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Cropping system research

A framework based on a literature review

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Titel/Title in English:
Växtodlingssystemforskning – ett ramverk baserat på en litteraturstudie
Cropping system research – a framework based on a literature review

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Referat:
För utveckling och utvärdering av odlingssystem (OS) inom jordbruket behövs forskningsansatser som baseras på vetenskapliga utvärderingar av OS med mångfunktionella syften. Av denna anledning har SLU bildat en Odlingssystemkommitté vars uppdrag är att verka för en samordning av SLU:s resurser och insatser inom växtodlingssystem och skogsskötsel, som i sin tur initierat denna litteraturstudie av jordbrukets OS. För att OS-forskningen ska baseras på pågående vetenskaplig ämnesområdeskunskap föreslås ett ramverk. Först och främst ska det odlingssystem som avses studeras definieras i termer av vad det ska innefatta (t.ex. växt, mark, skötsel m.m.) vilka utdata som det ska utvärderas mot (t.ex. ekosystemtjänster) samt vilka faktorer som påvekar detta (t.ex. väder, priser etc.). Forskningen föreslås sedan kunna delas in i sex huvudkategorier, vilka dock i flera avseenden överlappar vandra. OS-forskningen föreslås syfta till (i) design av OS med relevans för (ii) odling i praktiken. Forskning inom (iii) markanvändning länkar denna forskning till alternativa OS (t.ex. inom skogskötsel) och omvärlds-faktorer. Till grund för alla utvärderingar utnyttjas forskning inom (iv) förutsägelser och skattningar samt (v) skalning, vars metodutveckling baseras på (vi) förståelse-forskning med ett starkt stöd i den vetenskapliga ämnesområdesforskningen (t.ex. växtpatologi, ekologi, marklära, växtfysiologi, växt-odlingslära m.m.). Studien baserar sig på en omfattande litteraturstudie där många citat tagits från andra publikationer och dokument. Dessa citat betraktas som arbetsmaterial som inte publiseras men kan erhållas vid förfrågan till författaren av denna rapport.

Summary:
In order to advance development and evaluation of cropping systems (CS) in agriculture, research efforts are required based on scientific evaluations of CS for multi-functional purposes. For this reason, SLU has formed a Cropping System Committee, tasked with coordinating SLU resources and efforts in crop cultivation systems and forest management. The Committee commissioned this review of the agricultural CS literature so that CS research could be based on current scientific knowledge. Based on the review, a framework is suggested. First, the CS under study should be defined in terms of what to include (e.g. plant, land, management, etc.), which outputs to evaluate (e.g. ecosystem services) and the factors influencing these outputs (e.g. weather, prices, etc.). CS research should then be divided into six main categories, which overlap in some respects: The main purpose of the research is proposed to be (i) the design of CS relevant to (ii) cultivation in practice. Using (iii) land use research CS is linked to alterntive CS (e.g. forestry) depending on e.g. socio-economic and environmental factors. All evaluations are based on research on (iv) predictions and assessments and (v) scaling, using methodological developments based on (vi) research on understanding that has strong support in subject areas concerned (e.g. plant pathology, ecology, field science, plant physiology, plant production, etc.). The comprehensive literature review presented in this report is to a large extent based on quotes taken from other publications and documents. Full details of these may be obtained upon request from the author.

Ämnesord: Design, praktik, markanvändning, modeller, skalning, förståelse-forskning
Keywords: Design, practice, land use, models, scaling, research on understanding
Omslagsfoto/Cover Photo: Pär Aronsson; Arable land and its interaction with surrounding ecosystems

Content

Table 1. Definitions of abbreviations and commonly used terms in this report

Abbreviations, terms	**Definition**
Innovation	Implementation of a scientifically tested CS design (often small-scale) in practical farming
Actors	Farmer, advisory service, authority, research, consumer
AHF	Agriculture, field horticulture and forestry
BAP	Best available practice
C	Carbon
CC	Climate change
CS	Cropping system
DSS	Decision support system
GM	Genetically modified (crop)
-K:	Indicates that the information is taken from a seminar in Krusenberg (Uppsala) in January 2015 organised by the SLU Cropping System Committee.
LCA	Life cycle assessment
LUC	Land use change
N	Nitrogen
NPP	Net primary production
P	Phosphorus
Disciplinary	Refers to disciplines outside science
Prototyping	Prototyping iterative process to implement CS in practical farming in the following steps: Farmers - Issue - Research - Effects - Design - Implement - Farmers - … and so on
SLU	Swedish University of Agricultural Sciences
SOC	Soil organic content
Subject area	Scientific discipline
VG region	Västra Götaland region
"*xxxxx*"	Denotes *exact* quotes from the literature (italics given in double inverted commas)
"xxxxx"	Denotes modified quotes from the literature (plain text given in double inverted commas)

Extended summary

The aim of this literature review was to help create a platform facilitating cropping system (CS) research at SLU. Although focusing on agriculture, it also sought to facilitate integration with corresponding research in horticulture (in open field) and forestry.

