustainability Map, Sustainability Function Deployment and Sustainability Management Handbook) and the way they are applied to the system in reality;
- a concrete list of strengths and weaknesses;
- an indication of relevance for practice;
- an indication of practicality and feasibility in practice;
- a list of recommendations for improvement

An indirect aim is to get relevant input for the discussion and conclusions in the last chapter of this thesis.

8.4 Material and methods

The most important part of expert validation was a half-day's session in which the expert panel was faced with the model and some outcomes and asked for their evaluation as well of the outcomes as of the basic assumptions and the method of use. This section will describe how this session was prepared and held and what kind of experts were invited.

The case study 'Economic aspects and quality management of potato production at the mixed ecological farm system of the ir. A.P. Minderhoudhoeve', as described in Chapter 6, was used for illustrative model outcomes.

8.4.1 Expert panel

The aims, as listed in Section 8.3, reflect an overall judgment of the model and methodology, which requires a broad expert panel with different kind of experts that can form counterparts during discussion. The expert panel consisted of 8 persons that were selected on basis of several criteria (see Table 8-1).

Table 8-1 Characterization of the expert panel according to expert's specific backgrounds.

expert	information modeling	information & communication technology	knowledge systems	(farm) management research	farm economics	applied agricultural research	ecological agriculture	(quality) assurance systems	scientific potato research	potato production practice	potato processing
e1	x	x	x	x	x			x			
e2	x	x	x	x							
e3	x								x	x	x
e4				x		x	x			x	
e5				x			x	x		x	
e6							x			x	
e7*								x		x	x
e8				x	x	x		x		x	

* this expert was prevented from attending the expert validation session

The experts e3 to e8 had some relation with potato production, ranging from practical application to scientific research. They were expected to be able to give a better judgment, because the illustrative outcomes of the potato case study are meaningful to them. Furthermore, they are supposed to be able to judge on relevance, practicality and feasibility of the model and its farm management consequences. Although they could be mainly seen as potato specialists, their background was broader, so it was supposed that they could also imagine how the model could be applied to other parts of a mixed ecological farm system. Experts e1 and e2 were not really familiar with potato production, but can be characterized as information modelers. As e3 to e8 are not, they were supposed to be a good counterpart during group discussions.

Several experts had a background in (farm) management research and some others in (quality) assurance systems; two topics that are also very relevant with respect to this thesis' model. Three experts (including a farmer) had a background in ecological agriculture.

8.4.2 Preparation

For preparation, all members of the expert panel were sent the following in advance:

- an unofficial advertisement brochure;
- a draft of Chapter 5 of this thesis (general instantiation);
- a draft of Chapter 6 of this thesis (potato case study).

The unofficial advertisement brochure is a leaflet that is set up as a kind of advertisement and presents the complete model and methodology in a simple way. Using this, the experts could obtain a first, quick impression of what it was all about.
By reading Chapter 5, they could obtain a more detailed description and explanation. Furthermore, Chapter 5 provides a general instantiation of the model (in particular the Product Flow Model), so that they can keep this in mind when focusing on potato production in Chapter 6. In Chapter 5 they could also obtain an idea of how the software tools that are used to instantiate the model work.
Chapter 6 provided a case study on most expert's knowledge domain, so that they could obtain a better impression of how the model and methodology is ought to work in practice. In an accompanying letter, it was stated that the case study was not yet complete. They were asked to reflect on how the examples could be extended or improved. In this way, it was supposed that they got more closely in touch with the model and methodology.

8.4.3 Panel session

A session of 4 hours with the whole panel was held and consisted of three parts:

- general introduction;

- computer demonstration of the model and methodology;
- evaluation.

These will be described in more detail in the following subsections.

8.4.3.1 General introduction

First, there was room for getting acquainted with each other, especially to know each other's professional background and what kind of expert role they would play in this session.
Then it was explained what expert validation means (as described in Section 8.2) and what the aims of the session were (as described in Section 8.3). In this way, the participants were made aware of what was expected from them.
Next, some theoretical background about designing sustainable farm systems and mixed ecological farming was briefly presented, as described in Chapters 2 and 3 of this thesis. This ended up in presenting the ultimate objective of the model and methodology, described as:

> The objective of the model and methodology is to provide support in translating and concretizing sustainability in the daily, operational management of a mixed ecological farm in such a way that it is in line with the learning behavior of a farmer, which is based on experience and experiments.

This was emphatically presented as the goal for which they had to validate the model for. Therefore, it was written on a large piece of paper and constantly visible during the whole session.

8.4.3.2 Computer demonstration

The model and methodology were then demonstrated using the software that was developed for instantiation. Examples from the potato case study were used for this purpose. In this way, the experts could get more acquainted with the model and methodology and also obtain insight in how information and communication technology (ICT) contributes to the objective. During this demonstration, there was also room for informative questions and discussion with respect to the choices that were made in modeling potato production.

8.4.3.3 Evaluation

In general, the main objective of a panel session is to obtain a well-balanced and well-considered judgment through discussion between individual members. However, to have a good discussion, each individual member must have or obtain his or her personal judgments first. Hence, the evaluation was built up as follows:

- first impression;

- questionnaire;
- discussion in groups;
- plenary feedback and discussion.

The first two parts were meant to structure each individual expert's thoughts. First, they were asked individually:

> "Taking into account the objective of the model and methodology: describe in a few words your general opinion about the model and methodology. What especially did appeal to you and what did not?"

Next, they individually had to fill in a small questionnaire in which they had to assign marks to aspects of the model and methodology. The questionnaire can be found in Appendix V. This resulted in a quasi-quantitative assessment. Although the main goal of this questionnaire was to structure each panel member's thoughts, it could provide some quantitative indication. However, these figures are not statistically valid. Still, it could be interesting to look at the possible differences between experts with a different background.
After that, the panel was split up into two groups. Both groups were asked to discuss the following topics:

- product flow modeling;
- sustainability mapping;
- sustainability function deployment;
- sustainability management handbook;
- the model and methodology as a whole.

One group was asked to try to mention strong points and the other group weak points. This choice is based on the idea that in this way strengths and weaknesses would become clearer. The group of experts was split up according to the following division:

strengths-group: {e2, e5, e6, e8}
weaknesses-group: {e1, e3, e4, e7}

This division was not at random, but made with the intention to obtain a balance between the different backgrounds of each individual expert.
After group discussion, the results were collected and discussed in a plenary session. The outcomes of this discussion can be seen as the most important result of this expert validation.

8.5 Results

Results were obtained from:

- answers to the question about a first impression
- answers to the questionnaire
- feedback from group- and plenary discussion

They are presented in the following subsections.

8.5.1 First impression

The answers from the first question were very diverse and were often put as questions, which indicated that everything was not yet a hundred percent clear. Therefore, the answers were not directly experienced as useful results. Some remarks were incorporated into the final results, because they reappeared during the final discussion. From the final discussion, it became clear that questions were replaced by statements, as a result of interaction during the discussion. Hence, it can be concluded that the first question had reached its goal, namely structuring the expert’s thoughts.

8.5.2 The questionnaire

Results from the questionnaire were also seen as intermediate results, because at that point of the session, no interactive discussion had taken place yet and a lack of clarity still existed among panel members. Furthermore, the number of participants was relatively low and their background was too diverse to obtain statistically valid information. However, some preliminary indications could be obtained from the results that are shown in Table 8-2.
Questions 1.1and 1.2, which directly refer to the goal of the model and methodology, have a good average score. Two times a 2 was assigned (by e3 and e1), but it cannot be logically connected with the background of these experts. The added value of ICT (1.3) is generally recognized, especially by the information and knowledge modeling experts (e1, e2 and e3). The flexibility of the model was also well appreciated, except by e5, but from later feedback, it could be concluded that his opinion had changed positively afterwards.
The submodels, from Product Flow Model to Sustainability Management Handbook, were well appreciated, although the answers vary (questions 2.1 to 5.1). There does not seem to be any logical relation with the background of the experts. Some experts remarked that the principle behind the Sustainability Management Handbook is good, but it is not elaborated enough yet. This remark also came back during the final discussion.
From the answers to question 6.1, including some additional remarks that were made, it can be concluded that the model and methodology is applicable to ecological agriculture, but

probably also to conventional agriculture. On average, it is judged that the model and methodology are suitable for the ecological production principles of recycling and especially of preventive and management.

Question 6.4 resulted in different answers, including various remarks. It can be concluded that the system should be an instrument in the hands of the farmer, but consultants can help to set up and maintain the system; fine-tuning should then be left to the farmer.

Table 8-2 Results of the questionnaire. The questions are listed in rows and the experts in columns.

question	expert panel							**average**
	e1	e2	e3	e4	e5	e6	e8	
1 The whole								
1.1	5	3	2	4	5	3	4	**4.0**
1.2	2	4	3	3	5	4	4	**4.3**
1.3	3	5	5	4	5	4	2	**3.7**
1.4	5	5	3	5	1	4	4	**3.0**
2 Product Flow Modeling								
2.1	4		2	3	4	3	3	**3.3**
3 Sustainability Mapping								
3.1	5	4	4	4	3	2	4	**3.0**
4 Sustainability Function Deployment								
4.1	4	4	4	3	4	3	4	**3.7**
5 Sustainability Management Handbook								
5.1	3	3	4	3	5	3	3	**3.7**
6 General								
6.1	*ecological*	*both*	*conventional*	*ecological*	*both*	*both*	*both*	
6.2	4	5		3	5	4	4	**4.3**
6.3	3		5	3	5	2	3	**3.3**
6.4	*both*	*both*	*farmer*	*farmer*	*farmer*	*both*	*both*	
6.5	2	2	4	2	5	2	2	**3.0**
6.6		2	4	3	4	2	3	**3.0**
6.7	5	5	4	3	5	3	5	**4.3**
6.8	*active*	*active*	*active*	*informed*	*informed*	*informed*	*informed*	

The answers about the feasibility and practicality (6.5 and 6.6) are less positive and rather negative when looking at the farmer (e6). Apparently, it was also a question that was difficult to answer, because many conditional remarks were made. They stated that it can depend on the kind of farmer and some experts were also more optimistic taking into account the future, when certification for the whole production chain will have become common practice.

Most experts think that the model and methodology can be very well combined with certification systems. Especially, the experts in this domain (e1, e5 and e8) were optimistic.

Expert e5 remarked that it is necessary then to include registration procedures than can be verified in the Sustainability Management Handbook.
Finally, none of the experts indicates that he or she is not interested in future development of this model. Some of them even possibly want to be actively involved (6.8). This is in line with the enthusiastic atmosphere that was felt during the session.

8.5.3 Strengths and weaknesses and plenary discussion

The results from the group discussions and plenary discussion are presented in the same order in which they were discussed: first each submodel and then the whole model and methodology.

8.5.3.1 Product Flow Model

The Product Flow Model was considered to be a good representation of the primary production process. It provides insight in the mutual relationships between production processes. The Product Flow Model was seen as an indispensable part of the whole. In relation to the overall objective, the Product Flow Model provides the right degrees of accuracy, i.e. the subdivision into production units and flows. Because of its generic features, it is very flexible. Much heterogeneous information can be put into the model. However, examples on soft goals like animal welfare, labor conditions were not illustrated, so questions remained whether this kind of information can also be easily incorporated.
The generic and flexible nature can also become a weakness, because questions about the aggregation level easily arise during instantiation. For example: what production units must be distinguished and when is a flow split up into two or more flows? Do you have to create one flow *seed potatoes*, or do you have to split it up for different cultivars? Indeed these questions arise, but the instantiation of the Product Flow Model is always an iterative process and the sustainability goals will largely determine the aggregation degree of the Product Flow Model. Because the goals are also dynamic, the Product Flow Model is never complete. Especially the properties of flows will be changed regularly, while the number of production units and flows will not change that often.
It was also mentioned that instantiation of the Product Flow Model in reality will require some education and experience. This is comparable to other similar systems like ISO or HACCP. This pleads for a role of a consultant in implementation of the system. Through experience of these consultants, a kind of ‘best practices’ on how certain production situations should be modeled will occur after some time. There will be convergence to a kind of reference information models (Beers et al., 1993). However, these should not become a straitjacket and undo flexibility and farm-specificity.
It was mentioned that the concept of *internal resources* and accompanying *internal resource flows* and *replenishment flows* remains unclear. Clearer and stricter definitions are needed.

Finally, it was remarked that visualization of the Product Flow Model is a strength, but simplicity should be maintained in order not to endanger it.

8.5.3.2 Sustainability Mapping

A strong point of Sustainability Mapping is that a farmer is forced to make his goals explicit and to develop clear definitions. In this way, it supports consciousness-raising of one’s identity and development of a vision. Sustainability Mapping then acts like a mirror. The focus on connecting goals with flows was also considered as a very strong point.

The decomposition of sustainability goals from general to detailed level was also seen as strength. However, the question arose whether sustainability can be viewed as a sum of subgoals. Is it possible to approach it in a hierarchical way? Are there not many cross-connections? Indeed there are, but this should be the strength of multi-faceted structured entity programming (Elzas, 1989): alternation of aspects and entities breaks down a complex problem. One and the same entity can occur under different aspects and all aspects together maintain the complexity, but in a structured way. This makes cross-connections possible. In the end several subgoals can be reflected in one and the same operation, so that sustainability is approached in an integrated way. Apparently, this was not clearly communicated, perhaps because in the potato case study, only the economic aspect of sustainability was illustrated.

As in the Product Flow Model, soft goals like labor satisfaction, animal welfare were not illustrated and it was doubted whether these could be taken into account in the same way.

Some panel members remarked that the number of branches and levels could easily become too large, although this depends very much on personal perceptions. The developed software, that allows collapsing of and focusing on branches, should help to overcome this problem.

It was suggested to extend Sustainability Mapping with a weighting mechanism (like in Sustainability Function Deployment), so priorities can be set and also a kind of overall sustainability score can be calculated. This score could be used for benchmarking with colleagues or competitors.

8.5.3.3 Sustainability Function Deployment

The measurability of concrete goals, set on product properties, was considered as a very strong point of Sustainability Function Deployment. The priority and score system is also considered as a good concept, although it remained unclear how and if it would work in practice.

Sustainability Function Deployment could function as a kind of strength-weakness-analysis of the production process. Then, it also functions as a kind of mirror for the farmer and it reflects his craftsmanship and know-how.

The idea to work with bandwidths instead of fixed goals was also considered as a strong point.

It was observed that Sustainability Function Deployment probably takes quite some time and that it can be difficult for an individual farmer to identify the appropriate associations between flow properties and operations. There is a risk that certain associations, which do exist in reality, remain hidden. Hence, some panel members suggested incorporating default values, taken from external knowledge sources.

8.5.3.4 Sustainability Management Handbook

A strong point of the Sustainability Management Handbook is that it is well in line with the current trend of certification, while at the same time it can be extended with own specific goals, knowledge and experience. The knowledge used, can be either generally accepted or based on experience or intuition.

The Sustainability Management Handbook can be of great value in case of farm succession, more workers on the farm and illness. It can also support discussions in farmer study groups.

Again, some panel members pleaded for incorporating existing, external knowledge instead of starting with an empty handbook.

It was observed that the Sustainability Management Handbook does not provide enough interaction yet. The farmer is not confronted with actual values that are monitored. Hence, the idea of self-reflection and learning does not come into its own yet. However, it was accepted that it is technically possible to incorporate these features and this should be done in future case studies.

It was also suggested to incorporate automatic detection of conflicting goals that are set in Sustainability Mapping or Sustainability Function Deployment or to be warned when work instructions conflict with each other.

8.5.3.5 The whole

It was concluded that the principle of sustainability assurance (preventive management) is very well incorporated. By using the model and methodology, the production process becomes transparent, which is important nowadays with respect to consumer trust and marketing.

The current status of the system does not provide enough feedback yet in order to allow the evaluation of goals. So, the objective of tying in the learning behavior of the farmer does not yet come into its own.

Doubts were cast on the feasibility and practicality of the system. However, it was mentioned that the coming obligation of certification can take away these doubts and that the system becomes common practice in the future (within 5 to 10 years).

There was no agreement on the application of the system to a specific type of agriculture. Most panel members accepted that it could be applied to conventional agriculture as well and some thought that is even more applicable to conventional agriculture, because this type of

production system is better manageable by use of fast-acting instruments like chemical fertilizers and pesticides.
There was a general agreement that it is worthwhile to develop the system further and to test it with a larger group of farmers.

8.6 Discussion

The design of the whole model and methodology has resulted in a very generic system. This was done in order to be able to instantiate a very farm- and farmer-specific model. ICT is supposed to accelerate the process of instantiation. During discussion, there was a call for incorporation of existing knowledge to accelerate the process even more. In this respect, two types of knowledge can be distinguished: knowledge about farm management itself and knowledge about information modeling.
With concern to incorporating more farm management knowledge, two objections could be made. First, it depends on the generic applicability of external knowledge. To what degree is it valid in the context of a specific situation and does it correspond to the value-pattern of the farmer? Secondly, this could conflict with the idea that knowledge about sustainability should be obtained by learning (see Chapter 2). This is also connected with the personality of a farmer: is it someone who indeed wants to learn everything by himself or is it someone who believes or trusts that something works and does not want to know what the background exactly is. The first farmer will develop a better understanding of his specific production process, but his adaptive behavior may be too slow, so that in the end the second farmer turns out to be more successful or sustainable. The truth probably lies somewhere in the middle, but it is difficult to indicate exactly where. Hence, it is better to leave that to the farmer that will be actually concerned. Technically, it is possible to incorporate knowledge in the system or to make automatic links to external knowledge bases. However, there is a risk that the amount of knowledge will quickly be overwhelming and the level of accuracy and its up-to-dateness is often difficult to determine. Hence, it is probably better to leave it to the farmer to choose where he gets his knowledge from and what information filters he uses.
In Chapter 4, it was already suggested that knowledge about information modeling can easily be reused. For example, if the model is instantiated for a farm that grows potatoes, knowledge about what production units, flows and operations are identified, could be reused. The same holds for goals, associations, critical control points and work instructions concerning potato production. This process of reusing could be supported by ‘smart’ pieces of software that interactively (by asking them some questions) come up with a default configuration that can be customized afterwards. This is comparable to the so-called ‘wizards’ that can be found in many software applications nowadays. Indeed, this will result in a kind of standard reference information, but in this case they are developed as a kind of emergent property from practice.

If the reference information models are developed *ex ante*, they will easily become straitjackets and work out to be counterproductive.

During the discussion, some showed doubts whether soft goals like labor conditions, animal welfare, beauty of a crop, etc. could be taken into account. The model components offer various means of connection for this. An advantage of Sustainability Mapping is that qualitative goals can be included, while the methodology require the user to systematically split them up into concrete goals related to concrete product properties. An advantage of the Product Flow Model and Sustainability Function Deployment is that qualitative properties (e.g. color of a crop or a cow, smell of the soil) can be accounted for. So, it is suggested that 'soft' goals are often determined by 'hard' properties of product flows involved. For example, animal health and welfare will be determined by properties of feed and straw. In the Sustainability Management Handbook, all kind of critical control points and work instructions can be easily incorporated (e.g. control the sheen of the cow's skin or refresh straw on a daily basis). One thing, which remains debatable, is that certain goals or properties are difficult or too expensive to monitor (e.g. number of soil organisms that have an important nature value). However, this is a problem in general and there does not seem to be any problem, why soft goals could not be incorporated into the model. Doing another case study on this topic must further test this hypothesis. With respect to this topic, an advantage of the model and methodology is that intuitive knowledge, which is not (yet) scientifically approved, can be incorporated.

It is technically possible to extend Sustainability Mapping with a kind of weighting mechanism like it is applied in Sustainability Function Deployment. This can be used to prioritize between different goals, which seems to be a good idea. It was also suggested to extend this with a kind of sustainability score that is a weighted sum of the scores on subgoals. This could be used for benchmarking. Benchmarking is useful to compare farm results with colleagues or competitors in order to improve goals. However, if you want to compare at a high level in the Sustainability Map, it must be assumed that farms are comparable. This will hardly be the case in practice. Even when two farm systems are topographically adjacent to each other, they will differ, because each farmer has his own values and preferences. Besides, some goals, higher in the hierarchy, are difficult to measure, so comparison is hardly possible. Moreover, on entities high in the hierarchy, no clear goal can be set. In conclusion, it is possible to benchmark for generally defined and accepted indicators, but it does not make much sense to use a kind of overall sustainability score.

8.7 Conclusions

In this section, some main conclusions are drawn in referring to the objectives that were set for expert validation (see 8.3).

The Product Flow Model is considered as an appropriate representation of the object system. The rules for instantiation should be clear, although it will always require some education and experience. Sustainability Mapping helps a farmer to develop and make his vision explicit. The connection that is made with the Product Flow Model is a strong and essential point. Sustainability Function Deployment is a good instrument for further concretization of sustainability goals. The Sustainability Management Handbook is in line with the concept of certification, while it can be combined with own knowledge and experience. There are several imaginable situations in which the Sustainability Management Handbook plays a very valuable role. In the current version of the Sustainability Management Handbook there are not yet enough interactive elements included to provide appropriate feedback.

With respect to the overall objective of this model and methodology (see p. 183), it can be concluded that it provides good support for translating and concretizing sustainability to the daily, operational management at a mixed ecological farm. It can be doubted if all kind of aspects of sustainability can be taken into account. It was argued that it is possible, but some more case studies should give a more decisive answer on this issue.