The definition of a cropping system (CS) is central to research on CS and may differ depending on the purpose of the research. The definition often includes a set of management procedures applied to a specifically treated area cultivated with crops. The purposes of a CS and what it should provide are basically covered by the concept of ecosystem services (provisioning, supportive, regulating and cultural services) in the short and long term. The design and activities of CS are framed by the demand that CS should lead to (or not prevent) environmental (ecological), economic and social sustainable land use. The objective of CS research is to design CS, generate scientific knowledge on CS used in practice and integrate CS in a land use perspective. The research should also aim at assessing, predicting and understanding effects on CS and those caused by CS. In this report, CS research is divided into six general research categories (design, practice, land use, predictions and assessments, scaling, understanding), aiming at adapting the structure of CS research to its objectives, methodologies and related subject-area research.

(i) *Design:* For CS, this is characterised by an optimisation problem where the situation is usually 'comparing apples with pears'. Strict scientific methodologies are combined with expert judgements, taking advantage of the extensive subject-area knowledge available. Modelling is a central activity in integrating different types of knowledge, but collaboration between different actors with very different skills requires a framework. Examples of questions raised within the design category might be: How is resilience of an agroecosystem defined? and What are the main steps in designing multi-crop CS?

(ii) *Practice*: CS research should be relevant to farming in practice. This requires work with relevant stakeholders and consideration of their interests (e.g. insurance, business, governing). CS research should combine knowledge of practical farming (e.g. rotations, tillage methods, databases) with empirical knowledge and methods for transfer of knowledge between science and practice (e.g. prototyping). The application of models requires a decision on whether to use simple or complex models, with or without expertise, to evaluate questions such as: What factors prevent the introduction of agroecology into agriculture?

(iii) *Land use:* This sets boundary conditions and influences the external drivers (inputs) to which CS must adapt (e.g. increased acreage for agriculture would influence soil types for CS). CS, in turn, influences land use (e.g. yield levels strongly influence the competitiveness of agriculture versus alternative land use). CS research needs to define scales (farm, regional, national, European, global) to properly determine the link to alternative land use. Questions to answer might be: How can outputs of CS be regulated by the spatial distribution of CS in a region?

(iv) *Predictions and assessments:* These involve extrapolations. Depending on available inputs and time frames, predictions have the character of forecasts, which can be evaluated for their reliability, or scenarios, which in most cases are never evaluated since only a few of them, if any, will materialise. The extrapolations are based on adopted analogies between empirical knowledge and the unknown situation, which results in use of different type of models (e.g. statistical or mechanistic models, or both). The need for CS models to integrate subject-specific sub-models requires the use of a flexible model framework that can be updated with new sub-models when available. The uncertainties in modelled outputs due to uncertainties in inputs, model applications and model structures form the basis for risk assessments. Predictions and assessments provide answers (often hypothetical) to questions such as: How do nitrogen (N) and carbon (C) dynamics change with new CS designs in the long term?

(v) *Scaling*: Data are mostly available on different scales than that to which they will be applied and therefore need to be adapted to the intended scale (by upscaling or downscaling). This requires extrapolation but, in comparison with predictions and assessments, statistical models are more often used, including concepts like the data aggregation effect, which is a measure providing answers to questions on e.g. the error arising from use of coarse-resolution soil data on the CS assessed. Scaling also concerns more mechanistic issues, such as: How do biodiversity and ecosystems depend on the scale studied?

(vi) *Understanding*: Measures for grading understanding are not well defined, but the ability to predict the outputs, given proper information on the prerequisites (inputs), is often regarded to be one of the clearest measures. This type of measure also links research on understanding to the predictions/assessments and scaling research categories, which in turn provide tools and information needed by the research on design, practice and land use. Transparent models and conceptual frameworks with high predictability can be analysed for their functioning and comparison with current scientific knowledge provides input to understanding. A central question is to understand which subject area models to include and how to integrate them to make predictions and assessments for CS. It is also critical to understand the reasons for uncertainties in the evaluations, both due to model concepts and the availability, precision and use of data. Model and database-specific issues, such as how to estimate parameter values or which databases are available at SLU, are treated in a separate section of this report.

Finally, an example of a CS design study is explored by applying some of the findings in this literature review to a study on designing crop rotations with optimal use of N, N losses and gross margins for "legumes in Västra Götaland" under current conditions. This is done by speculating about how different studies might have solved a number of questions: (a) How is the design procedure structured? (b) Predictions/assessments: How are crop rotations generated? How are N use, N losses and gross margins assessed? How are inputs achieved? (c) Scaling: How are scales defined and scaling assessed? (d) Understanding: How valid are the assessments (predictions)? What are the major scientific questions remaining to be resolved to achieve accurate assessments? (e) Practice: How is information/knowledge from practice used in the design? How is the design of crop rotation implemented in practice? (f) Land use: How do the projections of future cropland/grassland areas on global and continent scale influence areas of Sweden and the design of legume-based crop rotations in Västra Götaland? How does the design of legume-based crop rotations for Västra Götaland influence the projections of future cropland/grassland areas of Sweden?

The material used in this literature review is presented in a separate document (Appendix), which is structured in accordance with the main questions addressed by the different publications. The Appendix, which includes a number of direct citations from the publications reviewed and unpublished graphs from seminar presentations, is available on request.

In conclusion, this review showed that a considerable amount of work is needed to create a functional research platform for cropping systems. Although current CS designs are reasonably well adapted for their current purposes, the scientific basis and evaluations are still unclear. Increased knowledge and the use of scientifically based analytical methods are needed to enable optimisation of CS design when drivers (exogenous inputs, e.g. climate change and technological development) are changing, and when the purposes of, and constraints on, CS are altered (e.g. increased food supply and reduced environmental impact). The structure of the CS research proposed in this report would clarify the link between CS design optimised for this purpose and the subject-area scientific knowledge (e.g. GM crops) on which it is based. It would also clarify which methods based on empirical knowledge from practice that is still not verified scientifically. This study is a first attempt to structure CS research and did not aim to provide a final solution. Hence, further development of the framework is required.

1. Introduction

1.1 Background

The Swedish University of Agricultural Sciences (SLU) has the task of developing knowledge of biological natural resources and sustainable use and management of these. However, the scientific research on cropping systems (CS) is currently not well structured. There is a need to establish an approach where systems thinking, multi-functionality and sustainability are integrated into the analysis, design and evaluation of CS (SLU, 2015). For this reason, SLU has formed a Cropping System Committee tasked with coordination of SLU's resources and efforts on agricultural and open-land horticultural crop production systems and forest management (including research, education, infrastructure and collaboration).

The committee initiated a review to "*summarise the state of the art regarding research on the design and assessment of cropping systems*", and that would "*be useful for a team of researchers involved in a cropping system platform, in their research on (i) redesign and (ii) assessment (ex-ante; forecast; scenario) of cropping systems, considering the production of commodity and non-commodity ecosystem services in agriculture, horticulture, silviculture and associated border zones. The framework should be at the level of land use within Sweden and abroad*" (SLU, 2015).

SLU is not yet coordinating its extensive research and monitoring of agriculture so that these can be effectively linked to cropping system research. The reasons for this are uncertain, but some questions arise: Is the demand for CS research too low to justify organised coordination? Is there a lack of experts (i.e. researchers) that can integrate subject-area research at CS level? Have CS experts not received a sufficient mandate to utilise findings from subject-area research or are the methodologies not applicable in CS research? Are the experts not coordinated sufficiently, and if so, why? Are the experts governed by other and/or excessive short-term goal formulations and not available to answer the broader issues that usually characterise CS research? Does the disciplinary nature of crop and soil sciences within universities prevent the integration of knowledge and interdisciplinary and system-orientated approaches? and/or Is CS so complex and diverse that it is difficult to identify what should be included in research, making investments in the area unsafe? This literature review aimed at developing a structure for CS research that would support a continuous process of analyses and development of CS and to which CS research projects and administrative methods would contribute. The results are presented in two documents, this report and a separate appendix (available on request, see section 1.4, Method).

1.2 Structure

Cropping systems research is very extensive and no single subject area can cover all its parts. The way in which different research studies are related to each other and can utilise each other's results is therefore crucial. However, the connections are often unclear, partly because definitions and methodologies differ between disciplines. In an attempt to structure this review of CS research, the design of CS, where stakeholders and researchers collaborate, was set as the starting point. Design of practical cultivation can be carried out e.g. by means of common rules regarding how crops and management practices can be combined, and the extent to which they contribute to the desirable outputs of CS. The scientific knowledge should then be applied in planning cropping in practice, both in a tactical (e.g. determination of fertiliser regime) and a strategic context (e.g. climate change impacts on crops and scenarios for supply needs). This requires a methodology for making predictions (extrapolations) over time and enabling scaling (extrapolation) of information from one spatial resolution to another, which in turn may mean that the boundaries of the CS under study may change, and the CS in agriculture might interact with CS in horticulture or forestry in terms of land use. To make studies of CS in this context meaningful for each other, the CS first needs to be defined.

The structure of this report is based on a research category perspective aiming at describing CS research in relation to its objectives, methodologies and related subject-area research (Figure 1). CS studies are often difficult to strictly allocate to the six different research categories defined here, since they usually deal with issues where several of the categories are included simultaneously. First, however, it is necessary to define what is meant by cropping system (CS) from a systems perspective, i.e. what is included in the system, its boundary conditions, what it delivers and its functioning (see sub-section 'Definition' below).

Next, CS is examined from an application perspective, focusing on how CS can be structured so that its aims can be achieved (section 2.1, Design), and how this can be implemented in practice (section 2.2). On the larger spatial and social scales, CS of agriculture is integrated with alternative types of farming (section 2.3, Land use). Practice refers to various time scales from hours, days and individual years to decades and centuries, and spatial scales from field and farm level to watershed and regional, national and global level. In section 2.4, methodologies used to make Predictions/assessments (extrapolations), both in the near or longer term, are described. A special section is devoted to methodologies of extrapolation in space, for example, from field to regional scale (section 2.5, Scaling). Thereafter, CS is described in terms of the scientific issues concerning understanding that arise due to CS applications, which among other things include the development and testing of the models that are used for the applications (section 2.6, Understanding).

Models are used in many different contexts with regard to CS, and studies focused on these are treated separately (section "Models and databases" in the Appendix).