The second part of the goal, correspondence with the learning behavior of a farmer based on experience and experiments, is not shown convincingly enough yet. However, it can be made plausible that it can be taken into account when goals are monitored and interactive feedback is provided in the Sustainability Management Handbook. Again, for a more decisive answer about this, the model should be applied to a real farm for several years, which was beyond the scope of this study. The role of external knowledge with respect to learning was discussed and it was concluded that this role would largely depend on the type of farmer.

The model is probably less relevant for the current situation of farms nowadays, but it will become more relevant in the near future. This depends on development of production chains in which certification and transparency will play an important role. Certification concerns (i) say what you want to do (ii) do what you say and (iii) show you have done it at the moment transactions take place (Beulens, personal communication). This is fully in accordance with the methodology that was presented in this thesis. Hence, this development will automatically enhance the feasibility of the system, because it will become economically attractive and perhaps inevitable, to be part of a production chain.

Applicability of the system is not considered high yet. Further evaluation by real application of the system in practice is required. Related to future developments, farmers must get used to it and then it will become common practice within several years.

Some recommendations on details of the model were already made in Section 8.5.3. A general recommendation is to carry out more case studies to illustrate other aspects of sustainability. One case study on recycling management, which was not used for this expert validation, is already provided in Chapter 7. Furthermore, it was concluded that an additional test of the model for a larger group of farmers would be very interesting. Then, also a benchmarking feature could be developed although the objective should not be to develop a benchmark for overall sustainability. For this purpose, the system, especially the software tools, should be improved first. The software must become more robust and also the interfaces must be evaluated critically. By applying it to a larger group, the idea of reference information models and ‘wizards’ may also be elaborated.

Mind Map 11 in Appendix VI summarizes the most important aspects of this chapter.

9 General discussion and conclusions

Adaptive management is not really much more than common sense.
But common sense is not always in common use.
C.S. Holling (1978, p. 136)

9.1 Introduction

This thesis started with the statement that sustainability is an important issue, but it turns out to be difficult, when you want to put it into practice. Chapter 2 made clear that sustainability in agriculture is very relevant, because it deals with the quality of life and therefore concerns whole society. In this thesis, it was tried to develop an approach that supports implementing sustainable agriculture in practice. This final chapter evaluates to what extent this has succeeded.

First, the research questions, as were put in Chapter 1, are revisited. Secondly, some main conclusions are drawn. Finally, recommendations for further research are provided.

9.2 Revisiting the research questions

In Chapter 1, the main research question was put as follows:

- How can sustainability be implemented in the operational management of a farm system?

This question was split up into several sub-questions that will be evaluated in order to answer the main question.

a) What is sustainability and what is sustainable farming in particular?
b) What does the management control of a farm look like?

From Chapter 2, it can be concluded that these two questions must be integrated, because sustainable development should be seen as a design process that is embedded in farm management and control, aiming at a dynamic steady state.

Sustainability implies an interactive relationship between society and the environment. Society wants to sustain itself and depends on the environment, so people have to maintain the environment in a proper way. It was concluded that this requires an integrated attitude towards nature that considers:

- nature as *matter* that can be exploited,
- nature as *carrier* of life and
- nature as *philosophy* that creates culture.

Beside this collective perspective of sustainability, an individual perspective can be also distinguished, for example, from a farmer's point of view. It means that, beside an attitude towards nature, an attitude towards other people must be developed, containing a social and economic dimension. This takes place through a negotiation process, sometimes explicitly but more often implicitly. Hence, from a farmer's perspective, sustainability has social, economic and ecological aspects.

From this perspective, sustainability was defined as the ability to continue surviving in a constantly changing environment, which is constituted by *adaptive capacity*. This can be established and maintained by *adaptive management*. This means that a farm system must be adaptable to a changing environment. Hence, sustainable development is viewed as a design process, in which no end states or final goals can be defined. This design process is characterized by *learning-by-doing*, in which the system is gradually changed. It is tuned to goals and when these goals are reached sufficiently, new goals come in sight and can be explored, again: because the environment is continuously changing.

Because sustainable development is an active design process, the farmer and his decision-making play an essential role. With respect to the attitudes mentioned, he has to integrate visions, intentions and values, equally important to economic goals in decision-making. In other words, he has to integrate soft and hard parameters. In a step-by-step manner, he has to:

- make his goals explicit with respect to sustainability,
- link results from his farm system with these goals and
- keep in touch with them in daily reality.

Hence, in order to create adaptive capacity, a methodology was searched for in which goals can be easily changed and quickly translated to daily, operational management. Taking this into account, it was concluded that research concerning implementing sustainability should not aim at optimizing the farm system itself, assuming that the farmer is a rational decision-maker. No, the farmer as a human factor with his own personal values and norms is explicitly part of it. Besides, sustainability goals cannot be fixed beforehand and the way to reach them is characterized by a learning process. Hence, a research approach should aim at optimizing the managerial *design process* instead of the farm system. In Chapter 4, it was concluded that this approach is still underdeveloped in scientific agricultural research.

A solution was searched for by consulting management literature. According to the management control paradigm of De Leeuw (2000), a managed system is controlled by a

managing system. The managing system, in this case the farmer, is supported by an information system. The information system combines feedback from the managed system and information from the environment in which the firm is situated. In this way, a regulative management cycle can be discerned that aims at structuring unstructured goals like sustainability.
Combining these findings with the theory about sustainable development of farm systems, a three-phase methodology was defined that aims at implementing sustainability in operational farm management:

a) negotiation
b) heuristic problem solving
c) operational control

ad a) In this phase, the farmer tries to make his sustainability goals explicit in negotiation with the environment and reflecting his own personal values. According to Röling (1994b), this can be characterized by a coupled system of a 'soft' decision-making platform and a 'hard' ecosystem. It is attempted to make unstructured sustainability goals more structured. Negotiation also implies that the farmer is not completely at the mercy of the external environment, but he can also influence it. So, to a certain extent he can try to create his own future, which was referred to by the term *agency*.

ad b) This phase is characterized by iterative design cycles that further structure goals. It tries to link results from the production system with these goals. This process is characterized by a step-by-step search process. This search is not blind, but based on 'clues' that indicate promising pathways based on knowledge, experience and intuition. This results in heuristic management rules. Although all three phases together can be characterized as a learning process, this phase is in particular based on learning-by-doing and learning-from-practice.

ad c) The heuristics that result from the previous phase can be viewed as solutions that enable the farmer to keep in touch with his sustainability goals. Therefore, they must be implemented in operational management, because then the farmer is faced with daily reality in which all goals come together. In the sequel, solutions are tested for consistency.

In this way, sustainability was defined and integrated in the management of a farm system. However, the three phases are still rather general and abstract, so they were concretized further.
From the management control paradigm, it was concluded that an information system could play a key role. Because sustainability concerns different aspects and involves whole farm management, it was concluded that a *modeling approach*, supported by information and

communication technology, was needed to order and structure information in the appropriate way. ‘Appropriate’ means that it must be in line with the three-phase methodology.
Logically, the next question would have been what information is concerned with sustainable farming. It can be thought of all kind of sustainability indicators like energy use, labor conditions, farm results and how they should be monitored or calculated and managed. In Chapter 4, it was illustrated that many modeling approaches indeed focus on one or a few of these indicators. However, there is a risk that optimal solutions are found for these specific sustainability goals that do not correspond to the practice of a farmer that faces all problems at the same time. Hence, these models might be useful to generate knowledge, but in order to correspond to actual farm management, a more generic approach is needed. This becomes even more important when realizing that sustainability goals will constantly change due to the changing environment. For each specific goal, new models should be made and the farmer would have to wait for them to become operational. This hampers sustainable development and therefore it is better that the farmer immediately tries to develop his own heuristics that later on perhaps can be subject for further scientific approval.
This meant that the modeling approach should provide possibilities to be applied to a *farm- and farmer-specific* situations. So, in this *generic* modeling approach, it was not tried to include specific information on sustainability goals, but to define the *type* of information, as stated by the third sub-question:

c) What type of information from the farm system is needed for sustainable farming?

From the management control paradigm it was concluded that the type of information can be put in a model of the *desired farm system* and a model of the *production system*.

Desired system
The model of the desired farm system makes sustainability goals explicit in a goals-means hierarchy. This mainly takes place by the model component that was called Sustainability Mapping, which breaks down unstructured goals into more structured goals. Especially in this component, negotiation with the environment must take place. This is also a key moment, in which personal values play an important role and attitudes towards society and nature must be set.
By using the multi-faceted structured entity (MSE) modeling method, sustainability is not regarded as a simple sum of sub-goals. Entities and aspects can be relevant to more than one goal, so that cross-connections can be established. Another important aspect of Sustainability Mapping is that the model forces the farmer to translate goals further into operational management.
Also in the model component Sustainability Function Deployment goals are set, more specifically on product properties. Again, the farmer has to make explicit what is really

important to reach his goals to his opinion. During this process, farmer's craftsmanship plays a key role.
The strength of this modeling approach is that goals and means are connected in an alternating way and at the same time the scope is constantly reduced until the moment of the actual execution of operations.

Production system – ecological production
In Chapter 3, it was concluded that the type of information with respect to management control of the production system depends on how you look at agricultural production. Two different views were distinguished and compared with each other: production ecology and ecological production. It was concluded that in production ecology, the soil is considered to be just a substrate and the focus is on 'matter-input-matter-output-relations'. At the opposite side, ecological production views the soil as a living system and an important production factor and is highly 'ecological-process-oriented'. Ecological production takes the environment as starting point and production as the balancing item on the budget in contrast with production ecology that turns this around. Beside ecological aspects, ecological production emphatically takes social aspects into account when defining production levels. Thus, nature as matter, carrier and philosophy are fully integrated. Furthermore, it was concluded that ecological production accounts for farm- and farmer-specificity, emphasizing craftsmanship and learning behavior. So, it was concluded that this type of agricultural production better corresponds to the previously described notion of sustainable farming.
It was argued that mixed farming could be regarded as the most appropriate way of ecological production. However, to benefit from better knowledge development in specialized systems, this should be realized by local co-operation of several farms. This means that organizational problems have to be solved. In this respect, ecological production should be regarded as a future type of organic farming, because in practice, organic farming does not yet correspond to the theory described. The hypothesis is that current practice of organic farming can be improved by using the model and methodology developed in this thesis, based on the theory of ecological production.
With concern to management control, two important principles were identified: *preventive management* and *recycling management*. Preventive management sees the production system as a chain of linked processes with intermediate products that all are relevant to reach a certain sustainability goal. By managing all intermediate products into a desired direction, it is tried to reach the final goal. Thus, goals become dependent on a series of concatenated processes. Preventive management was mainly illustrated by the potato case study in Chapter 6. Recycling management elaborates on this concept by not only defining chains, but also cyclic processes that correspond to the basic material cycle of uptake, degradation and mineralization of organic material. Hence, information on internal resources, especially the soil, should be included. Besides, it is important to use external input as little as possible, so

information on external resources should also be included. Recycling management was mainly illustrated by the nutrient management case study in Chapter 7. Although preventive and recycling management are distinguished as separate principles, they will usually coincide in practice.

Information concerning the production system was modeled in the Product Flow Model. The production system is modeled in terms of production units with flows in between, so that product chains and cycles could be identified. Production units consist of operations that are the means of connection for influencing intermediate products. Internal and external resources are connected with these production units through intermediate product flows, so that internal resources and product import and export can be managed indirectly by the operations of the production units.

Initially, the Product Flow Model models the production system as it occurs in the view of the farmer. At a later stage, purposeful sub-chains or sub-cycles are identified and for that purpose, the Product Flow Model can be slightly changed. In this way, it is guaranteed that the information is in line with farmer’s practice.

In this way, the relevant type of information was put into two models. In management control, this information should be used in a purposeful way, so the next sub-question was asked:

> d) How does this information need to be processed in order implement sustainability in operational management?

In Chapter 4, it was stated that information on the desired system and the production system must be *connected* and *translated* into actions in operational management. The purpose of connecting and translating is to convert unstructured problems into structured tasks within the limited scope of operational management.

The entire model can be seen as a concatenated connection of goals and means. However, two major points can be indicated where connections are made. First, connections are made between goals from the Sustainability Map and product flows from the Product Flow model. At this point, identification of chains and cycles takes place. Secondly, Sustainability Function Deployment makes connections, or associations, between product flow properties and operations. In developing the Sustainability Management Handbook, these associations are then translated into critical control points. Critical control points concern actions carried out before, during or after the operation, that are important for reaching the goals that were set. Hence, these critical control points are accompanied by work instructions.

In this way, the problem scope of sustainability in time and space is reduced to getting grip on product properties when carrying out operations. The ecological production principles of preventive and recycling management are assured by operations. In Chapter 8, it was

remarked that this way of connecting and translating helps the farmer to make explicit what is really important for him and reveals the craftsmanship of the farmer. In this respect, it was mentioned that the process could be accelerated, when specific external knowledge was included. However, this should not hamper development of new, innovative, ideas by biasing the farmer.
Thus, the presented model can be used to implement sustainability in operational farm management. The question remains whether application of the model also helps the farmer to learn and thus improve his decision-making.

e) How should this information processing be done, so that the farmer is able to evaluate and improve decision-making?

In Chapter 4, two phases in model use were distinguished: first instantiation and incremental updating. Through first instantiation, it is supposed that decision-making has improved by the work instructions that were defined in the Sustainability Management Handbook. Because the environment is constantly changing and also because the farmer is learning, incremental updating fine-tunes the model. This means that the model becomes more farm- and farmer-specific.
Improvement of decision-making is mainly related to the second phase of the three-phase methodology: heuristic problem solving. In Chapter 2, the three important phases in heuristic problem solving were mentioned:

- *intelligence* – finding the occasion where to start problem solving or to make a certain decision;
- *design* – inventing, developing and analyzing possible courses or pathways to solve the problem;
- *choice* – choosing between the most promising pathways.

To indicate the instances where the intelligence phase is relevant, a schematic representation of how the model is used is shown in Fig. 9-1. From left to right, it starts with Sustainability Mapping that results in goals that are set on end entities. These goals are connected with an identified chain of flows from the Product Flow Model. By Sustainability Function Deployment, several properties areassigned to these flows, on which also goals are set. By defining critical control points and accompanying work instructions, it is attempted to manage these goals. So, two points where goals are involved can be distinguished (evaluating points 1 and 2): in the Sustainability Map and in product flow properties. The line graphs indicate that these goals must be monitored and registered, so that they can be evaluated in order to detect progress. Goals that are not reached can be considered to be problems. These

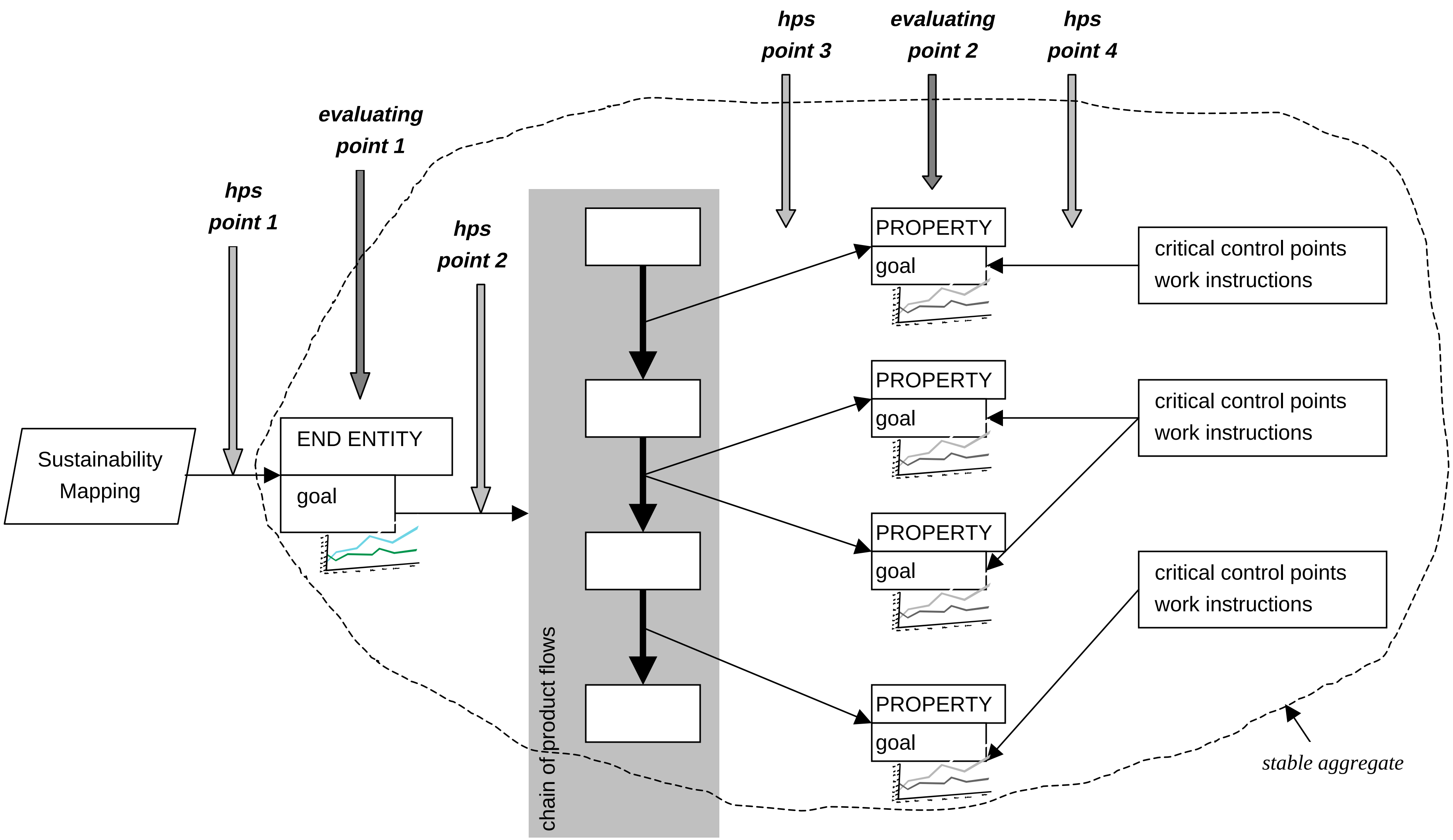


Fig. 9-1 Schematic representation how the model is used. At two points goals are involved and monitoring and evaluation takes place. At four places moments for heuristic problem solving (hps) can be identified. Further explanation in text.

two points determine four points where heuristic problem solving or learning possibly takes place.

If a goal of a certain product flow property is not reached (evaluating point 2), a solution can be searched for in defining or redefining critical control points and work instructions (heuristic problem solving points 4). It is also possible that the property goal depends on preceding flows. In that case, the related chain of product flows should be redefined or operations that influence the properties of these preceding flows should be redefined (heuristic problem solving point 3).

If a goal of a certain end entity is not reached (evaluating point 1), a more complex problem situation occurs. It is possible that the connected chain of product flows is not defined appropriately. If this chain is redefined (heuristic problem solving point 2), it automatically means that heuristic problem solving points 3 and 4 are also involved. It is also possible that the connected chain is appropriate, but that the associated properties or the goals that are set on them need to be redefined (heuristic problem solving point 3). This will automatically result in redefinition of critical control points and work instructions (heuristic problem solving point 4).

At this point, it can be made clear what was meant by *stable aggregates*, mentioned in Chapter 2, that are important to maintain an adaptive capacity. Stable aggregates are structures that combine entities, a certain chain of product flows, related flow properties and accompanying critical control points and work instructions as indicated in Fig. 9-1. These combined structures are important for quickly adapting to changes in the environment.

Heuristic problem solving point 1 is left for discussion. This point concerns defining the appropriate aspects, entities and goals with respect to the overall goal 'sustainable farm'. However, in Chapter 8, it was argued that a measure for overall sustainability is difficult, or impossible, to define. This is related with the definition of sustainability that was described as the ability to continue. Ultimately, this can only be determined *ex post*, when it is too late and it has become clear that the farm *was* not able to continue. Besides, it was made clear that sustainability involves normative choices. So, by definition, it is impossible to evaluate sustainability objectively. On the other hand, the model does not prohibit to evaluate general agreed sustainability goals like energy use, animal welfare, labor conditions, etc.

Although heuristic problem solving is ascribed to play a key role in this model and methodology, the process itself is not supported. Only the time points where to start heuristic problem solving, intelligence, are identified and how the result, a heuristic management rule, must be implemented in operational management is taken care of. Hence, it was concluded in Chapter 8 that the learning aspect does not yet come into its own, although it is potentially there. For that purpose, the model and methodology should be tested further in practice, for example, by implementing it in some farms. It is also possible to extend the model. For example, the Product Flow Model could be extended with a simulation model, which makes it possible to carry out *what-if-analyses*. For that purpose, input-output relations for

production units must be defined. This could be done by using data that were collected through monitoring and evaluation. In this way, a farm-specific simulation model can be established. Each time data are monitored and put into the computer, relationships could become more reliable. This sounds easy, but in reality, it will be difficult to develop a valid simulation model, mainly because the relationships can be very dynamic and also the farm system changes and each time new relationships must be defined. It is also possible that other existing models, which were classified in Chapter 4 as invalid for supporting whole farm management, could be used at this stage.
However, what-if scenarios cannot be the only basis for heuristic problem solving. In addition, the farmer will have to use external knowledge from all kinds of literature resources, colleagues or any other source of information. Besides and most important, he will use intuitive knowledge. Thus, there are several possibilities that are used by the farmer to define and choose promising alternatives. Finally, real learning-by-doing takes place by implementing these alternatives in practice and evaluating them.
Finally, as was mentioned in Chapter 4 and concluded in Chapter 8 that use of the model and methodology should not be left to the farmer only, but a consultant should support him. This consultant will not only become experienced in using the model, but will also be able to advise farmers concerning the actual content and nature of sustainable farming practices. However, this type of advice should not be derived from laboratory experiments, but derived from and validated in practice. Besides the role of this consultant should be much more the role of facilitator than one of an advisor. As described in Chapter 2, heuristics, derived from practice, thus also become input for scientific knowledge development. In this way, design-oriented and experimental research, ecological production and production ecology, really become each other’s complements.

Hence, it was shown how sustainability could be implemented in the operational management of a farm system. Although the focus is on operational management, it was shown that it is tightly connected with tactical and strategic choices that are made. The model does not provide support in making tactical and strategic choices, but it can elucidate weak spots in the farm configuration. For example, if a certain goal cannot be reached by redefining critical control points and work instructions, the weak spot in a product chain (e.g. a crop, a type of store or a machine) could be identified. So, indirectly, some support on tactical and perhaps strategic management is provided.
The model could be seen as an integrated design environment that supports the farmer in designing his farm system. Because the software is not completely developed it must be regarded as a prototype of a decision support system.
In accordance with the citation of Holling above this chapter, it can be concluded that the developed model and methodology are just a matter of logical thinking and common sense. It is hoped that this model will contribute to common use of this common sense.

9.3 Major conclusions

Sustainable farm systems

- Sustainable farm development is a dynamic design process, carried out by the farmer. This process should aim at creating sufficient adaptive capacity in order to respond effectively and fast enough to a constantly changing environment.
- Sustainable development requires development of an integrated attitude towards nature that includes exploitation, conservation and sense making. From a profit-making firm's point of view, an additional attitude towards society must be developed.
- The attitudes towards nature and society require that soft and hard parameters are integrated in farm decision-making.
- In regard of sustainable development as a design process, the farm system is an important focusing point, because the farmer is the most important agent of change. However, the farmer should be aware of possible unsustainable situations outside the farm's boundaries, caused by his farm system.
- The operation is the basic unit for implementing sustainability, because here all goals and constraints come together in time and space. To put sustainability into practice, the farmer must be forced to translate sustainability to operational management.
- It is impossible to measure an overall degree of sustainability, because sustainability goals cannot always be made concrete, are not always measurable, and are not always comparable. Moreover, sustainability has a strong normative dimension and it can be reached in several ways.

Agricultural production

- The concept of production ecology is an unsuitable model for implementing sustainability in farm management, because it focuses on production and does not explicitly include the natural ecosystem, society and the farmer. Besides, it was argued that production ecology reduces the adaptive capacity of the farm.
- The concept of ecological production, as described in this thesis, is suitable for implementing sustainability in farm management, because it takes the environment as starting point, it explicitly includes social and economic demands and farmer's skills.
- Ecological production is process-oriented and works along principles of prevention and recycling.
- Mixed farming is considered to be the ideal for ecological production, because in this type of farming, the entire material cycle is under farmer's control.
- It is expected that when using the model and methodology along with the concept of ecological production, as described in this thesis, organic farm production can be enhanced in practice in the economic sense, while it remains ecologically and socially compatible.

- Production ecology belongs to the area of experimental research, while ecological production belongs to the area of design-oriented research. Experimental research and design-oriented research are each other's complements.

Modeling farm systems

- A modeling approach for designing sustainable farm systems must use a design-oriented approach. It must focus on optimizing the managerial design process rather than optimizing the farm system itself, because the farmer, as a human factor, is in between them.
- Hence, the model should be generic, while a methodology must be provided on how the model is made farm- and farmer-specific. Much room should be left to the farmer's craftsmanship and the model must be in accordance with the perception of the farmer.
- The methodology must focus on making the farmer's vision, intentions and values explicit and help him link this with his daily management.
- Heuristic problem solving is seen as the key to improve decision-making. In heuristic problem solving, external and intuitive knowledge is combined and, most importantly, farm-bound knowledge is developed in a learning-by-doing way.
- Reference information models can be useful to accelerate the instantiation of a generic model, but they must have been developed from practice.
- In every modeling approach, the underlying philosophical view must be made explicit.

Evaluation

- The relevance of the model in this thesis will increase when certification becomes more common practice. The model also enhances transparency, which is important in the current trend of getting broader grouping of agriculture-based activities into production chains and networks.
- Expert validation is an appropriate way of testing models that are not focused on simulation or calculation of a production process and where model outcomes are bound to subjective opinions.

The major conclusions are also summarized in Mind Map 12 in Appendix VI.

9.4 Suggestions for further research

In Chapter 8, some suggestions and recommendations for improvement and further research were already provided. In this section, the most important ones are summarized, but also some additional suggestions will be made. It can be concluded that the modeling approach that was developed is a good step on the road towards implementing sustainability in farm management. However, it was only a first important step and there is still a long way has to

be gone in order to achieve an information system that can be used in practice by most farmers. First, it can be concluded that the model was not yet fully implemented according to the specified requirements. This mainly concerns the 'feedback part' of the model that should help the farmer to evaluate goals by linking these with results. Secondly, it was mentioned that knowledge could be developed by instantiation of the model for specific situations. This knowledge could be reused for new instantiations (see middle part of Fig. 4-1). For this purpose the model must be applied to practical situations at least a number of times.
This section provides some directions for improvement of the model and methodology and how it should be embedded in current trends and developments.

9.4.1 Model improvement and knowledge development

Several improvements can be made to the information model (process model and data model) that was defined in Chapter 4. In the current model, it is not possible to store historical data concerning monitoring results. This is a prerequisite to support evaluation. This could currently be achieved by incorporating registration forms in the Sustainability Management Handbook. These data could then also be used to build reference information models that can be used for accelerating instantiation. It was suggested that these reference information models should be developed from practice. For that purpose, the model should be applied to quite a number of farms. Before the model can be applied to real practical situations, the software tools must be developed further. Until now, not so much efforts was put in software development. It is advisable to develop a new system, build by professional software developers, which preferably provides an internet-based solution.

9.4.2 Improvement of the methodology

Negotiation was presented as an important process for setting sustainability goals. However, in this study not much attention was paid to how this process actually takes place. This could be further elaborated by doing more case studies. From expert validation, it became clear that it is especially useful to try out case studies with respect to soft goals like labor conditions, animal welfare, nature values, etc.
A crucial role in the decision-making process was assigned to heuristic problem solving. It was already concluded that especially the 'intelligence phase' and how results of the search process could be incorporated in farm management were elaborated. The design of experiments itself is not supported. It is a good suggestion to extend the model for this purpose. In the previous sections, it was explained that a simulation model could extend the Product Flow Model in order to carry out *what-if-analyses*.

9.4.3 Integration with quality control systems and certification

The handbook was defined as a set of critical control points and work instructions. The suggestion was made to look at existing standard systems like ISO or HACCP in order to extend the handbook. Moreover, because these systems are already being implemented at farms there is a need for harmonization in this development (Kamp, 2001). Since the model and methodology in this thesis are set up in a very generic way, this model could be used as a kind of basic reference model.

It can be concluded that the potential for applicability is high, but the model should be tried out further in practical situations. Hence, it is suggested to carry out pilot projects in which several of the aforementioned suggestions can be taken into account. To correspond to current trends, these projects should be embedded in a chain or network approach in which several links of the chain are combined. In this respect, it would also be interesting to look at possibilities for mixed farming in the way of cooperation between farms at a regional level. Certification should be viewed as an important incentive and binding factor in these projects.

Appendices

I The mixed ecological farm at the ir. A.P. Minderhoudhoeve

The Ir. A.P. Minderhoudhoeve is an experimental farm of Wageningen University in eastern Flevoland in the Netherlands. The farm is 30 years old and covers an area of 247 ha. on a heavy clay loam soil with a good water status. Until recently, it was used for large-scale experiments of different university departments. In 1995, the farm was split up into two separated mixed farms: and ecological and an integrated variant. Both sub-farms work with their own set of objectives and constraints.

The mixed ecological farm at the ir. A.P. Minderhoudhoeve (further abbreviated as APMeco) serves as an important object of study for developing and validating the model of this thesis. ‘Mixed’ means that crop and livestock production are integrated and ‘ecological’ is synonymous for organic.

The APMeco covers an area of 90 ha is laid out in a quadrant as shown in Fig I-1. The area is split up into 9 fields of 10 ha each. Two fields (20 ha in total) are used as permanent pasture and include some buildings and a yard. The remaining 7 fields are used for growing crops with a rotation of 7 years, which is schematically shown in Fig I-2.

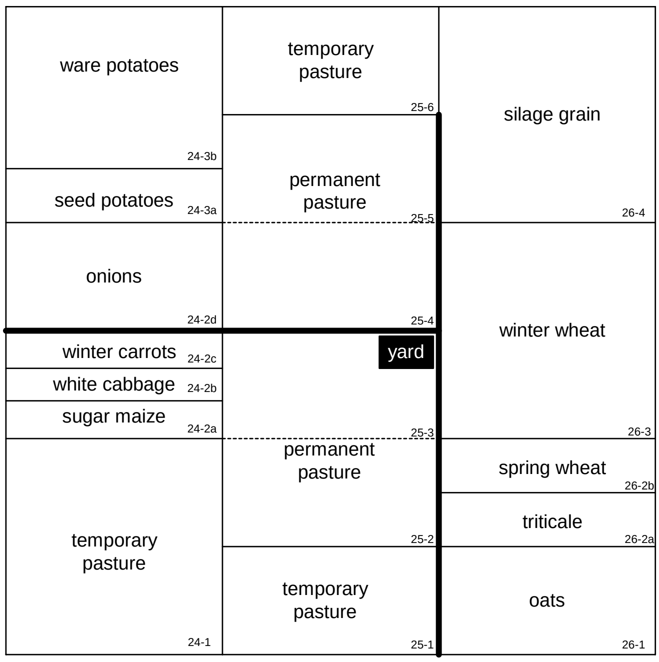


Fig I-1 Spatial overview of APMeco with the specific crops for the year 1997. The bold black lines are paved paths. The numbers refer to a division in sub-fields and are used for management registration.

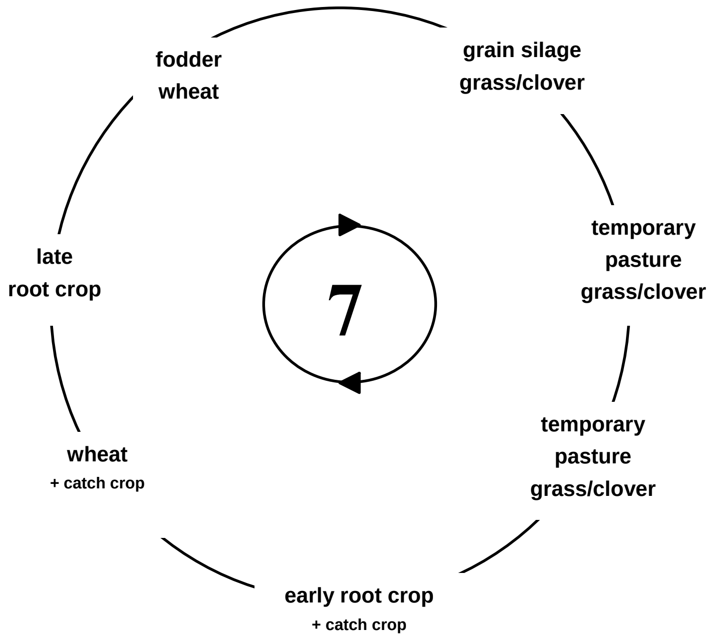


Fig. I-2 The 7-yearly crop rotation

The cow herd consists of 55 dairy cows and accompanying young cattle. Approximately 5 bulls are kept for own breeding. The dairy cows are kept in a modern tie-up house, while the other cattle is kept in a semi-deep litter stable. A herd of sheep is kept, mainly for better grazing of the pastures.

Additional references are Oomen et al. (1998), Lantinga and Oomen (1998) and (Lantinga et al., forthcoming).

II Entity-Relationship Diagramming

This appendix briefly describes the entity-relationship diagramming representation formalism, which is used in this thesis.

Terminology

Entity
A ‘whole’ that has a meaning in practice for which data is collected and recorded, such as objects, persons, abstract concepts or events.

Entity type
A set of entities that display the same behavior and characteristics within a certain level of abstraction.

Relationship type
A logical association between two entity types.

Notation

mandatory 1:1 relationship type
an **'a'** is related to one **'b'** and vice versa

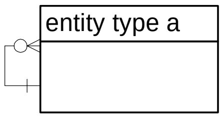
optional 1:1 relationship type
an **'a'** may be related to a **'b'**; and a **'b'** is relatated to one **'a'**

mandatory 1:n relationship type
an **'a'** is related to one or more entities **'b'**; and a **'b'** is relatated to one **'a'**

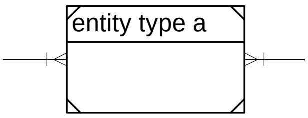
mandatory 1:n relationship type
an **'a'** is related to zero or more entities **'b'**; and a **'b'** is relatated to one **'a'**

optional 0:n relationship type
an **'a'** is related to one or more entities of **'b'**; a **'b'** may be relatated to one **'a'**

n:m relationship type
an **'a'** is related to one or more entities of **'b'** and vice versa



mandatory 1:n recursive relationship type
an **'a'** is related to zero or more entities of **'a'**



associative entity type
an **'a'** is an association between two other entities

III Data Dictionary

This appendix provides a description of all fields of the database used in this thesis. They are listed per database table, categorized for each model component. The first column indicates whether a field is a primary key and/or foreign key. The second column lists the name, the third and fourth column the type and size of the field. The entity-relationship diagram is provided in Fig. 4-5.

Key	Name	Type	Size	Description

Definitions

PK	Name	Text	50	Unique name of a particular term
	Definition	Memo	-	Definition in words

Product Flow Model

ProductionLines

PK	ProductionLineID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the production line
	Comments	Memo	-	Possible comments

MIMOUnits

PK	MIMOUnitID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the MIMO-unit
	Type	Text	50	Type of MIMO-unit: production unit, internal resource or external resource
	Comments	Memo	-	Possible comments
FK	ProductionLineID	Long Integer	4	Reference to the production line a MIMO-unit belongs to
	PinX	Long Integer	4	Technical; x-coordinate of the MIMO-unit in the graphical representation in

				Visio.
	PinY	Long Integer	4	Technical; y-coordinate of the MIMO-unit in the graphical representation in Visio.

Flows

PK	FlowID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the flow
FK	FromMIMOUnitID	Long Integer	4	Reference to the MIMO-unit this flow originates from
FK	ToMIMOUnitID	Long Integer	4	Reference to the MIMO-unit this flow goes to
	Type	Text	50	Type of flow: product flow, internal resource flow or replenishment flow
	Comments	Memo	-	Possible comments
	BeginConn	Text	50	Technical; indicates at what point the beginning of the flow is attached to the MIMO-unit in the graphical representation
	EndConn	Text	50	Technical; indicates at what point the end of the flow is attached to the MIMO-unit in the graphical representation

Sustainability Map

MSETreeNodes

PK	MSETreeNodeID	Long Integer	4	Unique identifier
FK	ParentID	Long Integer	4	Number that refers to the parent node in the hierarchical MSE tree
	Type	Text	50	The type of node: an entity, aspect or specialization
FK	Name	Text	50	Name of the node
	Comments	Memo	-	Possible comments

	Goal	Memo	-	The goal of an entity in words
	Minimum	Text	50	The lower bound of the goal
	Maximum	Text	50	The upper bound of the goal
	ActualValue	Text	50	The actual value of the goal

MSETreeNodes_x_Flows

PK/FK	FlowID	Long Integer	4	Reference to a flow
PK/FK	MSETreeNodeID	Long Integer	4	Reference to a node of the Sustainability Map
	Comments	Memo	-	Possible comments

Sustainability Function Deployment

FlowProperties

PK	FlowPropertyID	Long Integer	4	Unique identifier
FK	FlowID	Long Integer	4	Reference to a flow this property belongs to
FK	PropertyID	Long Integer	4	Reference to a property
	ActualValue	Single	4	Actual value of the property
	Minimum	Single	4	Lower bound of the goal that is set on the property
	Maximum	Single	4	Upper bound of the goal that is set on the property
	Importance	Integer	2	Importance of the property in relation to other properties. Domain: {1,2,3,4,5}
	Comments	Memo	-	Possible comments

MIMOUnitOperations

PK	MIMOUnitOperationID	Long Integer	4	Unique identifier

FK	OperationID	Long Integer	4	Reference to an operation
FK	MIMOUnitID	Long Integer	4	Reference to a MIMO-unit
	Description	Memo	-	Description in words of the operation
	Comments	Memo	-	Possible comments

MIMOUnitOperations_x_Flowproperties

PK/FK	MIMOUnitOperationID	Long Integer	4	Reference to an operation of a specific MIMO-unit
PK/FK	FlowPropertyID	Long Integer	4	Reference to a property of a specific flow
	Association	Long Integer	4	Value of the association that is made. Domain: {0.1.3.9}
	Comments	Memo	-	Possible comments

Operations

PK	OperationID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the operation

Properties

PK	PropertyID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the property
FK	UnitOfMeasurement	Text	50	Reference to a unit of measurement of the property

UnitsOfMeasurement

PK	UnitOfMeasurement	Text	50	Unique unit of measurement

Sustainability Management Handbook

MIMOUnitOperationCCPs

PK	MIMOUnitOperationCCPID	Long Integer	4	Unique identifier

FK	CCPID	Long Integer	4	Reference to a critical control point
FK	MIMOUnitOperationID	Long Integer	4	Reference to an operation of a specific MIMO-unit
	Comments	Memo	-	Possible comments

CriticalControlPoints

PK	CCPID	Long Integer	4	Unique identifier
FK	Name	Text	50	Name of the critical control point

Workinstructions

PK	WorkinstructionID	Long Integer	4	Unique identifier
FK	MIMOUnitOperationCCPID	Long Integer	4	Reference to a critical control point for a specific operation of a specific MIMO-unit
	Instruction	Memo	-	Description of an instruction in words
	Comments	Memo	-	Possible comments

IV Example of a Sustainability Management Handbook concerning potato production

This appendix provides an example of the Sustainability Management Handbook for potato production as described in the case study in Chapter 6. It is classified into operations for each production unit. For each operation, the properties of each flow that were associated with that particular operation are listed first. They were derived from Sustainability Function Deployment. Then the critical control points are listed, followed by related work instructions. Sometimes, work instructions refer to certain forms, but this is for illustrative purposes only; the forms are not included.