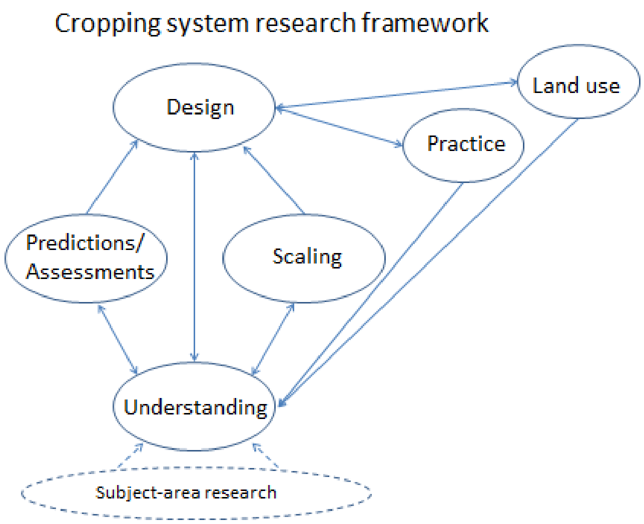


Figure 1.
The sections of this study are structured in terms of six research categories:
(Number refers to section in Appendix C)
(1) Design of cropping systems (CS).
(2) CS in practical farming.
(3) Land use (interaction with alternative CS).
(4) Predictions and assessments of how drivers and properties affect CS (mainly extrapolation over time).
(5) Scaling (mainly over space).
(6) Understanding the functioning of CS.

Lines represent main flows of information in terms of models, rules, data etc.
CS research is focused on Design with the aim of being relevant for Practice and Land use, and provides feedback to Understanding. Understanding, which is strongly linked to subject-area research, provides Predictions/Assessments and Scaling methodologies to be used in Design.

Examples of cropping system research issues

Below, the kind of issues that can be addressed within each research category are exemplified by formulating the main research questions in some studies (although most studies fall into more than one category). Methodology, results and conclusions from these studies are described in the Appendix. The Appendix also reviews many more studies, the research questions of which can be found in the section "Contents of the Appendix" (Chapter 6).

CS definition

-How large are the differences between subclasses within conventional farming compared with organic CS (Gosme et al. 2012)?

-To what factors (e.g. area or yield) can estimates of environmental impacts be related when comparing organic and conventional CS (Kirchmann et al. 2016)?

Design

-How can transparent agronomy models supplement empirical prototyping (Rossing et al. 1997)?

-How can decision support systems (DSS) expand the concept space of participatory design (Cerf et al. 2012)?

-How can the successional stages from native grassland through annual cropping to a steady state grain-legume intercropping system be categorised (Crews et al. 2016)?

Practice

-What are the effects of managing disease on oilseed rape (Hossard et al. 2013)?

-How can local knowledge and biophysical modelling be used to choose measures to reduce N losses (Dupas et al. 2015)?

-Which definitions of extreme weather can form the basis for insurance against crop losses (de Toro et al. 2015)?

-How can the manager be mimicked by models (Moore et al. 2014)?

Land use

-How are effects of climate and socio-economic changes on the use of Swedish agricultural land modelled (Eckersten et al. 2007a)?

-Can the temporal trends and large-scale spatial patterns in global agricultural land use be understood from simplified socio-economic processes at national level (Engström et al. 2016)?

-How can outputs of CS be regulated by the spatial distribution of CS in a region (Chopin et al. 2015)?

Predictions/assessments

-How can the effects of landscape composition on the predator species Carabids be predicted (Legrand et al. 2011)?

-Is there a critical threshold of organic fields in a region above which pathogen outbreaks are more likely to occur (Gosme et al. 2012)?

-Can agriculture reduce its nutrient loads to the Baltic Sea to meet environmental targets, and still remain at its current production levels (Blombäck et al. 2013)?

-How can the crop requirements and improved utilisation of N be predicted (Jeuffroy et al. 2013)?

-How can models be used to evaluate best choices of cultivars (Jeuffroy et al. 2014)?

-What do scenario assessments predict for future farm N losses and farm gross incomes for different sites in Europe (Wolf et al. 2015)?

-How can a flexible platform for simulating farming and agro-ecosystems be built (Bergez et al. 2013)?

-How can the degree to which legumes contribute to greater sustainability of cropping systems be assessed (Reckling et al. 2016a)?

Scaling

-What is the error from using coarse-resolution weather data inputs when assessing regional crop production (Hoffman et al. 2015; Zhao et al. 2015)?

-How are different measures for comparing organic and conventional CS related to scales (Kirchmann et al. 2016)?

-How do biodiversity and ecosystem services depend on the scale under study (Winqvist et al. 2012)?

Understanding

-What are the effects of N fertilisation on cereal-legume intercrops (Pelzer et al. 2014)?

-Which factors influence the choice of winter wheat management plans (Nave et al. 2013)?

-How have legume-producing systems evolved since 1950 (Voisin et al. 2014)?

-What are the reasons for declining grain legume production in Europe (Zander et al. 2016)?