<table>
<tr><td colspan="2">production unit: 1 sprouting seed potatoes
operation: 1.1 purchase</td></tr>
<tr><td>flow properties
1. seed potatoes
▪ Phytophtora
▪ Rhizoctonia
▪ size
▪ physiological age
▪ tuber defects
▪ external seed potatoes</td><td rowspan="2">instructions
1. Calculate the amount of seed potatoes that needs to be bought by assessment of the amount of seed potatoes needed for ware and seed potato growing and the existing amount of farmer’s own seed potatoes. Write down the results on the seed potato control form.
2. Check if the purchased seed potatoes satisfy the specified requirements (see seed potato specifications). Usually the seed potatoes will be certified so that they automatically satisfy them. In other cases the appropriate assessments should be carried out. Write down the results on the seed potato control form.</td></tr>
<tr><td>critical control points
1. quantity
2. seed potato properties</td></tr>
</table>

<table>
<tr><td colspan="2">production unit: 1 sprouting seed potatoes
operation: 1.3 storing</td></tr>
<tr><td>flow properties
2. sprouted seed potatoes
▪ sprout length
3. sprouted seed potatoes
▪ sprout length</td><td rowspan="2">instructions
1. Measure the temperature, humidity and light intensity of the storage barn, register it on a daily basis and apply corrective measures if necessary. Write down the results at the storing registration form.
2. Measure the average sprout length at the end of the storage period by taking randomly selected samples. Write down the results on the sprouted seed potatoes control form.</td></tr>
<tr><td>critical control points
1. temperature
2. humidity
3. light intensity
4. seed potato properties</td></tr>
</table>

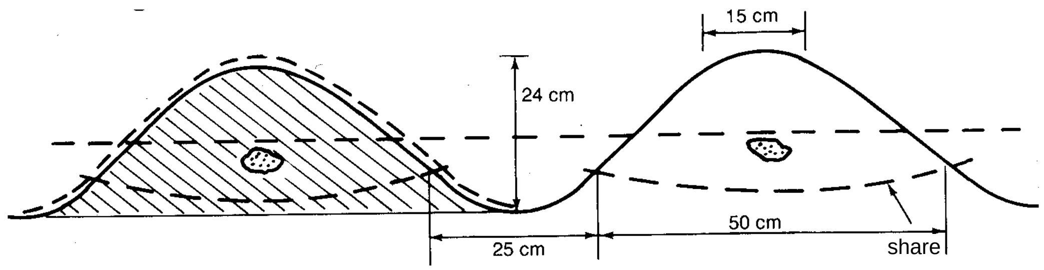
<table>
<tr><td colspan="2">production unit: 2 ware potato growing
operation: 2.1 seed bed preparation</td></tr>
<tr><td>flow properties
4. ware potatoes
▪ waxiness
▪ specific gravity
▪ fry color
▪ yield level
13. soil
▪ soil structure</td><td rowspan="2">instructions
1. Check the actual weather conditions and look at the weather forecasts to determine the appropriate moment of seed bed preparation.
2. Check the soil for crumbliness by crushing it in your hand. It should crumble easily and no clods should appear. To check the status of the underground, look over the field and check if it has a uniform non-altered gray-brown color (no black spots). Write down the results on the soil structure control form.
3. During preparation, regularly check the result of the operation by looking at the depth of the loosened soil, which should be 8 to 10 cm, and soil structure by feeling it with your hands. Adjust the machine or driving speed if necessary.</td></tr>
<tr><td>critical control points
1. weather conditions
2. soil color
3. soil structure
4. machine adjustments</td></tr>
</table>

<table>
<tr><td colspan="2">production unit: 2 ware potato growing
operation: 2.2 sowing</td></tr>
<tr><td>flow properties
4. ware potatoes
▪ yield level
5. terranal
▪ dose

critical control points
1. between-row-distance
2. within-row-distance
3. sowing depth
4. ridge structure
5. machine adjustments
6. terranal concentration
7. terranal dosage</td>
<td>instructions
1. Before sowing, check the between-row-distance adjustment of the sowing machine (should be 75 cm); adjust if necessary. Check it again after some meters of sowing.
2. Before sowing, determine the desired within-row-distance (about 35 cm) and adjust the sowing machine accordingly. During sowing (especially in the beginning), regularly check the within-row-distance; readjust if necessary. Write down the results at the sowing control form.
3. Before sowing, adjust the channel puller for the desired sowing depth. Especially check it at the start of sowing and regularly during sowing. The tuber must be located just below ground level and must have approximately 2 cm of loose ground under it.
4. Before sowing, adjust the ridgers for the desired ridge structures. Especially check it at the start of sowing and regularly during sowing.
5. Double-check the terranal concentration according the terranal specifications at preparing, before sowing. Write down the results at the sowing control form.
6. During sowing, regularly check the terranal dosage system if it is working properly.</td></tr>
</table>

<table>
<tr><td colspan="2">production unit: 2 ware potato growing
operation: 2.3 rotary cultivating rows</td></tr>
<tr><td>flow properties
4. ware potatoes
▪ yield level

critical control points
1. timing
2. ridge structure
3. machine adjustments</td>
<td>instructions
1. Determine the right time of rotary cultivating. It should be chosen as late as possible (because of faster warming up and weed control), but before the moment that plants and roots are damaged by this operation.
2. Before rotary cultivating, adjust the ridgers appropriately. Especially check it at the beginning of rotary cultivating and regularly check it during rotary cultivating. The ridges must satisfy the specifications as indicated in the picture below.</td></tr>
</table>



production unit:	2 ware potato growing
operation:	2.4 haulm destruction

flow properties *4. ware potatoes* ▪ fry color ▪ yield level **critical control points** 1. timing 2. weather 3. soil condition 4. haulm status before destruction 5. haulm status after destruction	**instructions** 1. Determine the time of haulm destruction. It should be as late as possible in order to reach a higher yield level and a good ripeness that is related to the fry color. If a serious infection of Phytophtora is detected, the haulm should be burned immediately. 2. Determine the method of destruction (pulling, burning or slashing) according to the weather and soil conditions and the haulm status before destruction. 3. Check the haulm status after destruction. Carry out a second destruction if necessary.

production unit:	2 ware potato growing
operation:	2.5 harvesting

flow properties *4. ware potatoes* ▪ blue discoloration sensitivity ▪ subcutaneous discoloration **critical control points** 1. tuber temperature 2. fall height	**instructions** 1. Measure the tuber temperature at the beginning of harvesting. Write down the results at the potato harvest control form. Do not start harvesting below a temperature of 12 °C. 2. Measure the fall height for each wagon that is used in combination with the harvest machine. It should not exceed 40 cm. Correct if necessary.

production unit: 2 ware potato growing **operation:** 2.6 loading	
flow properties *4. ware potatoes* ▪ blue discoloration sensitivity ▪ subcutaneous discoloration **critical control points** 1. fall height 2. tuber temperature	**instructions** 1. If potatoes are not transshipped at the same day of harvesting, measure the tuber temperature at the beginning of loading. Do not start loading below a temperature of 12 °C. 2. Measure the fall height for each wagon that is used. It should not exceed 40 cm. Correct if necessary.

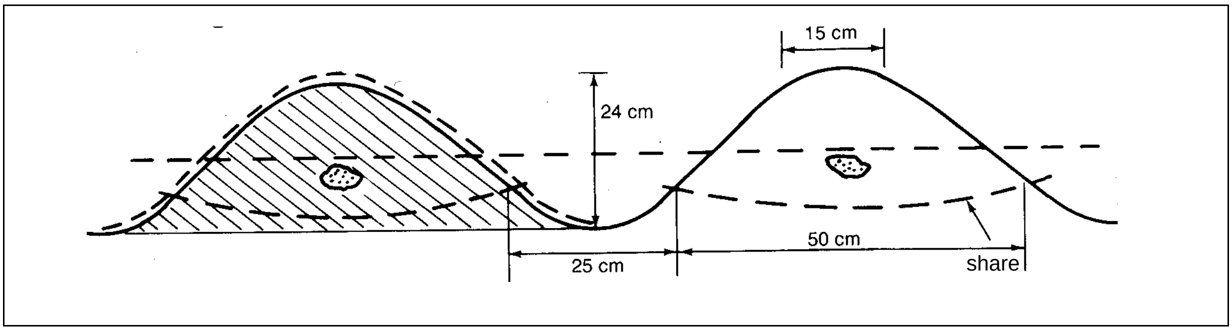
production unit: 3 seed potato growing **operation:** 3.1 seed bed preparation	
flow properties *7. seed potatoes* ▪ quality ▪ yield level *15. soil* ▪ soil structure **critical control points** 1. weather conditions 2. soil color 3. soil structure 4. machine adjustments	**instructions** 1. Check the actual weather conditions and look at the weather forecasts to determine the appropriate moment of seed bed preparation. 2. Check the soil for crumbliness by crushing it in your hand. It should crumble easily and no clods should appear. To check the status of the underground, look over the field and check if it has a uniform non-altered grey-brown color (no black spots). Write down the results on the soil structure control form. 3. During preparation, regularly check the result of the operation by looking at the depth of the loosened soil, which should be 8 to 10 cm, and soil structure by feeling it with your hands. Adjust the machine or driving speed if necessary.

production unit:	3 seed potato growing
operation:	3.2 sowing

flow properties *6. terranal* ▪ dose *7. seed potatoes* ▪ yield level **critical control points** 1. between-row-distance 2. within-row-distance 3. sowing depth 4. ridge structure 5. machine adjustments 6. terranal concentration 7. terranal dosage	**instructions** 1. Before sowing, check the between-row-distance adjustment of the sowing machine (should be 75 cm); adjust if necessary. Check it again after some meters of sowing. 2. Before sowing, determine the desired within-row-distance (about 20 cm) and adjust the sowing machine accordingly. During sowing (especially in the beginning), regularly check the within-row-distance; readjust if necessary. Write down the results at the sowing control form. 3. Before sowing, adjust the channel puller for the desired sowing depth. Especially check it at the start of sowing and regularly during sowing. The tuber must be located just below ground level and must have approximately 2 cm of loose ground under it. 4. Before sowing, adjust the ridgers for the desired ridge structures. Especially check it at the start of sowing and regularly during sowing. 5. Double-check the terranal concentration according the terranal specifications at preparing, before sowing. Write down the results at the sowing control form. 6. During sowing, regularly check the terranal dosage system if it is working properly.

production unit:	3 seed potato growing
operation:	3.3 rotary cultivating rows

flow properties *7. seed potatoes* ▪ yield level **critical control points** 1. timing 2. ridge structure 3. machine adjustments	**instructions** 1. Determine the right time of rotary cultivating. It should be chosen as late as possible (because of faster warming up and weed control), but before the moment that plants and roots are damaged by this operation. 2. Before rotary cultivating, adjust the ridgers appropriately. Especially check it at the beginning of rotary cultivating and regularly check it during rotary cultivating. The ridges must satisfy the specifications as indicated in the picture below.



production unit:	3 seed potato growing
operation:	3.4 selecting
flow properties *7. seed potatoes* ▪ quality **critical control points** 1. timing 2. weather conditions 3. removal	**instructions** 1. Start selecting at a crop stage of 90% of maturity. 2. If possible, carry out one or more selection rounds on a quiet, dark (cloudy) day with temperatures between 16-20 °C to recognize blackleg and one or more selection rounds on a dry and warm day to recognize stem rot. 3. The selected plants must be removed from the field and carefully transported to the compost heap that is covered.

production unit:	3 seed potato growing
operation:	3.5 haulm destruction
flow properties *7. seed potatoes* ▪ yield level **critical control points** 1. timing 2. weather 3. soil condition 4. haulm status before destruction 5. haulm status after destruction	**instructions** 1. Determine the time of haulm destruction. It should be as late as possible in order to reach a higher yield level. If a serious infection of Phytophtora is detected, the haulm should be burned immediately. 2. Determine the method of destruction (pulling, burning or slashing) according to the weather and soil conditions and the haulm status before destruction. 3. Check the haulm status after destruction. Carry out a second destruction if necessary.

<table>
<tr><td colspan="2">production unit: 3 seed potato growing
operation: 3.6 harvesting</td></tr>
<tr><td>flow properties
7. seed potatoes
▪ quality</td><td rowspan="2">instructions
1. Measure the tuber temperature at the beginning of harvesting. Write down the results at the potato harvest control form. Do not start harvesting below a temperature of 12 °C.
2. Measure the fall height for each wagon that is used in combination with the harvest machine. It should not exceed 40 cm. Correct if necessary.</td></tr>
<tr><td>critical control points
1. tuber temperature
2. fall height</td></tr>
</table>

<table>
<tr><td colspan="2">production unit: 3 seed potato growing
operation: 3.7 boxing</td></tr>
<tr><td>flow properties
7. seed potatoes
▪ quality</td><td rowspan="2">instructions
1. If potatoes are not transshipped at the same day of harvesting, measure the tuber temperature at the beginning of loading. Do not start boxing below a temperature of 12 °C.
2. Measure all fall heights. It should not exceed 40 cm. Correct if necessary.</td></tr>
<tr><td>critical control points
1. fall height
2. tuber temperature</td></tr>
</table>

<table>
<tr><td colspan="2">production unit: 4 seed potato storage
operation: 4.1 storing</td></tr>
<tr><td>flow properties
8. seed potatoes
▪ physiological age</td><td rowspan="2">instructions
1. Measure the temperature and humidity of the storage barn, register it on a daily basis and apply corrective measures if necessary. Write down the results on the storing registration form.
2. Calculate the physiological age of the seed potatoes from the temperature registration. Write down the results on the seed potato control form.</td></tr>
<tr><td>critical control points
1. temperature
2. humidity</td></tr>
</table>

production unit: 5 sorting seed potatoes **operation:** 5.1 sorting & selecting	
flow properties *9. seed potatoes* ▪ Phytophtera ▪ Rhizoctonia ▪ size ▪ tuber defects *10. seed potatoes* ▪ Phytophtera ▪ Rhizoctonia ▪ tuber defects ▪ amount **critical control points** 1. sorter window 2. band speed 3. light intensity 4. education 5. quantity	**instructions** 1. Before sorting, manually check the sorter windows for the appropriate size. 2. During sorting regularly check if the sorter windows are not being clogged. Clean them if necessary. 3. Measure the light intensity in the selection room before sorting and daily afterwards. Write down the results at the selection control form. The light intensity in the selection room should be at least 600 LUX. Replace defect lamps if necessary. 4. The people who are selecting should be well-educated in recognizing Phytophtora, Rhizoctionia and tuber defects. 5. Determine the right band speed by regularly taking samples (especially in the beginning) of selected seed potatoes and determine of the percentage Phytophtora, Rhizoctonia and tuber defects. Re-adjust band speed if necessary. 6. Calculate the amount of seed potatoes that can be sold to the market by estimating the amount of seed potatoes that is needed for own production of ware potatoes.

V Questionnaire for expert validation

This appendix shows the questionnaire that was used for expert validation as described in Chapter 8. The original questionnaire was written in Dutch.

---

time: 20 min.

Below you find a number of questions that you can answer on a scale ranging from 1 to 5. In general 1 = very negative and 5 = very positive. Circle the desired number. If you think you cannot give your opinion on a certain question, you can indicate that also. Some questions are multiple choice; check where appropriate.

<u>Hint:</u> try to answer the questions quick and impulse. Within a moment you can discuss about it further.

1 The whole

1.1 Could the model and methodology contribute to the concretization of sustainability at a farm?

not at all	1	2	3	4	5	surely

❑ no opinion

1.2 Could the model and methodology contribute to the learning process of a farmer?

not at all	1	2	3	4	5	very much

❑ no opinion

1.3 What is the added value of information and communication technology (ICT) with regard to the overall goal? (In other words: could you do the same in your head and use pen and paper?)

very low	1	2	3	4	5	very high

❑ no opinion

1.4 What do you think of the flexibility of the model?

very strict	1	2	3	4	5	very flexible

❑ no opinion

2 Product Flow Model

2.1 The Product Flow Model is a good representation of the primary production process. To what degree do you agree with this?

disagree	1	2	3	4	5	agree

❑ no opinion

3 Sustainability Mapping

3.1 Sustainability Mapping is a good way to map sustainability goals for a farm. To what degree do you agree with this?

disagree	1	2	3	4	5	agree

❑ no opinion

4 Sustainability Function Deployment

4.1 Sustainability Function Deployment is a good way to connect gaols with operational management. To what degree do you agree with this?

disagree	1	2	3	4	5	agree

❑ no opinion

5 Sustainability Management Handbook

5.1 The Sustainability Management Handbook provides good support for the operational management. To what degree do you agree with this?

disagree	1	2	3	4	5	agree

❑ no opinion

6 General

6.1 Do you think the model is especially applicable to:

❑ ecological agriculture
❑ conventional agriculture
❑ both equally applicable
❑ both not applicable
❑ no opinion

6.2 How suitable do you find the model for the principle of *preventive* management?

not suitable	1	2	3	4	5	suitable

❑ no opinion

6.3 How suitable do you find the model for the principle of *recycling* management?

not suitable	1	2	3	4	5	suitable

❑ no opinion

6.4 Supposing that the software is perfect (and thus very user-friendly), do you think the system should be maintained by a:

❑ farmer
❑ consultant
❑ both
❑ none of them
❑ no opinion

6.5 Beside a single time investment for implementation, the farmer/consultant will have to spend time on maintenance of the system. Do you think this is feasible in practice?

not feasible	1	2	3	4	5	feasible

❑ no opinion

6.6 By using the system, the farmer imposes himself a rather strong disciplinary way of working (measure, register, control). Do you think this is practicable?

not practicable	1	2	3	4	5	practicable

❑ no opinion

6.7 Do you think it is possible to combine the model with certification (e.g. EKO, EuerepGap, ISO, HACCP)?

not at all	1	2	3	4	5	very good

❑ no opinion

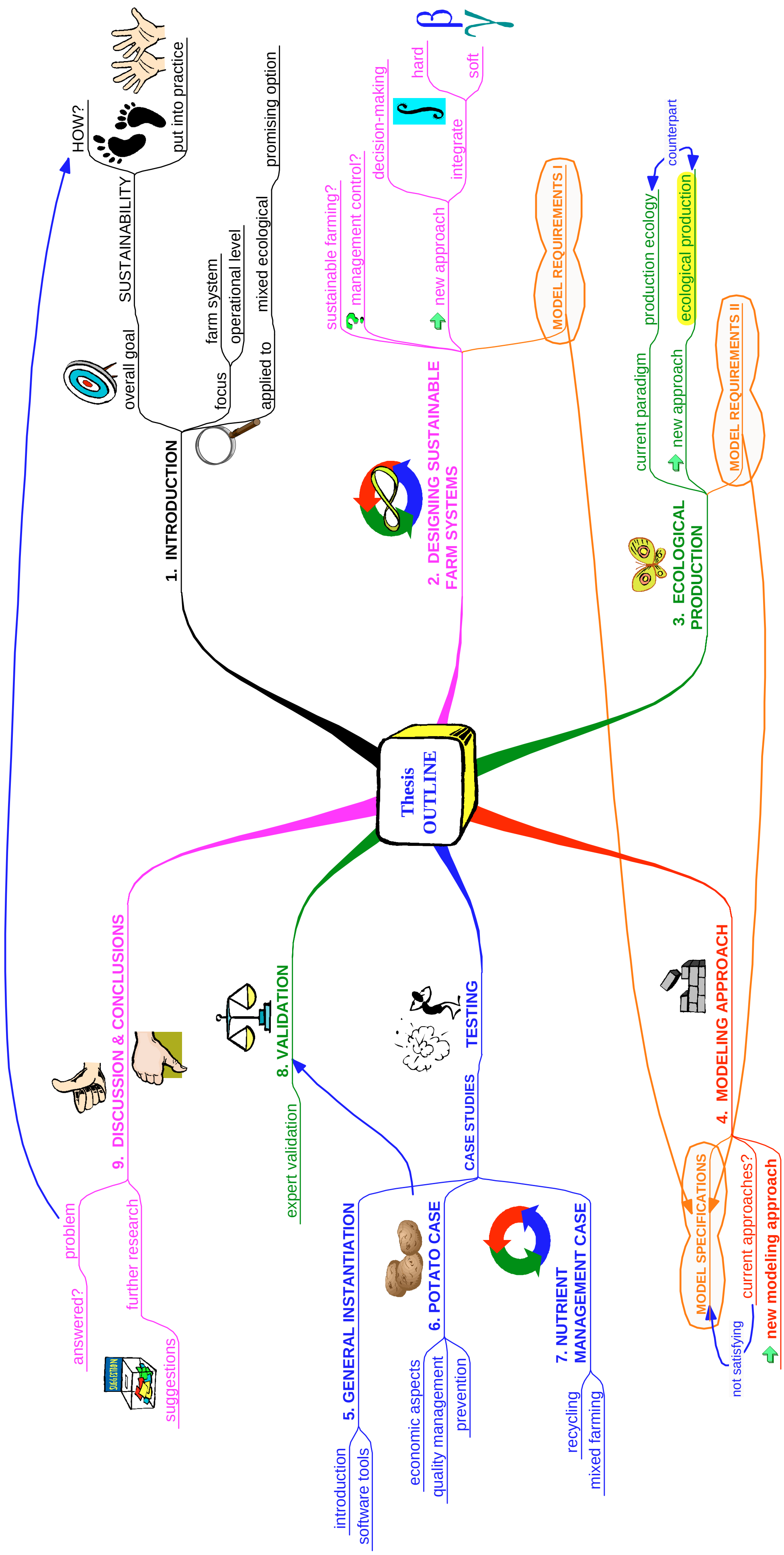
6.8 If this project in one or another way is going to be continued, would you like to be:

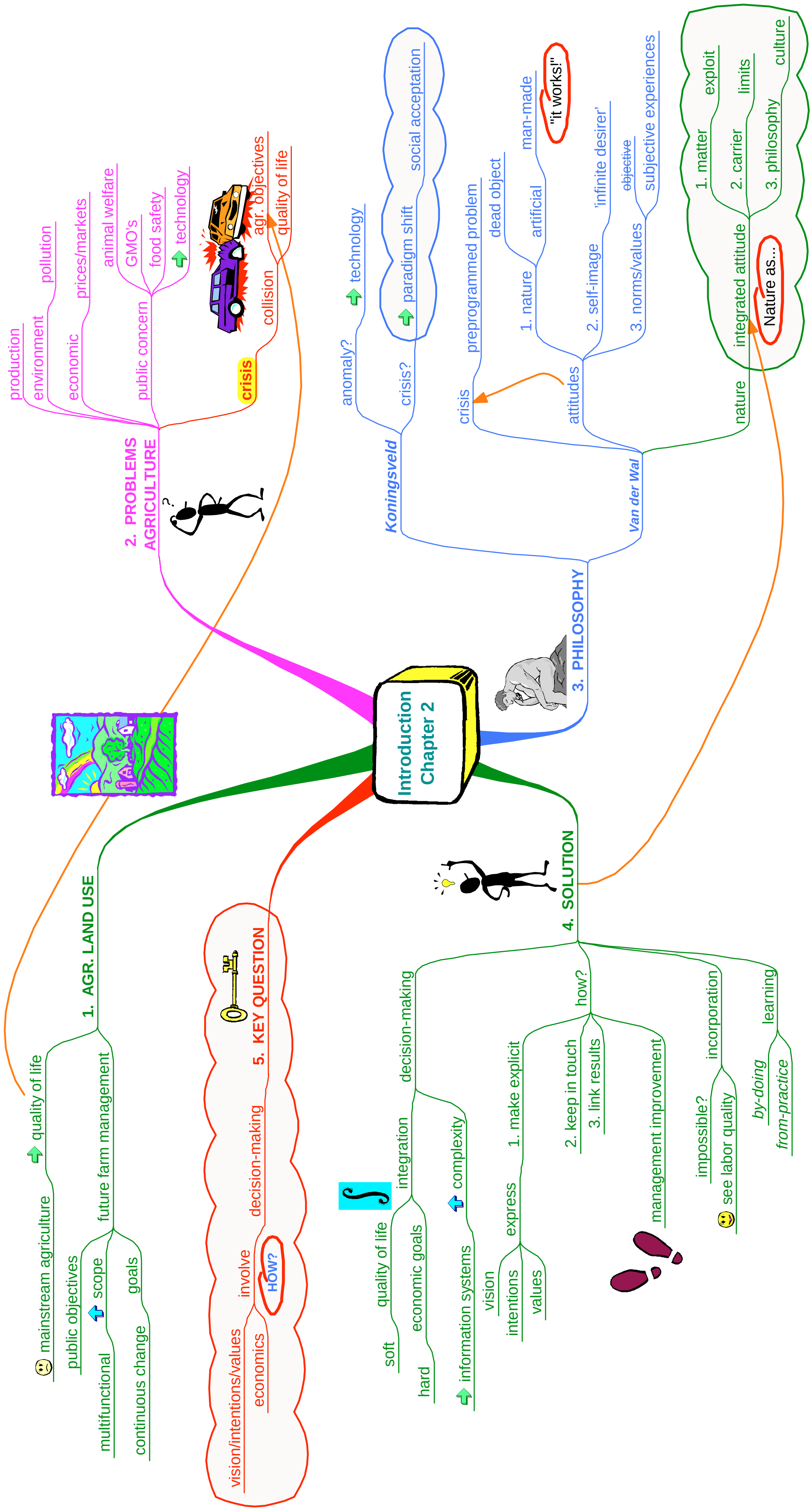
❑ actively involved?
❑ get informed?
❑ none of them

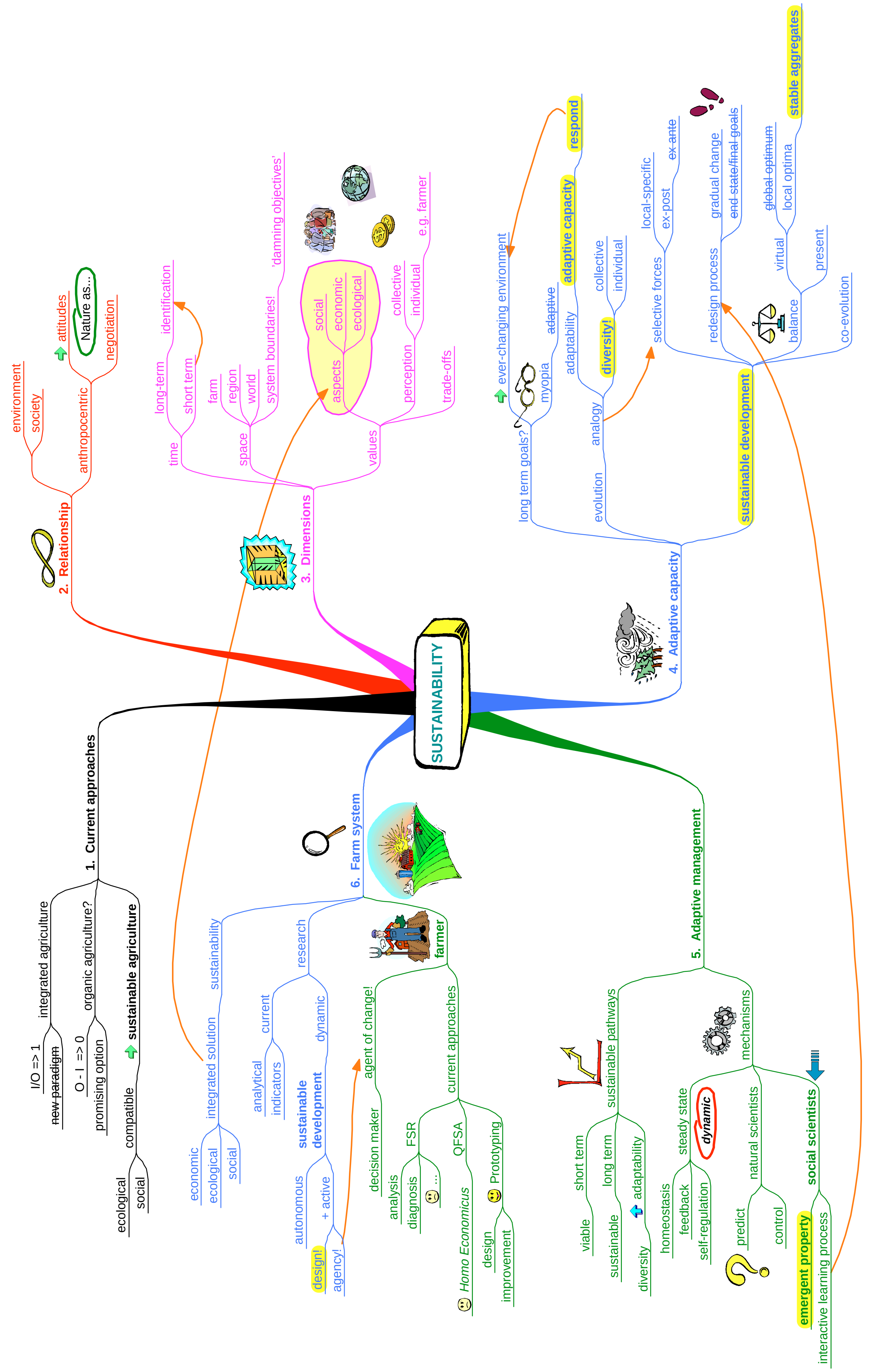
VI Mind Maps

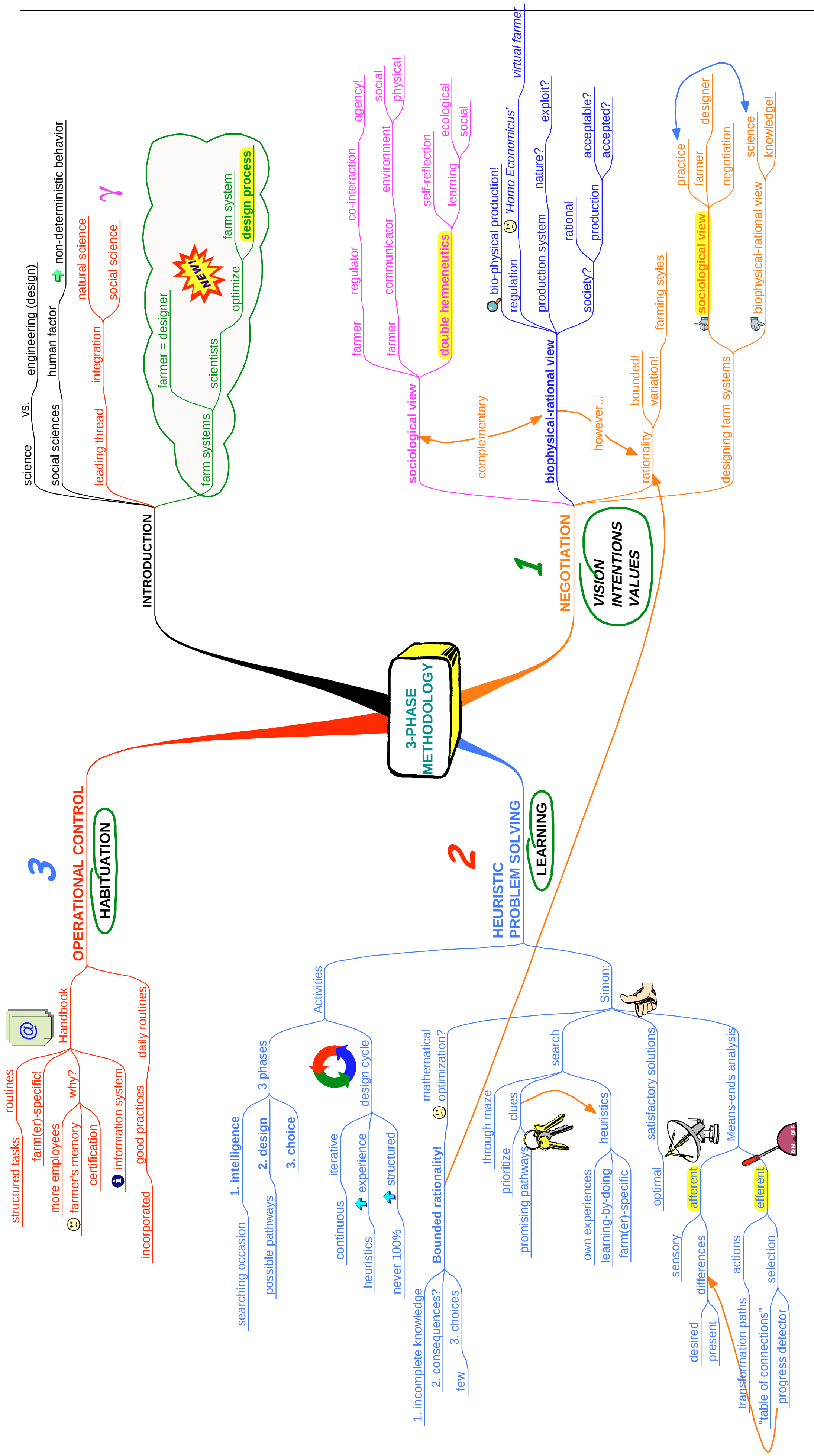
This appendix bundles the following mind maps that summarize several important parts of the text in this thesis.

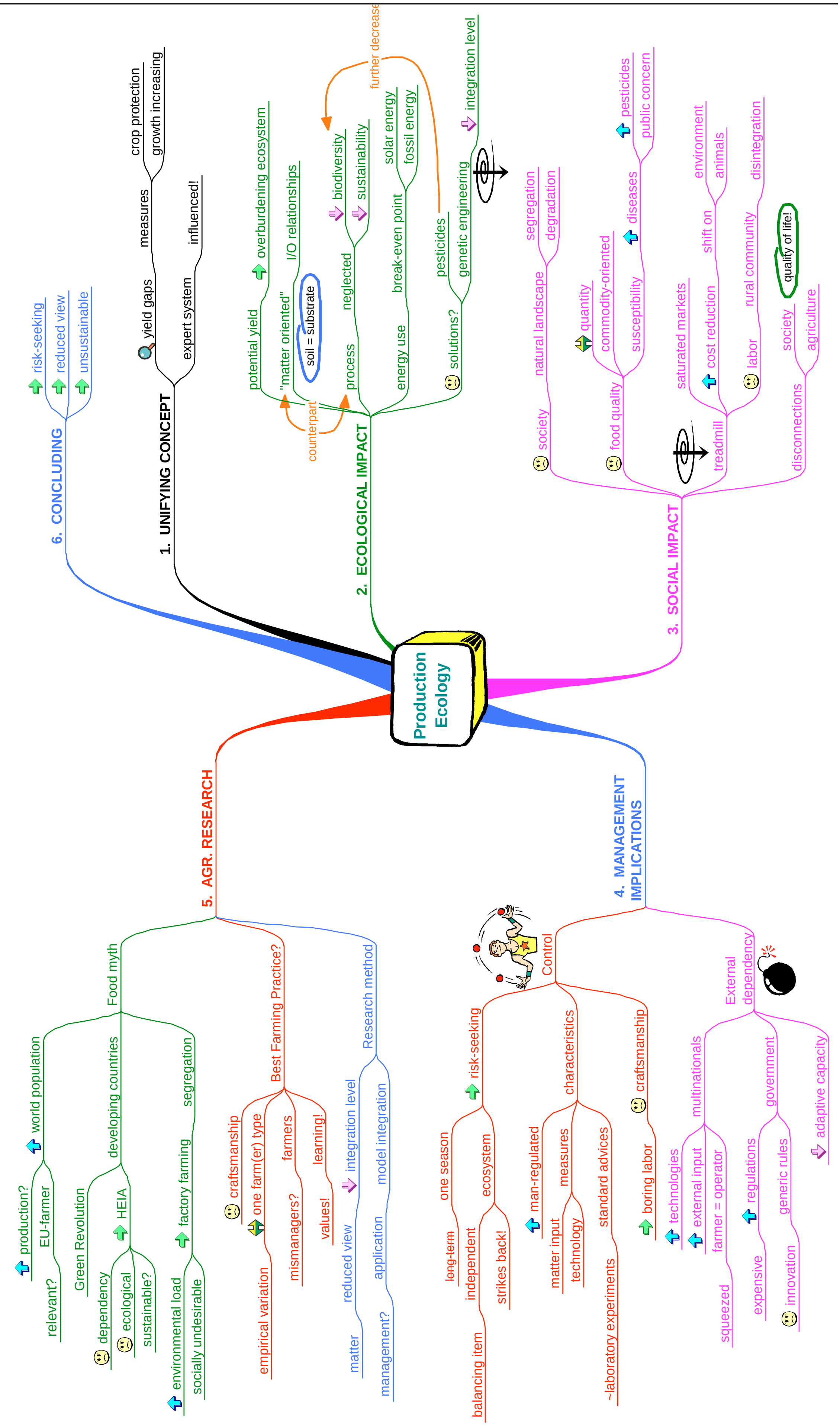
1. Thesis outline
2. Introduction Chapter 2
3. Sustainability
4. Three-phase-methodology
5. Production ecology
6. Ecological Production
7. Modeling approach
8. Model specifications
9. Potato case
10. Nutrient Management case
11. Expert validation
12. Major conclusions

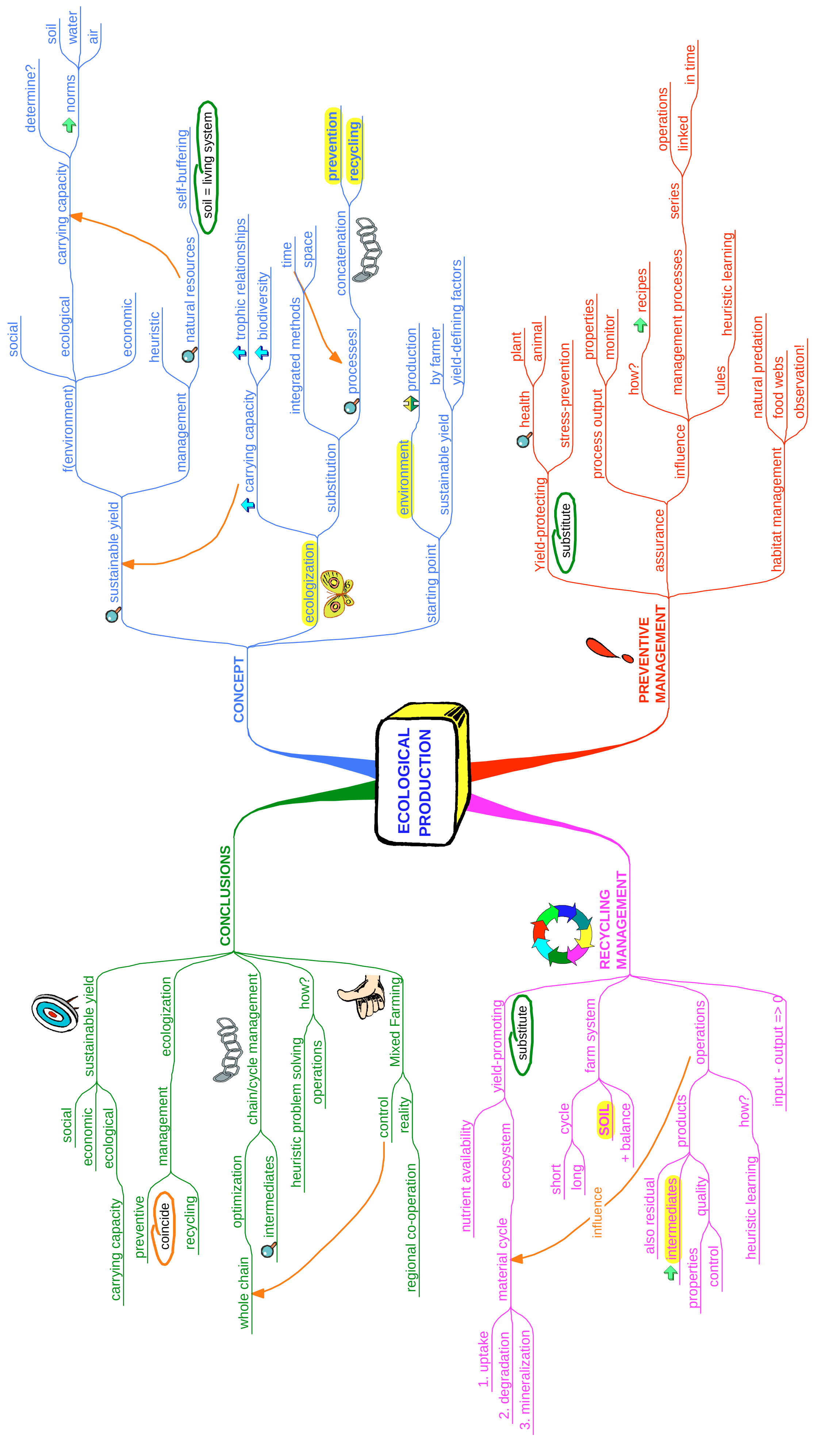

Thesis OUTLINE
1. INTRODUCTION
overall goal
SUSTAINABILITY
HOW?
put into practice
focus
farm system
operational level
applied to
mixed ecological
promising option
2. DESIGNING SUSTAINABLE FARM SYSTEMS
sustainable farming?
management control?
decision-making
new approach
integrate
hard
soft
MODEL REQUIREMENTS I
3. ECOLOGICAL PRODUCTION
current paradigm
production ecology
counterpart
new approach
ecological production
MODEL REQUIREMENTS II
4. MODELING APPROACH
MODEL SPECIFICATIONS
current approaches?
not satisfying
new modeling approach
TESTING
CASE STUDIES
5. GENERAL INSTANTIATION
introduction
software tools
6. POTATO CASE
economic aspects
quality management
prevention
7. NUTRIENT MANAGEMENT CASE
recycling
mixed farming
8. VALIDATION
expert validation
9. DISCUSSION & CONCLUSIONS
problem
answered?
further research
suggestions


Introduction Chapter 2
1. AGR. LAND USE
mainstream agriculture
quality of life
public objectives
scope
multifunctional
future farm management
goals
continuous change
2. PROBLEMS AGRICULTURE
production
environment
pollution
economic
prices/markets
public concern
animal welfare
GMO's
food safety
technology
crisis
collision
agr. objectives
quality of life
3. PHILOSOPHY
Koningsveld
anomaly?
technology
crisis?
paradigm shift
social acceptation
Van der Wal
crisis
preprogrammed problem
dead object
1. nature
artificial
man-made
"it works!"
attitudes
2. self-image
'infinite desirer'
3. norms/values
~~objective~~
subjective experiences
nature
integrated attitude
Nature as...
1. matter
exploit
2. carrier
limits
3. philosophy
culture
4. SOLUTION
decision-making
integration
quality of life
soft
economic goals
hard
complexity
information systems
how?
1. make explicit
express
vision
intentions
values
2. keep in touch
3. link results
management improvement
incorporation
impossible?
see labor quality
learning
by-doing
from-practice
5. KEY QUESTION
decision-making
involve
HOW?
vision/intentions/values
economics