1.3 Objectives

Cropping system objectives

The concept of ecosystem services includes the majority of the purposes of CS and is often split up into provisioning, supporting, regulating and cultural services. The management of a CS should promote its ability to deliver ecosystem services in the long term (SLU, 2015) to be used in the evaluation of ecological sustainability. To also provide the basis for an evaluation that includes economic and social sustainability, there is a need to assess CS as part of a wider community and in interaction with land use.

Cropping system research objectives

Research on cropping systems aims to: (i) contribute to the design of sustainable and applicable CS, and (ii) combine scientific knowledge applied in practice and knowledge from practical farming used in science to adapt CS to its goals (e.g. production and environmental goals). This requires CS research to also aim to (iii) integrate CS in a land use perspective. In addition, CS research should (iv) evaluate and predict how different structural changes (design), management factors and changes in environmental factors can alter the outputs of CS and its impact on the surrounding environment, which requires CS research to aim at: (v) understanding why various driving factors (weather, prices, farming, etc.) cause a certain impact on the CS, depending on its characteristics. SLU (2015) emphasised the importance of all these issues by proposing that CS research should develop knowledge of how various factors interact to generate ecosystem services, focusing on the interaction between the genetic material, the biotic and abiotic environment and human efforts to control production, which is summarised thus "*the aim of cropping systems research is to design, develop, assess and stimulate innovation of multifunctional and sustainable cropping systems*".

The aim of this review

The aim of this review was to describe and structure the current state of knowledge in cropping systems research and strengthen the basis for SLU’s research on this subject. This should provide opportunities to integrate CS research within agriculture, horticulture (open-field) and forestry (AHF) into a single platform in which there are opportunities to take advantage of skills and conceptual knowledge within AHF and, by extension, link CS research to land use research on a larger scale. The review covered a very large area of research, but did not set out to be comprehensive. However, based on the findings, a framework was developed for possible structuring of CS research and a step towards a CS platform. A large number of related studies (probably most of them) undoubtedly escaped our attention, but we believe that those studies can be fitted into the structure built up based on the studies analysed.

1.4 Method

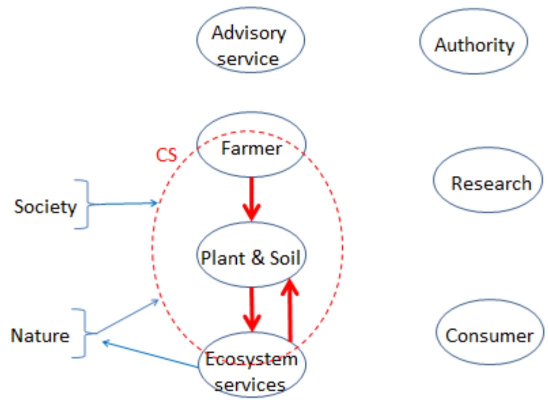
This review is based on summaries and analyses of scientific articles and reports from Web of Science and Universities. In addition, information from presentations at scientific conferences was used. CS research is extensive and it is difficult to find a unique structure for describing all its parts. Therefore, this report sometimes includes almost verbatim quotes from the different sources (with the aim of not distorting the original meaning), allocated into the more general research category structure given above. These analysis and quotes are presented primarily in a separate Appendix that is un-published, but is available on request. Within each research category in the Appendix, the text is structured by the questions that each study addresses (see Chapter 6, Contents of the Appendix). All references, including those in the Appendix, are listed at the end of this report. CS research is very extensive and no single subject area can cover all its parts.

2. Cropping system research

The framework devised here for CS intends to strengthen the base for SLU's main activities in the field of cropping, i.e. research, education, environmental monitoring and communication with cropping in practical agriculture. Based on a compilation of the various CS studies presented in the Appendix, this review sought to provide a picture of past and current CS research.

2.0 Definition of CS

A definition of the cropping system (CS) is the starting point for any analysis of it. The concept of CS often includes the land farmed, crop rotation (plants and their distribution in space and time) and measures to control CS (e.g. Sebillotte 1974; Fogelfors 2015; SLU 2015). A common general definition of a CS is that it consists of a set of management procedures applied to a specific, uniformly treated area, which may be a field, part of a field or several associated fields and even non-cultivated areas associated with the fields. The CS includes crops, crop sequence and crop and soil management (e.g. tillage, sowing, fertilisation, plant protection and harvest) for each crop in the crop sequence (Sebillotte 1974).