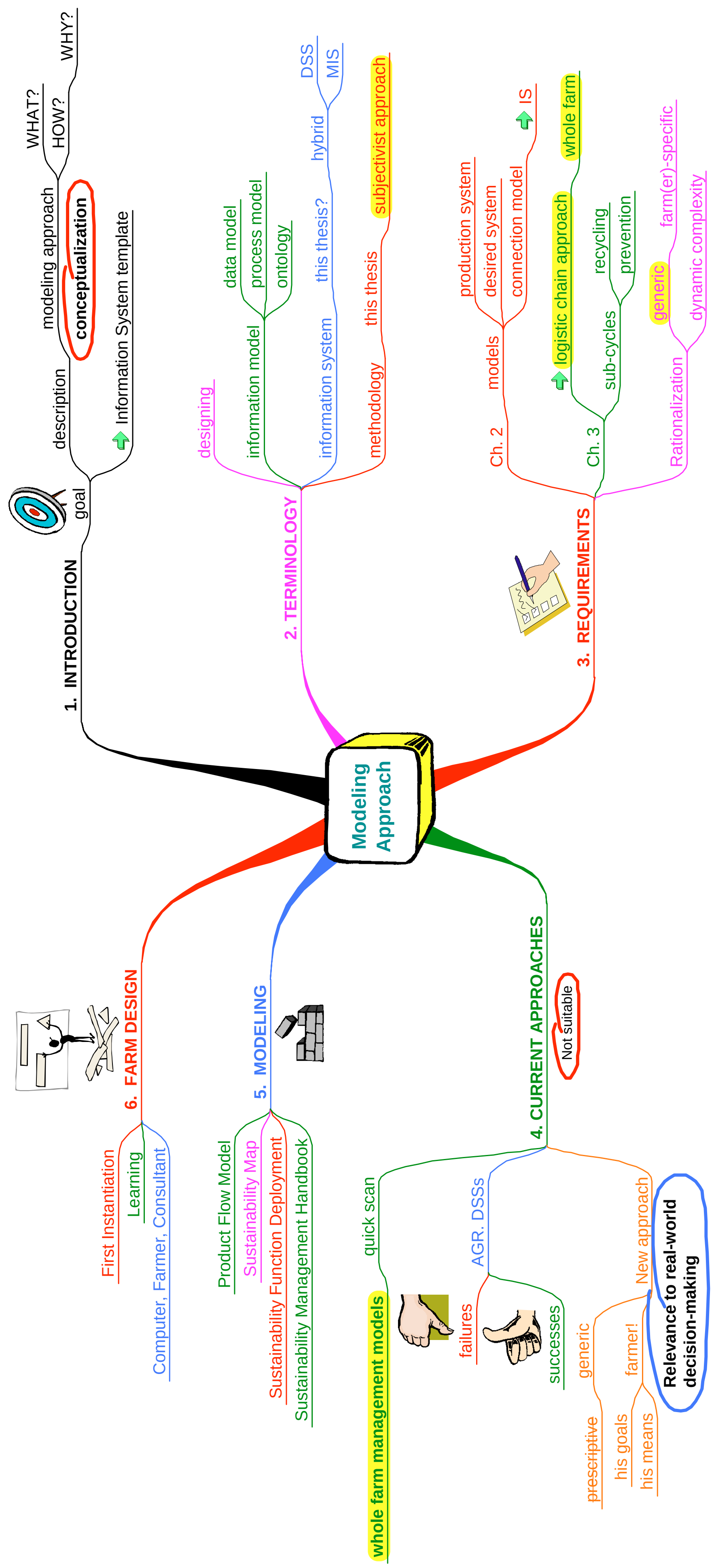

SUSTAINABILITY
1. Current approaches
I/O => 1
new paradigm
integrated agriculture
O - I => 0
promising option
organic agriculture?
sustainable agriculture
compatible
ecological
social
2. Relationship
environment
society
anthropocentric
attitudes
Nature as...
negotiation
3. Dimensions
time
long-term
short term
identification
space
farm
region
world
system boundaries!
'damning objectives'
aspects
social
economic
ecological
values
perception
collective
individual
e.g. farmer
trade-offs
4. Adaptive capacity
long term goals?
ever-changing environment
myopia
adaptive
adaptability
adaptive capacity
respond
evolution
analogy
diversity!
collective
individual
selective forces
local-specific
ex-post
ex ante
sustainable development
redesign process
gradual change
end state/final goals
balance
virtual
global optimum
local optima
stable aggregates
present
co-evolution
5. Adaptive management
sustainable pathways
short term
long term
viable
sustainable
adaptability
diversity
mechanisms
steady state
dynamic
homeostasis
feedback
self-regulation
natural scientists
predict
control
social scientists
emergent property
interactive learning process
6. Farm system
sustainability
integrated solution
economic
ecological
social
research
current
analytical
indicators
dynamic
sustainable development
autonomous
+ active
design!
agency!
farmer
agent of change!
decision maker
current approaches
FSR
analysis
diagnosis
...
QFSA
Homo Economicus
Prototyping
design
improvement

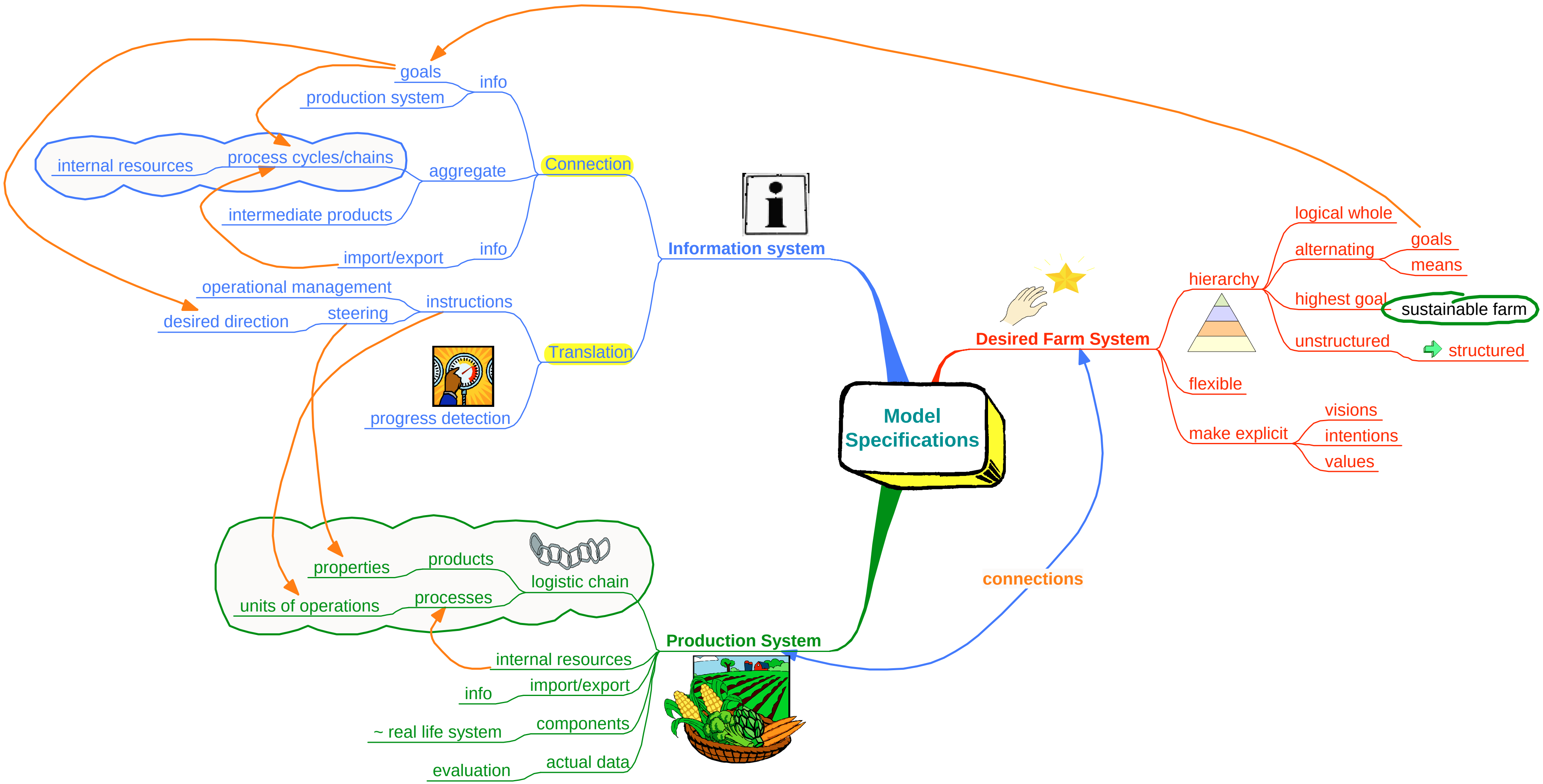

3-PHASE METHODOLOGY
INTRODUCTION
science vs. engineering (design)
social sciences
human factor
non-deterministic behavior
leading thread
integration
natural science
social science
γ
farm systems
farmer = designer
scientists
NEW!
optimize
~~farm system~~
design process
1
NEGOTIATION
VISION
INTENTIONS
VALUES
sociological view
farmer
regulator
co-interaction
agency!
communicator
environment
social
physical
double hermeneutics
self-reflection
learning
ecological
social
complementary
biophysical-rational view
bio-physical production!
regulation
'Homo Economicus'
virtual farmer
production system
nature?
exploit?
society?
rational
production
acceptable?
accepted?
however...
rationality
bounded!
variation!
farming styles
designing farm systems
sociological view
practice
farmer
designer
negotiation
biophysical-rational view
science
knowledge!
2
HEURISTIC PROBLEM SOLVING
LEARNING
Activities
3 phases
1. intelligence
searching occasion
2. design
possible pathways
3. choice
design cycle
iterative
continuous
experience
heuristics
structured
never 100%
Bounded rationality!
1. incomplete knowledge
2. consequences?
3. choices
few
mathematical optimization?
Simon:
search
clues
through maze
prioritize
promising pathways
heuristics
own experiences
learning-by-doing
farm(er)-specific
satisfactory solutions
~~optimal~~
Means-ends analysis
afferent
sensory
differences
desired
present
efferent
actions
transformation paths
selection
"table of connections"
progress detector
3
OPERATIONAL CONTROL
HABITUATION
Handbook
routines
structured tasks
farm(er)-specific!
why?
more employees
farmer's memory
certification
information system
daily routines
good practices
incorporated

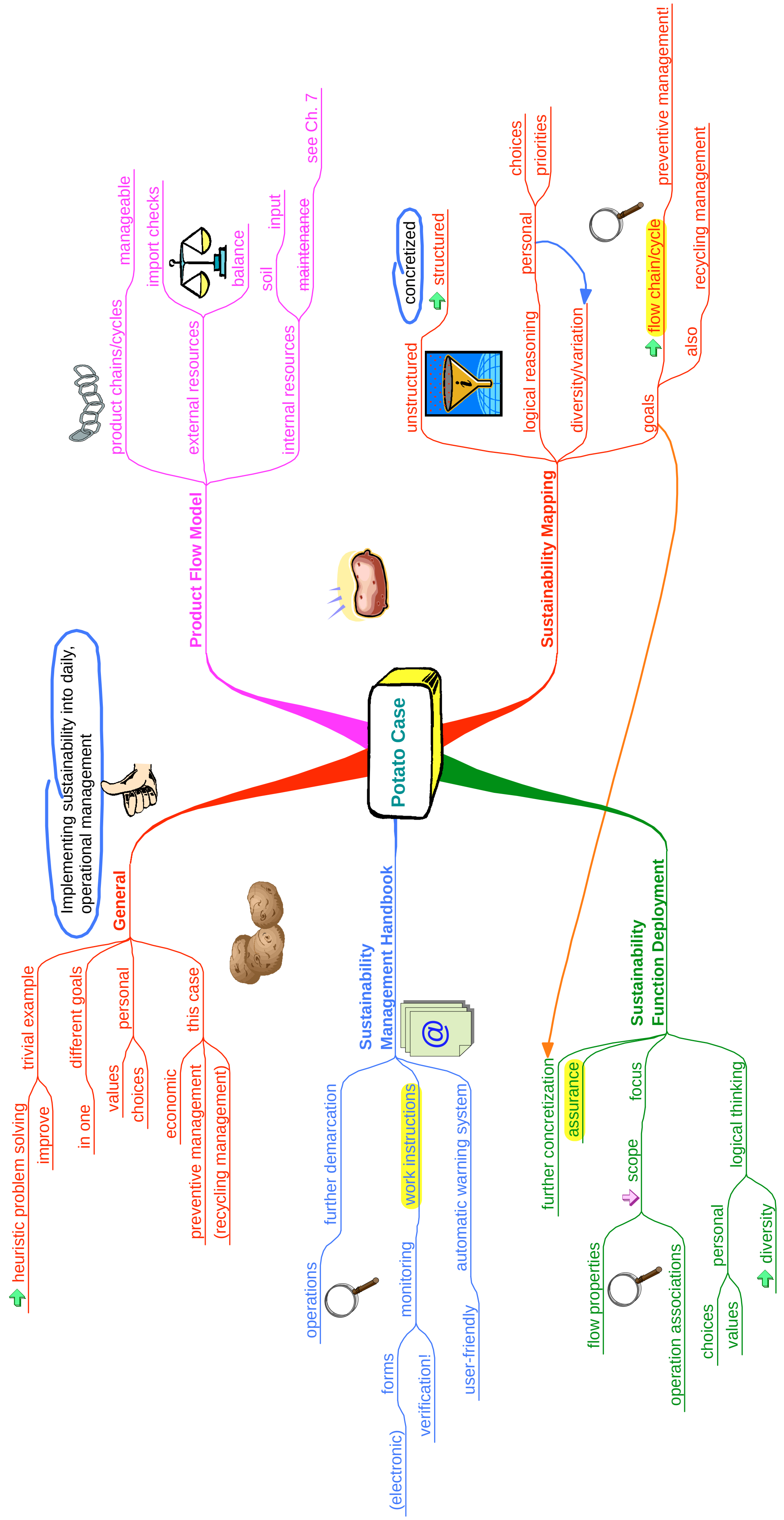

Production Ecology
1. UNIFYING CONCEPT
yield gaps
measures
crop protection
growth increasing
expert system
influenced!
2. ECOLOGICAL IMPACT
potential yield
overburdening ecosystem
"matter oriented"
I/O relationships
soil = substrate
counterpart
process
neglected
biodiversity
sustainability
further decrease
energy use
break-even point
solar energy
fossil energy
solutions?
pesticides
genetic engineering
integration level
3. SOCIAL IMPACT
society
natural landscape
segregation
degradation
food quality
quantity
commodity-oriented
susceptibility
diseases
pesticides
public concern
treadmill
saturated markets
cost reduction
labor
shift on
environment
animals
rural community
disintegration
disconnections
society
agriculture
quality of life!
4. MANAGEMENT IMPLICATIONS
Control
risk-seeking
one season
~~long-term~~
independent
balancing item
ecosystem
strikes back!
characteristics
man-regulated
measures
matter input
technology
standard advices
~laboratory experiments
craftsmanship
boring labor
External dependency
multinationals
technologies
external input
farmer = operator
squeezed
government
regulations
expensive
generic rules
innovation
adaptive capacity
5. AGR. RESEARCH
Food myth
world population
production?
EU-farmer
relevant?
developing countries
Green Revolution
dependency
HEIA
ecological
sustainable?
segregation
factory farming
environmental load
socially undesirable
Best Farming Practice?
craftsmanship
one farm(er) type
empirical variation
farmers
mismanagers?
learning!
values!
Research method
integration level
reduced view
matter
application
management?
model integration
6. CONCLUDING
risk-seeking
reduced view
unsustainable

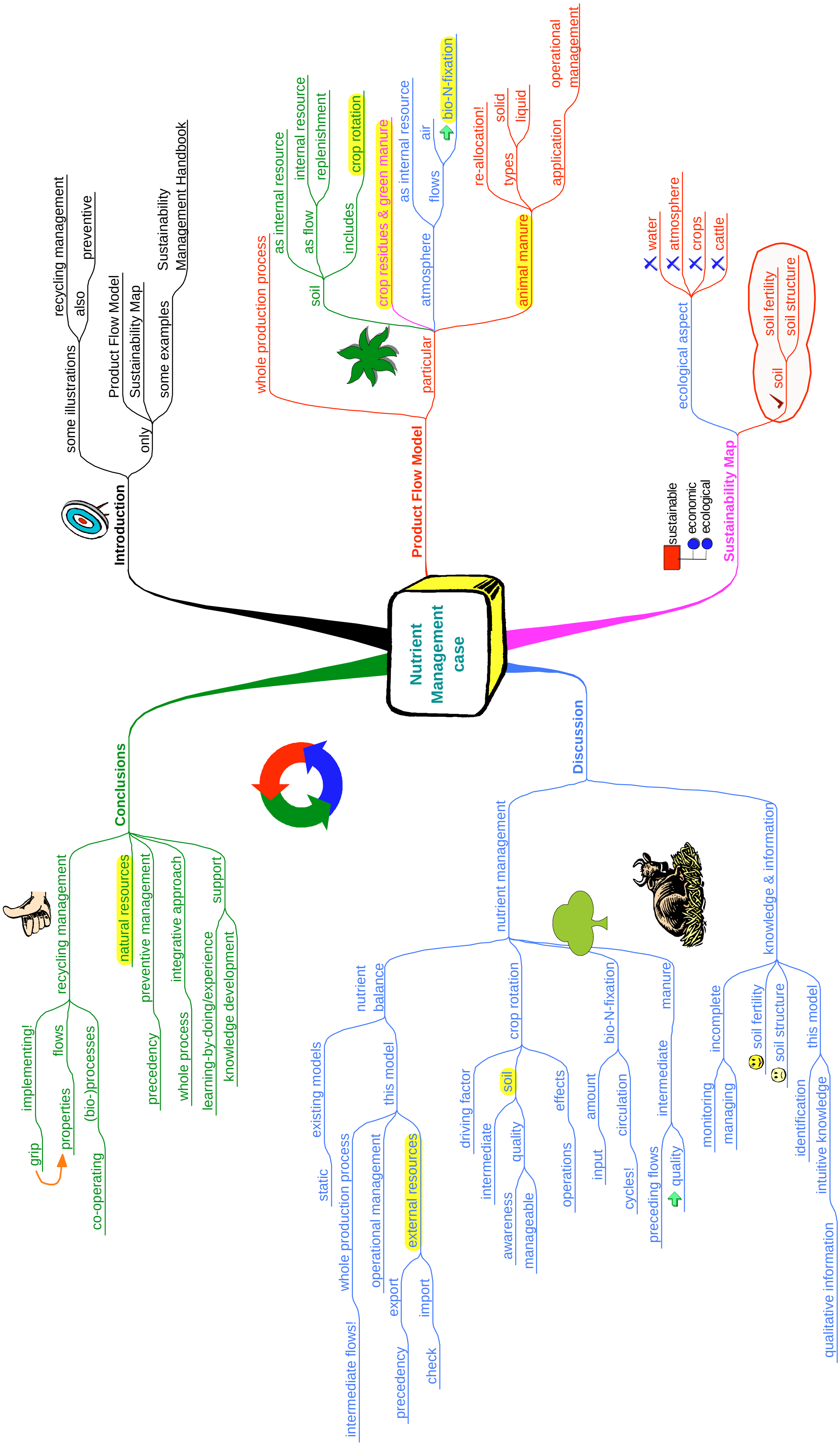


ECOLOGICAL PRODUCTION
CONCEPT
sustainable yield
f(environment)
social
ecological
carrying capacity
determine?
norms
soil
water
air
economic
heuristic
management
natural resources
self-buffering
soil = living system
carrying capacity
trophic relationships
biodiversity
substitution
integrated methods
time
space
processes!
concatenation
prevention
recycling
ecologization
starting point
environment
production
by farmer
sustainable yield
yield-defining factors
PREVENTIVE MANAGEMENT
yield-protecting
substitute
health
plant
animal
stress-prevention
process output
properties
monitor
assurance
influence
how?
recipes
management processes
series
operations
linked
in time
rules
heuristic learning
habitat management
natural predation
food webs
observation!
RECYCLING MANAGEMENT
yield-promoting
substitute
nutrient availability
ecosystem
material cycle
1. uptake
2. degradation
3. mineralization
farm system
cycle
short
long
SOIL
+ balance
influence
operations
products
also residual
intermediates
properties
quality
control
how?
heuristic learning
input - output => 0
CONCLUSIONS
sustainable yield
social
economic
ecological
carrying capacity
ecologization
management
preventive
coincide
recycling
chain/cycle management
optimization
intermediates
whole chain
how?
heuristic problem solving
operations
Mixed Farming
control
reality
regional co-operation

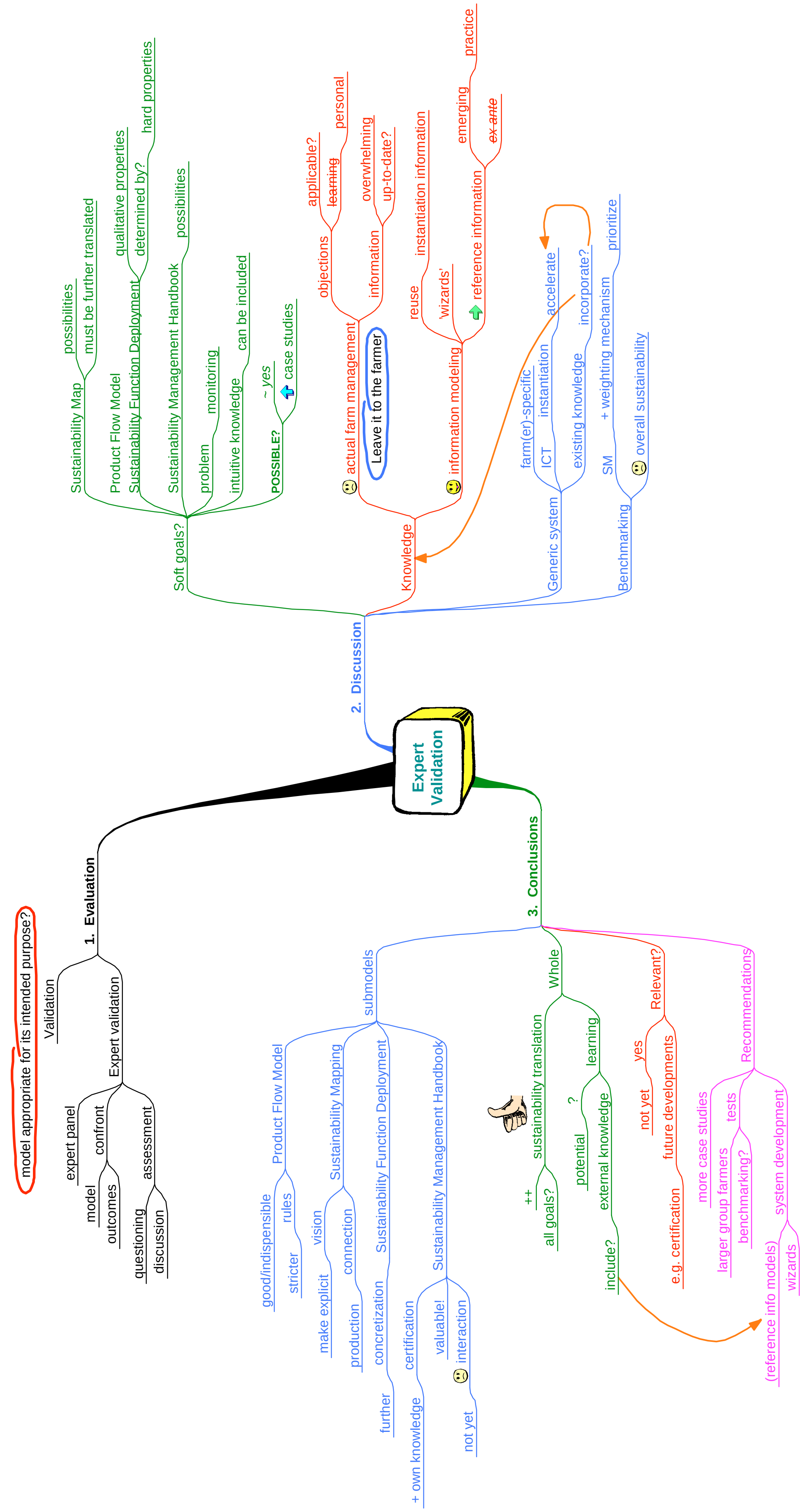

Modeling Approach
1. INTRODUCTION
goal
description
modeling approach
WHAT?
HOW?
WHY?
conceptualization
Information System template
2. TERMINOLOGY
designing
information model
data model
process model
ontology
information system
this thesis?
hybrid
DSS
MIS
methodology
this thesis
subjectivist approach
3. REQUIREMENTS
Ch. 2
models
production system
desired system
connection model
IS
Ch. 3
logistic chain approach
whole farm
sub-cycles
recycling
prevention
Rationalization
generic
farm(er)-specific
dynamic complexity
4. CURRENT APPROACHES
Not suitable
quick scan
whole farm management models
AGR. DSSs
failures
successes
New approach
generic
prescriptive
farmer!
his goals
his means
Relevance to real-world decision-making
5. MODELING
Product Flow Model
Sustainability Map
Sustainability Function Deployment
Sustainability Management Handbook
6. FARM DESIGN
First Instantiation
Learning
Computer, Farmer, Consultant

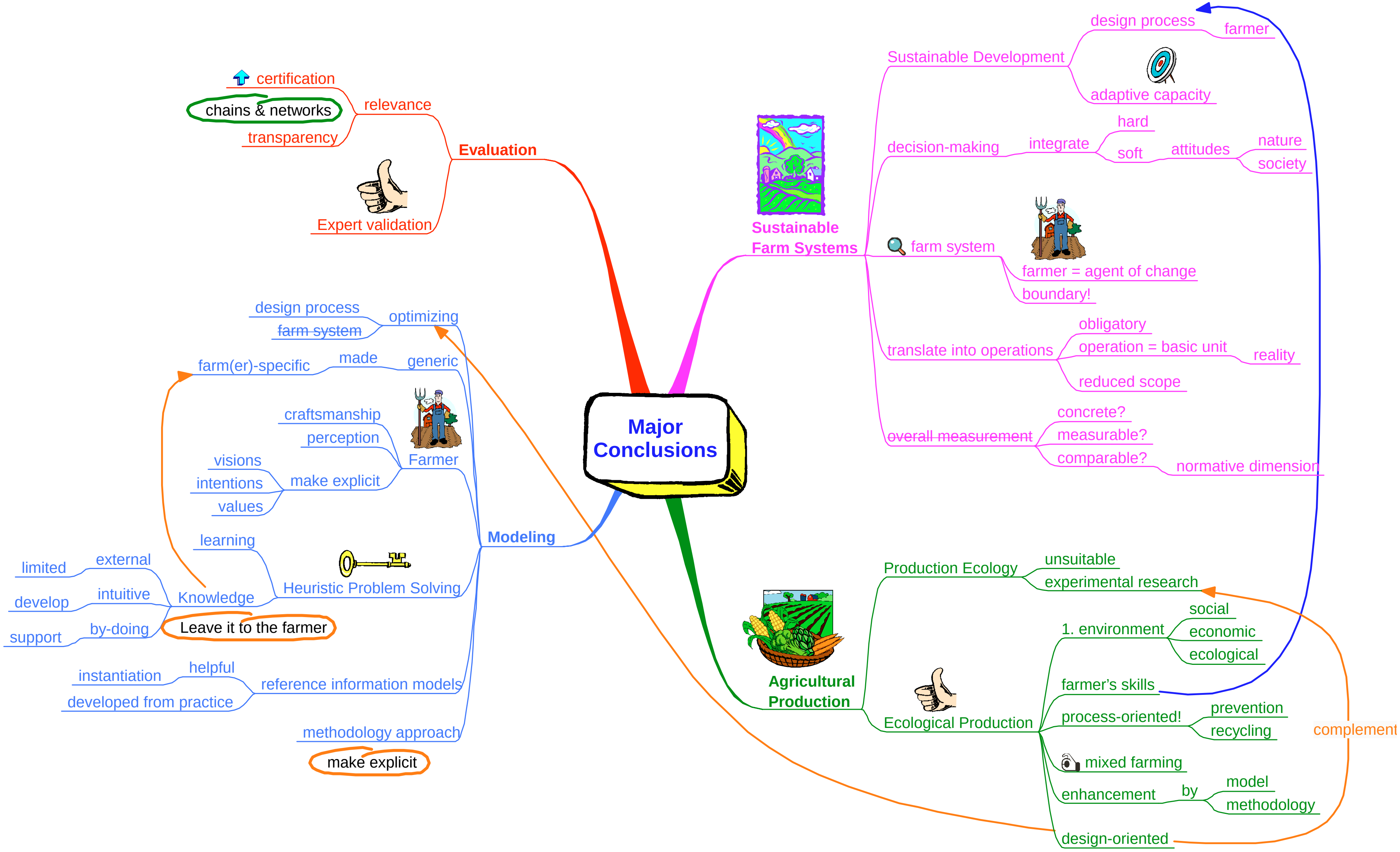

Model Specifications
Information system
Connection
info
goals
production system
aggregate
internal resources
process cycles/chains
intermediate products
info
import/export
Translation
instructions
operational management
steering
desired direction
progress detection
Desired Farm System
hierarchy
logical whole
alternating
goals
means
highest goal
sustainable farm
unstructured
structured
flexible
make explicit
visions
intentions
values
connections
Production System
logistic chain
products
properties
processes
units of operations
internal resources
import/export
info
components
~ real life system
actual data
evaluation


Potato Case
General
Implementing sustainability into daily, operational management
trivial example
heuristic problem solving
improve
different goals
in one
personal
values
choices
this case
economic
preventive management
(recycling management)
Product Flow Model
product chains/cycles
manageable
external resources
import checks
balance
internal resources
soil
input
~~maintenance~~
see Ch. 7
Sustainability Mapping
unstructured
concretized
structured
logical reasoning
personal
choices
priorities
diversity/variation
goals
flow chain/cycle
preventive management!
also
recycling management
Sustainability Management Handbook
further demarcation
operations
work instructions
monitoring
forms
(electronic)
verification!
automatic warning system
user-friendly
Sustainability Function Deployment
further concretization
assurance
focus
scope
flow properties
operation associations
logical thinking
personal
choices
values
diversity



Nutrient Management case
Introduction
some illustrations
recycling management
also
preventive
only
Product Flow Model
Sustainability Map
some examples
Sustainability Management Handbook
Product Flow Model
whole production process
particular
soil
as internal resource
as flow
internal resource
replenishment
includes
crop rotation
crop residues & green manure
atmosphere
as internal resource
flows
air
bio-N-fixation
animal manure
re-allocation!
types
solid
liquid
application
operational management
Sustainability Map
sustainable
economic
ecological
ecological aspect
water
atmosphere
crops
cattle
soil
soil fertility
soil structure
Discussion
nutrient management
nutrient balance
existing models
static
whole production process
intermediate flows!
this model
operational management
external resources
export
import
precedency
check
crop rotation
driving factor
intermediate
soil
quality
awareness
manageable
effects
operations
bio-N-fixation
amount
input
circulation
cycles!
manure
intermediate
preceding flows
quality
knowledge & information
incomplete
monitoring
managing
soil fertility
soil structure
this model
identification
intuitive knowledge
qualitative information
Conclusions
recycling management
implementing!
grip
flows
properties
(bio-)processes
co-operating
natural resources
preventive management
precedency
integrative approach
whole process
learning-by-doing/experience
support
knowledge development


Expert Validation
1. Evaluation
Validation
model appropriate for its intended purpose?
Expert validation
expert panel
model
confront
outcomes
assessment
questioning
discussion
2. Discussion
Soft goals?
Sustainability Map
possibilities
must be further translated
Product Flow Model
Sustainability Function Deployment
qualitative properties
determined by?
hard properties
Sustainability Management Handbook
possibilities
problem
monitoring
intuitive knowledge
can be included
POSSIBLE?
~ yes
case studies
Knowledge
actual farm management
objections
applicable?
learning
personal
information
overwhelming
up-to-date?
Leave it to the farmer
information modeling
reuse
instantiation information
'wizards'
reference information
emerging
practice
ex ante
Generic system
farm(er)-specific
ICT
instantiation
accelerate
existing knowledge
incorporate?
Benchmarking
SM
+ weighting mechanism
prioritize
overall sustainability
3. Conclusions
submodels
Product Flow Model
good/indispensible
rules
stricter
Sustainability Mapping
vision
make explicit
connection
production
Sustainability Function Deployment
concretization
further
Sustainability Management Handbook
certification
+ own knowledge
valuable!
interaction
not yet
Whole
sustainability translation
++
all goals?
?
potential
learning
external knowledge
include?
Relevant?
yes
not yet
future developments
e.g. certification
Recommendations
more case studies
tests
larger group farmers
benchmarking?
system development
(reference info models)
wizards


Major Conclusions
Evaluation
relevance
certification
chains & networks
transparency
Expert validation
Sustainable Farm Systems
Sustainable Development
design process
farmer
adaptive capacity
decision-making
integrate
hard
soft
attitudes
nature
society
farm system
farmer = agent of change
boundary!
translate into operations
obligatory
operation = basic unit
reality
reduced scope
overall measurement
concrete?
measurable?
comparable?
normative dimension
Modeling
optimizing
design process
farm system
generic
made
farm(er)-specific
Farmer
craftsmanship
perception
make explicit
visions
intentions
values
Heuristic Problem Solving
learning
Knowledge
external
limited
intuitive
develop
by-doing
support
Leave it to the farmer
reference information models
helpful
instantiation
developed from practice
methodology approach
make explicit
Agricultural Production
Production Ecology
unsuitable
experimental research
Ecological Production
1. environment
social
economic
ecological
farmer's skills
process-oriented!
prevention
recycling
mixed farming
enhancement
by
model
methodology
design-oriented
complement

Summary

Sustainable agriculture is an important, but complex issue. Without further implementation, it remains a vague statement, without perspectives for application. This thesis wants to help to make sustainability applicable at farm level. The research question focused on the question how sustainability could be implemented in operational farm management of a mixed ecological farm. It started with thorough desk research, looking for ideas, interpretations and methodologies concerning sustainable development. What is it? How did it get implemented? What should be done when farmers are expected to become skilled in decision-making leading to sustainable development of their farm? A modeling approach was used for structuring and ordering relevant information. The model is considered to support farmers in decision-making so that the results concerned will bring their farms to a state of sustainable development.

Chapter 2 made clear why agriculture is essential for the quality of life and therefore concerns whole societies. The relation between agriculture and society however has become gradually undermined due to serious problems evoked by too intensive ways of production. This chapter introduced why integration of soft and hard parameters in decision-making by farmers could be a solution. Is it possible to give soft issues such as farmers' visions, intentions and values a same weight in deliberations about farm economy and management? It was found that sustainable agriculture could be considered as an integrated solution for economic, ecological and social problems. It was concluded that sustainable development is a dynamic design process in an ever-changing environment. Design as such, must aim at achievement and maintenance of adaptive capacities towards this environment, present in natural resources. So, the farmer, being the human factor in the farm system, has to play an essential role. That brought us to the combination of relevant concepts found in scientific literature about management and sociology. The chapter ended by presenting a methodology in three phases: (i) negotiate with the environment, (ii) solve problems in a heuristic way and (iii) operational control. This methodology was used for the definition of the information model, required for finding an answer to the research question.

Chapter 3 focused on the present discussion about the (dis)advantages of integrated and ecological farming. Which are the characteristics involved and what about the related needs of the manager? Production ecology as a unifying concept behind mainstream and integrated agriculture was discussed at first. The main conclusion was that this concept is oriented towards input-efficiency. Environment and nature are balancing items in that concept. The 'matter-input-output-relationship' dominates all priorities in decision-making, farm

management and research or extension agendas. The other concept, ecological production, gives priority to the environment or nature and considers farm economy as balancing item. That does not mean that ecological farming is not profitable, on the contrary. It was concluded that profitability of ecological production is in ecologization of farm economy. Sustainable development of ecological farming systems is in management of the cyclic farm-bound processes. Sustainable farming is in creating preventive management and in caring for cyclic processes among farm-bound natural resources. This form of management considers the farm production system as a logistic chain of products, which is also the main requirement for modeling. It was concluded that ecological farming is better for meeting the demands concerning sustainable agriculture. Due to its controlled experimental basis, production ecology is suitable for deepening our understanding about crops and related improvement of yields without increased burdening of environment and nature. In that concept however, farmers remain very much dependent on external input such as synthetic chemicals, extension, research institutes and Governments. That does not improve farmers' skills in management and their awareness of societal needs.

Chapter 4 described the development of an information system that supports farmers in designing sustainable farm systems, based on ecological production principles. It defined a new modeling approach, because it is argued that existing farm management models are too specific and do not correspond to real word decision-making and management practice. The information model consists of a process model and a data model. The process model consists of several submodels. The Product Flow Model represents the production system as a logistic chain or network of processes and intermediate products. The Sustainability Map represents the sustainability goals in a hierarchical way and connects them to the Product Flow Model by identifying relevant product flow cycles or chains. These connections are further elaborated by Sustainability Function Deployment, which makes associations between operations and flow properties. Finally, these associations are translated into critical control points and accompanying work instructions in the Sustainability Management Handbook. An entity-relationship diagram that can be instantiated as a relational database represents the data model. Software tools were developed to view and manipulate the data in this database. This makes it possible to evaluate and improve decision-making with respect to sustainable development. It was concluded that the information system supports the farmer in making his visions, intentions and values explicit, that it corresponds to the principle of heuristic problem solving and that it assures sustainability in his daily, operational management. Furthermore, it is in line with the principles of preventive and recycling management of ecological production.

While the previous chapters provided the theoretical basis of the model and methodology, the next chapters provided some concrete case studies that should be considered as a proof that sustainability can be implemented in this way in operational farm management. **Chapter 5** functions as an introduction into the case studies. It described the whole model and its subcomponents in a nutshell and shows how they should be used. The ecological farm system at the ‘ir. A.P. Minderhoudhoeve’ has been used as a test in practice. Software tools that were used for instantiation were illustrated and explained. The case studies in the next chapters went into more detail with regard to several aspects of sustainability and ecological production.

Chapter 6 provided a case study that illustrates the model and methodology that was developed in this thesis, focusing on the economic aspect of sustainability as applied to potato production. The study shows how several goals, with regard to farm economics and quality production could be translated into the operational management level. It showed how unstructured goals could be translated into structured tasks. The Product Flow Model, in combination with Sustainability Mapping, showed how chains and cycles of products could be identified, connected to sustainability goals. Sustainability Function Deployment, in combination with the Sustainability Management Handbook, showed how goals can be further concretized and assured during the entire production process. The final result is an example of a handbook, which describes several critical control points and work instructions concerning the operations of potato production. The handbook showed how various sustainability goals come together in one operation. Especially, the ecological production principle of preventive management was illustrated, but also some examples of recycling management can be distinguished. It was illustrated that implementing sustainability goals is a matter of common sense and room is left for personal values and choices.

Chapter 7 provided a case study that illustrates the model and methodology that was developed in this thesis, focusing on nutrient management. The study showed what goals can be identified and how they can be connected with the primary production process by identifying chains or cycles of product flows in the entire Product Flow Model of the ecological farm system at the ir. A.P. Minderhoudhoeve. In this way, recycling management, but also preventive management, is being developed. Especially in nutrient management, the whole production process is involved and thus the idea of mixed farming becomes an important issue. It means that intermediate products, like manure and crop residues, become important for management. Management should focus on getting grip on the properties of these products. Internal resources, in particular the soil, play an important role in this process. Biological processes, related to soil life, should be stimulated and can be used to reach goals. However, this case study also showed that for the desired type of nutrient management a lack of knowledge exists. In this respect, it was shown that the model and methodology could help the farmer to develop his own heuristics to work on this. These heuristics could be used in agricultural research to develop a sounder theoretical basis.

Chapter 8 evaluated the model and methodology by applying expert validation. During a half-day's session, a panel of experts was confronted with the model and some illustrative outcomes of the potato case study. The panel was asked to assess whether the model and methodology satisfied its main objective, namely did it implement sustainability in operational farm management in line with the learning behavior of a farmer? This was done by questioning them and by group- and plenary discussions. Each model component, Product Flow Model, Sustainability Mapping, Sustainability Function Deployment and Sustainability Management Handbook, was discussed separately and also how the entire model is applied. The experts were asked for their opinion on relevance, feasibility and practicality of the approach. This has resulted in a list of strengths and weaknesses and also recommendations for improvement. The conclusion was that the model and methodology are supportive for translating and implementing sustainability in operational farm management and that, potentially, the approach corresponds to learning behavior, but this was not sufficiently justified.

Chapter 9 discussed the results of this study by revisiting the research questions. It was concluded that this study has succeeded in defining sustainability in operational terms. The unstructured, abstract goal 'a sustainable farm' can be made structured and concrete, while at the same time the management scope in time and space is reduced to the basic unit of operation. The model and methodology assure sustainability at the operational management level. Because a generic modeling approach was followed, the farmer is not prescribed what he should do, but he is supported in defining his own management rules. In this way, he is enabled to express and develop his vision, intentions and values in decision-making. It was made plausible that the model and methodology also enable the farmer to improve decision-making, but a more decisive statement can only be made after doing more testing in practice. It was argued that the concept of ecological production is a good candidate for sustainable agricultural production and that it corresponds to a design-oriented approach. The hypothesis was made that ecological production could be further improved by using this model and methodology, because it supports the principles of preventive and recycling management. It was indicated that the results of this study will become very relevant because of the current trend of organizing agricultural production in chains and networks, in which transparent communication plays an important role and has to be made verifiable by certification. Further research should be related to this emerging trend.

Samenvatting

Duurzame landbouw is belangrijk om na te streven, maar het is niet eenvoudig. Wanneer het niet wordt vertaald naar de praktijk, blijft het een vage doelstelling en kun je er eigenlijk niets mee. Dit proefschrift wil een bijdrage leveren aan het toepasbaar maken van het begrip duurzaamheid op het niveau van het boerenbedrijf. De centrale onderzoeksvraag richtte zich op de vraag hoe duurzaamheid kan worden ingebouwd in de operationele bedrijfsvoering van een gemengd ecologisch bedrijf. Daarvoor is eerst een grondige bureaustudie uitgevoerd inzake ideeën, interpretaties en methodologieën inzake duurzame ontwikkeling. Wat is het? Hoe kan het worden geïmplementeerd? Wat moet er gebeuren wanneer van boeren verwacht wordt om ervaren te worden in het maken van beslissingen die leiden tot duurzame ontwikkeling van hun bedrijf? Hiervoor is een modelleerbenadering gebruikt om de benodigde, relevante informatie te structureren en te ordenen. Het model kan worden gezien als een ondersteuning in het maken van beslissingen zodat de gevolgen van deze beslissingen leiden tot een duurzame ontwikkeling van het bedrijf.

Hoofdstuk 2 maakte duidelijk dat landbouw essentieel is voor de kwaliteit van leven en daarom de hele maatschappij aan gaat. De verhouding tussen landbouw en maatschappij is echter langzamerhand ernstig verstoord geraakt door problemen, veroorzaakt door intensieve manieren van produceren. Dit hoofdstuk maakte duidelijk waarom een oplossing gevonden kan worden door integratie van harde en zachte parameters in het maken van beslissingen. Is het mogelijk om zachte zaken zoals visie, intenties en waarden op een gelijk gewogen manier mee te nemen in overwegingen aangaande bedrijfseconomie en -management? Er werd gevonden dat duurzame landbouw kan worden gezien als een integrale oplossing voor ecologische, economische en sociale problemen. Tevens werd geconcludeerd dat duurzame ontwikkeling kan worden gezien als een dynamisch ontwerpproces in een continu veranderende omgeving. Het ontwerpproces moet zich richten op het ontwikkelen en onderhouden van het aanpassingvermogen aan die omgeving dat aanwezig is in natuurlijke hulpbronnen. Daarom speelt de boer, als menselijke factor, een belangrijke rol in het geheel. Dat leidde tot het combineren van relevante concepten uit de wetenschappelijke literatuur over management en sociologie. Vervolgens eindigde dit hoofdstuk met het presenteren van een drie-fase-methodologie voor het ontwerpen van duurzame bedrijfssystemen, namelijk (i) onderhandeling met de omgeving, (ii) heuristisch oplossen van problemen en (iii) operationele controle. Deze bevindingen fungeerden als uitgangspunten voor het definiëren van het informatiemodel, dat nodig was om een antwoord te vinden op de onderzoeksvraag.