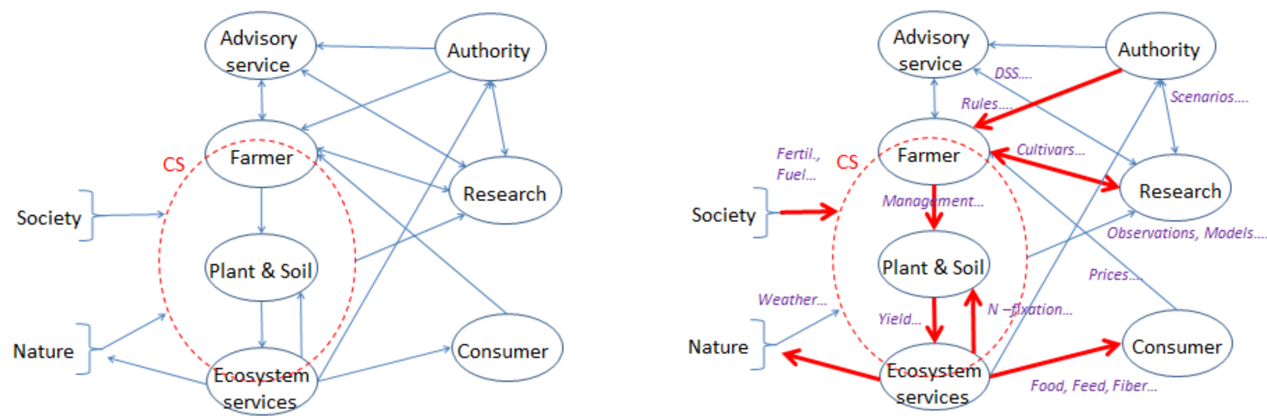


Figure 2.
Definition of cropping system (CS):
Upper left: CS includes objects and actors depending on its definition.
Lower left: There are several links between objects and actors.
Lower right: Which objects, actors and links should be included in CS research?

A CS is defined by its boundaries in terms of the factors that affect it (inputs; e.g. climate) and by CS-generated factors that affect the surroundings (outputs, e.g. crop yield and greenhouse gas (GHG) emissions). A complete definition of CS requires a clear specification of time and space, which is needed e.g. for comparisons of different CS. For example, if nutrient leaching (an output) is expressed per unit land area or per unit yield, then the delimitation of the surroundings is different, being a limited regional area and a world market, respectively (Kirchmann et al. 2016).

Some inputs that influence CS cannot be changed by CS, and CS has to adapt to them, e.g. inputs from the external world (nature, society in general and actors). These are called 'Inputs-exogenous' in our framework. Other inputs can be controlled by the CS itself (Inputs-endogenous; e.g. fertilisation). The results of CS activities (Outputs) ultimately depend on what the CS consists of (components) and how it works (functions), here called 'Contents'. Evaluations of the Outputs of CS are made in relation to the objectives it aims to achieve (Objective criteria), such as high yield.

Objective-criteria	*Inputs-exogenous*	*Inputs-endogenous*	*Contents*	*Output-endogenous*	*Output-exogenous*

There are five main actors (farmer, advisor, authority, researcher, consumer) (Figure 2) that interact with CS, four of which belong to the external world, while Farmer partly belongs to CS (e.g. in terms of management). Plants and soil in the field belong fully to the CS. The ecosystem services that the CS generates are partly included in the CS itself (e.g. yield and N fixation) while others are not (e.g. some quality concepts for nature and consumers, such as GHG emissions and food security at national or global scale). The ecosystem services that are part of CS can be both output from CS and input to it (i.e. Inputs-endogenous then become equal to Output-endogenous, e.g. N fixation).

The system boundary for CS varies depending on the questions to be answered. Studies with the intention of optimising the crop rotation (e.g. minimising GHG emissions and maximising yield) have a much narrower definition than, when the intention is to study the interaction between CS and the rest of society including consumer demand. This is exemplified by Preissel et al. (2015) in gross margin assessments of legume-based cropping systems for successively larger spatial and temporal scales, from single crop, crop sequence, crop rotation including all crops in a cyclic crop sequence and fallows, up to cropping systems also including costs and subsidies at farm level. In other studies, CS is defined instead by the physical and biological processes and services considered (often ecosystem services; e.g. Gaba et al. 2015), from which the corresponding spatial and temporal boundaries are derived.

Goal completion

The purpose of CS design is to achieve certain goals. Inputs and outputs may be desirable, unwanted or neither of these. For agro-ecological CS, the goals have been formulated in terms of seven principles: adapting to local environments, providing favourable soil conditions, diversifying species and genetic resources, enhancing beneficial biological interactions, minimising use and loss of water and energy, minimising use of non-renewable external resources, and maximising use of farmers' knowledge and skills (Watts. 2015). This goal setting relates to both external (exogenous) and internal (endogenous) driving factors and internal and external outputs. For other types of CS alternative objectives are the focus and alternative methods are used to reach the objectives. For example, conventional and organic CS in many cases have common goals, e.g. high production, low nutrient leaching, high profitability etc., but weight the importance of these differently, as well as referring to different scales (e.g. yields in the near future and soil quality in the far future).

To determine whether the goals are achieved or not, they need to be expressed in measurable quantities. CS can be characterised in terms of many factors. For example, on the basis of only 10 studies, 44 factors can be allocated to the categories biophysical conditions, management/inputs, outputs, farm/farmer and socio-economic conditions (see Appendix). Consequently, it is difficult to define a common template that allows comparison of different CS. Nevertheless, comparisons must be made in cases where there are alternative ways to crop a given land area. When such comparisons occur, they are generally made by means of a reduced number of evaluation factors. For example, Legrand et al. (2011) compared four CS in terms of number of management operations for cultivator, ploughing, sowing, molluscicide, insecticide and mechanical weeding needed during a three-year period. Behaderovic (2016, student work) compared the development of organic and conventional crop production systems over time in Sweden by means of rating ecosystem services as: provisioning (food, fuel, fibre, animal feed), supportive (pollination, nitrogen efficiency, detoxification, decomposition of organic matter), regulating (carbon sequestration, biological control, environmental impact) and cultural services (recreational value). In a study on how small farmers in Mexico have adapted to and prepared for climate challenge, Altieri et al. (2015) used 14 indicators (identified by farmers) to evaluate their capacity to respond to climate disturbances. The indicators were: "*soil texture, soil cover, living barriers, conservation tillage, water management, soil organic management, terraces, % food produced on farm, independence of external inputs, seed banks, animal forage, crop diversity and protected areas*".