Hoofdstuk 3 richtte zich op de huidige discussie over de voor- en nadelen van geïntegreerde en ecologische landbouw. Wat zijn de daarmee verbonden eigenschappen en hoe zit het met de daaraan gerelateerde behoeften van de boer? Allereerst werd productie-ecologie, dat kan worden gezien als het algemeen verenigende concept achter geïntegreerde landbouw, besproken. De belangrijkste conclusie was dat dit concept zich richt op input-efficiency. In dit concept zijn omgeving en natuur sluitpost op de begroting. De 'stof-input-stof-output-verhouding' wordt sterk benadrukt in het maken van beslissingen, bedrijfsmanagement en onderzoeks- of voorlichtingsprogramma's. Het andere concept, ecologische productie, geeft prioriteit aan de omgeving en de natuur en beschouwt bedrijfseconomie als sluitpost. Dat betekent niet dat ecologische landbouw niet economisch rendabel zou zijn. De winstgevendheid van ecologische productie zit in ecologisering van de bedrijfseconomie. Duurzame ontwikkeling van ecologische landbouwsystemen zit in het management van cyclische, bedrijfsgebonden processen. Duurzame landbouw wordt gerealiseerd door het ontwikkelen van preventief management en het zorgdragen voor cyclische processen, die opgesloten liggen in bedrijfsgebonden, natuurlijke hulpbronnen. Deze vorm van management beschouwt het productiesysteem als een logistieke productketen. Dit is tevens het belangrijkste uitgangspunt voor het modelleren. De conclusie was dat ecologische productie beter voldoet aan de behoeften voor duurzame ontwikkeling. Productie-ecologie is vanwege zijn gecontroleerde, experimentele basis geschikt voor het verdiepen van kennis over gewassen en de daaraan gerelateerde opbrengstverbeteringen zonder toenemende belasting van de omgeving en de natuur. Op die manier blijven boeren echter wel erg afhankelijk synthetische middelen, voorlichting, onderzoeksinstituten en regeringsbeleid. Dit zal de managementvaardigheid van de boer en zijn bewustzijn van maatschappelijke behoeften niet vergroten.

Hoofdstuk 4 beschreef de ontwikkeling van een informatiesysteem dat boeren ondersteunt in het ontwerpen van duurzame bedrijven, gebaseerd op ecologische productieprincipes. Er werd een nieuwe modelleerbenadering gevolgd omdat bestaande modellen te specifiek zijn en niet overeenkomen met de werkelijkheid van het maken van beslissingen in de praktijk. Het informatiemodel bestaat uit een procesmodel en een datamodel. Het procesmodel is opgedeeld in verschillende sub-modellen. Het *Product Flow Model* representeert het productiesysteem als een logistieke keten of netwerk van processen en intermediaire producten. De *Sustainability Map* representeert de duurzaamheidsdoelen op een hiërarchische manier en koppelt ze met het Product Flow Model door het identificeren van relevante productenstroomcycli of -ketens. Deze koppelingen worden verder uitgewerkt door *Sustainability Function Deployment*, waarbij associaties tussen operaties en producteigenschappen worden gelegd. Tenslotte worden deze associaties vertaald in kritische controlepunten en bijbehorende werkinstructies in het *Sustainability Management Handbook*. Het datamodel is weergegeven in een entiteit-relatie diagram dat kan worden geïnstantieerd in een relationele database. Om de gegevens in de database in te voeren, te bekijken en te wijzigingen zijn een aantal computerprogramma's ontwikkeld. Dit maakt het mogelijk om het maken van beslissingen inzake duurzame ontwikkeling te evalueren en te verbeteren. De conclusie was dat het informatiesysteem (i) de boer ondersteunt in het expliciet maken van zijn visies, intenties en waarden, (ii) dat het aansluit bij het principe van heuristisch probleem oplossen en (iii) dat duurzaamheid wordt geborgd in zijn operationele management. Daarnaast sluit het aan bij de ecologische productieprincipes van preventief en kringloopmanagement.

Terwijl de vorige hoofdstukken de theoretische basis van het model legden, beschreven de daarop volgende hoofdstukken enkele concrete gevalstudies die gezien kunnen worden als een test of duurzaamheid op deze manier in het operationele management ingebouwd kan worden.

Hoofdstuk 5 fungeerde als een inleiding tot de gevalstudies. Het beschreef in vogelvlucht het hele model en zijn sub-componenten, alsmede hoe deze gebruikt dienen te worden. Het ecologische bedrijfssysteem op de 'ir A.P. Minderhoudhoeve' is gebruikt voor deze praktijktest. De computerprogramma's, die waren ontwikkeld voor instantiatie, werden in dit hoofdstuk ook verder geïllustreerd en uitgelegd. De gevalstudies in de daaropvolgende hoofdstukken gingen meer gedetailleerd in op enkele aspecten van duurzaamheid en ecologische productie.

Hoofdstuk 6 beschreef een gevalstudie die het ontwikkelde model en de methodologie illustreerde, gericht op het economische aspect van duurzaamheid en toegepast op aardappelproductie. De studie liet zien hoe enkele doelen, die gerelateerd zijn aan bedrijfseconomie en kwaliteitsmanagement, vertaald kunnen worden in het operationele management. Er werd gedemonstreerd hoe ongestructureerde doelen vertaald kunnen worden in gestructureerde handelingen. Het Product Flow Model, in combinatie met Sustainability Mapping, lieten zien hoe ketens en kringlopen van producten kunnen worden geïdentificeerd, gekoppeld aan duurzaamheidsdoelen. Sustainability Function Deployent, in combinatie met het Sustainability Management Handbook, toonden hoe doelen verder kunnen worden geconcretiseerd en geborgd in het gehele productieproces. Het uiteindelijke resultaat is een voorbeeld van een handboek, met daarin enkele kritische controlepunten en werkinstructies aangaande aardappelproductie. Het handboek liet zien hoe verscheidene doelen bij elkaar komen in één operatie. In het bijzonder werd het ecologische productieprincipe van preventief management geïllustreerd, maar ook enkele voorbeelden van kringloopmanagement konden onderscheiden worden. Er werd geïllustreerd dat het implementeren van duurzaamheidsdoelen een zaak is van gezond verstand terwijl er ruimte open gelaten wordt voor persoonlijke waarden en keuzes.

Hoofdstuk 7 beschreef een gevalstudie die het ontwikkelde model en de methodologie illustreerde voor nutriëntenmanagement. De studie liet zien welke doelen geïdentificeerd kunnen worden en hoe ze gekoppeld kunnen worden met het primaire productieproces door het identificeren van ketens of kringlopen van productenstromen in het gehele Product Flow Model van het ecologische bedrijf op de ir. A.P. Minderhoudhoeve. Op die manier wordt kringloopmanagement, maar ook preventief management, ontwikkeld. Met name bij nutriëntenmanagement, is het hele productieproces betrokken en wordt het idee van het gemengde bedrijf erg relevant. Het betekent dat intermediaire producten, zoals mest of gewasresten, belangrijk worden voor management. Management moet zich richten op het grip krijgen op eigenschappen van deze producten. Interne hulpbronnen, in het bijzonder de bodem, spelen een belangrijke rol in dit proces. Om doelen te bereiken moeten biologische processen, gerelateerd aan bodemleven, gestimuleerd worden. Deze gevalstudie liet echter ook zien dat er nog grote kennishiaten zijn aangaande deze gewenste manier van nutriëntenmanagement. In verband hiermee werd geïllustreerd dat het model en de methodologie de boer kunnen helpen om zijn eigen heuristieken te ontwikkelen om hieraan te werken. Deze heuristieken zouden gebruikt kunnen worden als uitgangspunt voor verder onderzoek om een meer wetenschappelijke basis te ontwikkelen.

Hoofdstuk 8 evalueerde het model en de methodologie door expert validatie toe te passen. Gedurende een sessie van een halve dag werd een panel van experts geconfronteerd met het model en enkele illustratieve uitkomsten van de aardappel-gevalstudie. Het panel werd gevraagd om te bepalen of het model en de methodologie voldeed aan zijn hoofddoel, namelijk het implementeren van duurzaamheid in het operationeel management van een agrarisch bedrijf in lijn met het leergedrag van een boer. Dit werd uitgevoerd door hen te ondervragen en door middel van discussie in groepjes en plenair. Elke modelcomponent, Product Flow Model, Sustainability Mapping, Sustainability Function Deployment en het Sustainability Management Handbook, werd afzonderlijk bediscussieerd en daarnaast hoe het gehele model wordt toegepast. De experts werd gevraagd naar hun mening voor wat betreft relevantie, haalbaarheid en uitvoerbaarheid van de benadering. Dit heeft geresulteerd in een lijst met sterktes en zwaktes als ook aanbevelingen voor verbetering. De algemene conclusie was dat het model en de methodologie ondersteunen in het vertalen en implementeren van duurzaamheid in het operationele management van een agrarisch bedrijf en dat het in potentie aansluit bij het leergedrag van een boer, maar dit laatste kon niet voldoende aangetoond worden.

Hoofdstuk 9 bediscussieerde de resultaten van deze studie door de onderzoeksvragen opnieuw langs te lopen. Er werd geconcludeerd dat de studie erin is geslaagd om duurzaamheid te definiëren in operationele termen. Het ongestructureerde doel ‘een duurzaam bedrijf’ kan gestructureerd en concreet worden gemaakt, terwijl tegelijkertijd de management scope in de tijd en in de ruimte is gereduceerd tot de basale eenheid van de operatie. Het model en de methodologie borgen duurzaamheid op het operationele managementniveau. Omdat een generieke modelleerbenadering werd gevolgd, wordt de boer niet voorgeschreven wat hij moet doen, maar wordt hij ondersteund in het definiëren van zijn eigen management regels. Op die manier wordt hij in staat gesteld om zijn visies, intenties en waarden te ontwikkelen en tot uiting te brengen. Het is aannemelijk gemaakt het model en de methodologie de boer ook in staat stellen zijn management te verbeteren, maar een meer doorslaggevende uitspraak hierover kan gedaan worden door verder uittesten in de praktijk. Er werd voor gepleit dat het concept van ecologische productie een goede kandidaat is voor een duurzame agrarische productie en dat het overeenkomt met een ontwerpgerichte benadering. De hypothese werd gesteld dat ecologische productie in de praktijk nog verbeterd kan worden door dit model te gebruiken, omdat het de principes van preventief en kringloopmanagement ondersteunt. Aangegeven werd dat de uitkomsten van deze studie meer relevant zullen worden vanwege de huidige trend om agrarische productie meer te organiseren in ketens en netwerken, waarbij transparante communicatie een belangrijke rol speelt en verifieerbaar moet zijn. Vervolgonderzoek met dit model moet in het kader van deze trend gedaan worden.

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Author index

A

Abadi Ghadim, A. K. 93, 94, 95
Ackoff, R.L. 97
Almekinders, C.J.M. 35, 37, 63, 64, 65, 67, 76
Altieri, M.A. 63, 71, 74
Andert, E. P. 178, 179
Anthony, R.N. 44, 85
Armstrong, A. 93, 94, 95
Ascough, J. C. 93, 95
Atkinson, D. 93, 94, 95
Avison, D.E. 85, 86, 88, 89, 117

B

Baker, J. B. 95
Barbier, E.B. 22, 35, 68
Barry, D. A. J. 93, 95
Becking, R. G. 110, 111
Beers, G. 87, 101, 102, 187
Bertrand, J.W.M. 101
Beulens, A.J.M. 2, 85, 86, 192
Bhende, M. J. 93, 94, 95
Blaise, P. 93, 94, 95
Boersma, O. H. 168
Borst, W.N. 87
Bos, J.F.F.P. 23
Bottcher, A. B. 94, 95
Boulier, F. 94, 95, 96
Bouma, J. 60, 69, 168
Brennan, D. 94, 95
Brodahl, M. K. 93, 94, 95, 96
Buzan, T. 11, 121

C

Cacho, O. J. 93, 95
Checkland, P. 23, 41
Collinson, M. 25
Conway, G.R. 22, 35, 68
Cox, P.G. 97

D

Dalsgaard, J. P. T. 95
Darmody, B. 93
De Koeijer, T. J. 33, 37, 38, 60, 69
De Leeuw, A.C.J. 39, 41, 42, 43, 50, 55, 85, 101, 105, 106, 196
Deer Ascough, L. A. 93, 94, 95
Dent, J. B. 22
Droogers, P. 60

E

Ebbing, M. A. C. 179
Eekels, J. 50
Ellis, J. R. 94, 95
Elzas, M. S. 106, 188
Encyclopædia Britannica 160
Ewel, J.J. 70

F

Fitzgerald, G. 85, 86, 88, 89, 117
Fleury, P. 93
Fresco, L. O. 22, 35, 40, 47

G

Ghadim, A. K. A. 94, 95
Goewie, E. A. 2, 33, 50, 54, 60, 66, 71
Gooday, J. 94, 95
Goudriaan, J. 69
Graafland, J. J 32
Gray, A. W. 86, 94, 95
GRI 37

Grieve, R. 93
Gross, K... 141

H

Habets, A. S. J. 93, 95
Hack ten Broeke, M. J. D. 93, 95
Hacker, R. B. 93, 94, 95
Hall, A.D. 50
Hammer, D.K. 85
Hansen, J.W.. 37
Hardin, G.. 34
Harrison, S.R. 178, 179
Harvard, M. 94
Herrero, M. 93, 94, 95
Hirschheim, R....................................... 88
Hobbs, R.J. ... 35, 36, 63, 66, 69, 77, 78, 80
Hofstede, G.J. 32, 98
Holling, C.S..................... 36, 76, 195, 204
Horn, G. W. 93, 94, 95
Hutchings, N. J. 93, 94, 95

J

Jansen, M. H....................................... 102
Johnson, B.L... 37
Johnston, D. A. W. 93, 94
Jones, G. W. 94
Jongen, W. M. F. 111
Jordan, C.F. 72

K

Kamp, J.A.L.M.................................... 208
Keating, B.A.................................... 97, 98
Keen, P. G. W. 42, 44, 86, 106
Kerr, D.V.................................... 178, 179
Kim, K.-J.. 110
King, R. P. 59, 78, 93, 94, 95
Kingwell, R. S. 93, 94, 95
Kirk, G. J. 93, 94, 95
Kleijnen, J.P.C............................ 178, 179
Klein, H.K. 88
Knutson, R. D............................ 93, 94, 95
Koningsveld, H. 31, 33
Kouka, P. J. 93, 95
Krisna, J. 94
Kristensen, E. S. 95, 96
Kroonenberg, S.B.................................. 35
Kropff, M. J.. 61
Kubicki, A. 94

L

Lampkin, N. 33, 60
Lantinga, E. A. 2, 76, 212
Leaver, D.. 39, 70
Leeuwis, C. 39
Lefroy, E.C............................... 37, 63, 80
Lewandowski, A. 178
Lewis, P.J. 88, 89
Long, N. 40

M

Maas, J. G. V.............................. 110, 111
McCown, R.L...................... 93, 94, 97, 98
McSweeny, W. T. 94
Mettrick, H. 38
Miele, M.. 48
Milham, N. 94, 95
Miller, J. W. 101
Morton, S.R.. 35, 36, 63, 66, 69, 77, 78, 80
Mulder, J. A. 64, 65, 72

N

Neher, D.A. 63, 74, 76

O

Odum, E.P.. 66
OECD.. 30, 37
Oenema, O. 93, 95
Oficial, R. T. 95
Ohlmer, Bo...................................... 95, 96
Olesen, J. E.. 23

Olney, G. 93, 94, 95
Olney, G. R. 93, 94, 95
Oomen, G. J. M. 93, 95, 160, 212
Opschoor, J.B. 37, 70
Ören, T. I. 106

P

Pannell, D. J. 94, 97
Papy, F.. 105
Park, J. 35, 36, 37, 38
Parker, C. 85, 97
Passioura, J. B. 39
Pathak, S. M. 94
Peratec 73, 114
Pionke, H. B. 93, 94, 95
Powell, R. 94, 95
Preston White, K. 178, 179
Pretty, J. N. 47, 63, 68

Q

Qureshi, M.E. 178, 179

R

Rabbinge, R. 61
Röling, N. G. 22, 32, 34, 37, 41, 46, 69, 197
Roozenburg, N. F. M. 50
Rossing, W. A. H. 38, 50
Rotz, C. A. 93, 94, 95

S

Salinas, H. 93, 94, 95
Schiere, J. B. 22, 25, 34, 65, 68
Schilizzi, S. G. M. 94, 95, 96
Schoney, R. A. 93, 94, 95
Scott Morton, M. S. 42, 44, 86, 106
Seaton, R. A. F. 35, 36, 37, 38
Seligman, N. G. 98
Sells, J. E. 94, 95
SER 21, 32
Sevilla Guzmán, E. 69
Shaffer, M. J. 93, 94, 95, 96
Shah, P. 47, 63, 68
Shaner, W.W. 25, 40, 47
Sheng, G. 178, 179
Shewry, P. R. 93, 94, 95
Shomo, F. 93, 94, 95
Shortle, J. S. 94
Sibbald, A. R. 93, 95
Simon, H. A. 19, 21, 29, 35, 36, 37, 38, 39, 44, 48, 49, 50, 85, 86, 105, 106, 108
Sinclair, T. R. 98
Smeding, F.W. 45, 63, 73
Smeulders, S. 93, 95
Smith, J. U. 94, 95
Sonneveld, M.P.W. 60
Spedding, C. 40, 41
Standing, W. 93, 94
Steenkamp, J.E.B.M. 111
Stomph, T. J. 22, 23, 68
Stonehouse, D. P. 94, 95
Stroosnijder, L. 22, 26, 38
Swinton, S. M. 93, 94, 95

T

Tekelenburg, A. 22, 32
Thompson, D. 94, 95
Thornton, P. K. 93, 94, 95, 96

U

UN 37
UNCED 30
Uribe, J. V. 93, 94, 95

V

Van Bergeijk, J. 69
Van de Fliert, E. 73
Van de Ven, G.W.J. 23, 93, 94, 95
Van der Ploeg, J. D. 22, 30, 35, 36, 38, 40, 44, 46, 47, 48, 52, 62, 65, 68, 137

Van der Wal, K. 31, 34, 69
Van der Werff, P. A. 34, 63, 66, 168
Van Eijnatten, F. M. 39, 50, 53
Van Ittersum, M. K. 61
Van Laar, H. H. 69, 76
Van Mansvelt, J. D. 64, 65, 72
Van Nunen, J.A.E.E. 85, 86
Van Strien, P.J. 177
Van Trijp, J.C.M. 111
Velthof, G. L. 93, 95
Venkataram, J. V. 93, 94, 95
Vereijken, P. 23, 26, 38, 50
Vijverberg, A.J. 52

W

Wang, S. J. 93, 94, 95
Warren, J. 93, 94
Watson, C. A. 93, 94, 95
West, N. E. 68
Westphal, P. J. 22, 40, 47, 93, 95
Weterings, R. 37, 70
White, D. 179
WRR 22, 36, 38

X

Xin, JianNong 94, 95

Y

Yin, R.K. 21

Z

Zachariasse, L.C. 52
Zeigler, B. P. 105, 106

Curriculum Vitae

Jacques (Sjaak) Wolfert is geboren op 18 december 1970 te Dirksland en opgegroeid op een witlofteeltbedrijf, gecombineerd met kleinschalige akkerbouw en vollegrondsgroenteteelt. In 1990 behaalde hij het VWO-diploma aan de scholengemeenschap 'Guido de Bres' te Rotterdam. Daarna studeerde hij Landbouwplantenteelt met als specialisatie Gewasecofysiologie aan de toenmalige Landbouwuniversiteit Wageningen. In 1996 rondde hij *cum laude* deze studie af. Zijn afstudeervakken bestonden uit een combinatie van Theoretische Productie-ecologie en Informatica. Een stage vond plaats aan de Landbouwuniversiteit van Poznań in Polen onder toezicht van de toenmalige vakgroep Theoretische Productie-ecologie.

Aansluitend op zijn studie startte hij een promotie-onderzoek bij de toenmalige vakgroep Ecologische Landbouw en de vakgroep Informatica van de Landbouwuniversiteit Wageningen. Het onderzoek betrof het ontwerp van een model dat boeren ondersteunt in het ontwikkelen van een duurzaam bedrijf, toegepast op het gemengd ecologische bedrijf. Dit proefschrift is het resultaat hiervan. Het promotie-onderzoek was gekoppeld aan het gemengde bedrijfssystemenonderzoek op de ir. A.P. Minderhoudhoeve, een proefbedrijf van Wageningen Universiteit. In het kader hiervan was hij mede-organisator van de 'First International Workshop on Mixed Farming Systems in Europe', gehouden in 1998 te Dronten.

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