All these different evaluation opportunities can be combined in many different ways and several different types of CS are mentioned in various studies, for example: Organic, Integrated, Direct drilling or Conventional (Legrand et al. 2011); Sustainable intensification or Ecological intensification (Bommarco et al. 2013; Bartomeus et al. 2014); Traditional agroecosystem, Modern industrial system, Organic/Ecological farm or Natural systems agriculture (Vendermeer ed. 2011); Agroecology, Organic, Permaculture, Sustainable crop intensification, Climate-smart, Traditional or IPM (Ponti et al., 2007; Aliteri et al. 2015; Watts ed. 2015). In addition, within a specific type of CS further characterisation can be made, e.g. Gaba et al. (2015) divided multiple cropping systems into synchrony crops at a specific location, asynchrony crops at a certain location or synchrony crops at different locations.

2.1 Design

Design aims to develop CS to enhance desirable and mitigate undesired inputs, outputs and changes of CS. Design of CS can be based on rigorous scientific methodology in which the proposed changes of CS can be derived transparently from scientifically proven functions of CS and the desirable goals of CS. Design can also be based on proposals in which a clear inference to scientific knowledge is lacking. In most cases, however, design is made by combining these two methodologies, since the design of a CS aims at achieving the best possible results in practice. It is of key interest for the research to investigate the extent to which this design is based on the respective methodology.

Outputs

Design of crop rotations involves a complex optimisation problem which, figuratively speaking, involves 'comparing apples with pears'. Should the different variables be presented separately, or combined in a single entity, such as an index or a "monetary value"? Adaptation of "indicators" to stakeholder needs has been mentioned as a problem (e.g. as regards soil biodiversity; Clermont-Dauphin et al. 2014). It is reasonable that the way in which the results are presented is determined by those who will use the values, which in practical contexts would be stakeholders and in scientific contexts researchers. The users' interpretation of the outputs can be difficult and output presentations would then require adjustments, both from the computing side (e.g. more concrete outputs) and the user side (e.g. education). A third option is to use specialists (e.g. an expert group) who can translate information between the computational and user sides. These problems become large in the design of CS as a whole, and only using transparent methods is probably an unattainable optimum goal when aiming at achieving the best possible CS design for practical agriculture.

Modelling

A constantly recurring question regarding the modelling of CS is the degree to which the system dynamics explicitly need to be taken into account when evaluating the functioning of the CS. For example, variations in weather conditions, both within and between seasons, affect the relationship between gross margin and N losses, and thus affect the evaluation of which crop rotation would be optimal. Current models (theories) for generating crop rotations often lack transparent methods for these evaluations (e.g. Reckling et al. 2016a), and they are instead evaluated by expert judgment.

A central part of the CS platform is tools and methodologies that can make use of the extensive subject-area knowledge on parts of the CS that is available in the scientific community in terms of validated models, and combining this scientific knowledge with expert knowledge. In many models for generating rotations (e.g. ROTOR, Bachinger and Zander 2007; PRACT, Naudin et al. 2015; Reckling et al. 2016a etc.), relatively simple indices are estimated to evaluate parts of the system, whereas in other approaches dynamic process-based models are used to estimate biophysical factors that form the basis for the design of CS (e.g. SOILNDB, Johnsson et al. 2002; DSSAT, Jones et al. 2003; APSIM, Keating et al. 2003; MONICA, Nendel et al. 2011; Colnenne-David and Doré 2014). The choice of method to a large extent depends on assumptions about which method is least uncertain, which in turn depends on the relationship between uncertainties in inputs and uncertainties in model concepts and applications (e.g. Montesino-San Martin, 2014).

Framework

For the cooperation between different actors with very different skills, a framework for design is needed. Various studies have identified various stages in the design process, which often complement each other. As regards a general order in those stages, although not found in any single study, an example might be as follows: Step (i) is to diagnose situations and stakeholders that the design concerns (e.g. Cerf et al. 2012). (ii) Thereafter, problems are formulated (e.g.

Rossing et al. 1997), as are the goals of the outputs that CS should generate. (iii) Restrictions to the design are defined and ranked (Colnenne-David and Doré 2014). Step (iv) is to generate different CS, which can be done with methodologies ranging from pure expert judgements to fully transparent methods where alternative CS are evaluated for the specified conditions. In the latter case, a structured collection of input data is used to feed transparent scientific topics models (e.g. Rossing et al. 1997; Bergez et al. 2010; Naudin et al. 2015). Finally, (v) the CS generated is evaluated against the goals using transparent methodologies (which can also be used to evaluate the CS proposed by expert judgements). There are usually more goals to be achieved than those explicitly expressed by the transparent methods, and an overall subjective evaluation of all participating players is probably a necessary last step.

2.2 Practice

It is the task of the university of agricultural sciences to solve agriculture-related problems that are raised by society (SLU 2015) and CS research should be relevant to cropping in practice (i.e. to farmers, advisory services, authorities and consumers). Because of this, the different actors need to collaborate. This means that scientific knowledge about CS needs to be translated into practical farming, both for a small scale in time and space (e.g. a fertilisation schedule for a particular field in the coming year) and for a larger scale (e.g. in the longer term, to reduce nutrient leaching from a basin).

CS research needs to address both the scientific issues that are important for cropping in practice and the knowledge from practical farming that is of interest to science. This calls for the development of methods on how to use empirical knowledge on cropping in CS research. Moreover, methods for the transfer of knowledge between science and practice need to be described, for example, the implementation of new CS into practical farming can be achieved in accordance with the concept of "prototyping" (Vereijken 1997). Researchers from different research areas also need to develop their competence to involve stakeholders in the research process, e.g. in participatory learning and action research (SLU 2015), or as already formulated by Sebillote (1990): "*There is a need for agronomists to take an interest in the decisions made by farmers*".

Cooperation with practice

The interests of practice can be taken into account for example by a company defining the issues that the optimisation of crop rotations should solve and the prerequisites for this optimisation (e.g. Li et al. 2015). On a more strategic level, the relevant authorities can exploit research models (including experts) to explore options for land use and farming practices that achieve targets on both production and environmental impact (e.g. Blombäck et al. 2013). In this type of project, CS research should contribute methodologies such as soil and crop models, optimisation models, DSS, etc., as well as the expertise to use these methods in a scientific way for practical purposes.

CS research can benefit from practice, for instance by utilising large datasets from practice to study how well the strict scientific theories and models simulate cropping in practice. Examples of such datasets are regular phenological observations by the Swedish Board of Agriculture (Jordbruksverket) pest control services (e.g. Eckersten and Kornher 2012) and registration of deoxynivalenol (DON) levels in harvested grain delivered to Lantmännen collection centres (e.g. Börjesson et al. 2015; Persson et al. 2017b). Knowledge from practice also needs to be utilised by CS research, for example with regard to the design of CS and crop rotation (e.g. Li et al. 2015; Reckling et al. 2016b), to find the relevant practical issues that need to be analysed scientifically.

The need by farmers to adapt to ongoing climate change is another example of when practice generates questions for CS research. Signs and predictions of future greater variations in weather have created a need among farmers to take out insurance against crop losses due to extreme weather, which in turn has created a need to evaluate to what extent harvest losses are due to bad weather (e.g. de Toro et al. 2015) rather than other factors, e.g. poor management.

The first step in cooperation between research and practice is to define the roles of all actors. For example, through role play stakeholders can mimic a public authority, farmers can mimic implementation in practice and researchers can try to mimic nature's response to proposed agricultural measures (including CS design). In one study, a special input/output group was used to communicate information between modellers and stakeholders playing these roles (Blombäck et al. 2013). In other studies, the concept of "Dialogical CS design" (diagnosis of uses and characterisation of users' use of existing tools; Cerf et al. 2012) has been used to include stakeholder knowledge in the design process.

Modelling

Process-based modelling is a commonly used tool in strategic planning because the extensive extrapolations often needed in these cases is best based on current knowledge of basic functioning of the CS. However, other methods such as spatial analogies (e.g. with regard to the effects of climate change, cf. Eckersten et al. 2007a) and conceptual modelling (e.g. Crews et al. 2016) are also commonly used. There are a huge number of alternative models and users, and to obtain a measure of uncertainty several applications are needed for each extrapolation study (e.g. for crop yields; cf. Palosuo et al. 2011; Asseng et al. 2013). These in turn provide the basis for risk assessments (e.g. for national crop and milk production; see Eckersten et al. 2015). It is difficult for stakeholders to interpret risk assessment measures, and analysis of how much of the variation is due to uncertainties in the assessment methods (i.e. their predictability) or to "natural" variation (i.e. how the system works) requires the assistance of an expert group.

For application of scientific knowledge of CS in practical farming in the short term (within a season or a few years ahead), tools for tactical planning are needed. There are models of different complexity, from relatively simple spreadsheets for gross margin calculations to comprehensive decision support system (DSS) programmes that include detailed process-based dynamic weather and management-driven models (e.g. APSIM 2016), or statistics-based models. Those predict-tions are usually linked to online observations. Depending on the CS outputs to be predicted, different models are used.

There is great demand from practical agriculture for operational models with high predictability. CS research needs to develop a framework in which the use of these models is combined in a desirable manner for practical farming. This means that CS research should be able to answer questions about when simple models based on e.g. temperature sums, such as those used for forecasts of the timing of the harvest of forage or pest control, are sufficient for the farmer's needs, or when more complex models that consider the interaction between different variables are needed. These predictions should be combined with the need for, and possibilities of, obtaining observed data from practical cultivation. To improve the use of models in practical agriculture, there is a need for continuous development of methodologies. Several decades ago, this was formulated as: "*agronomists must supply diagnostic and decision aid tools, and methods for analysing the history of cultivated fields are needed*" (Sebillote, 1990).

2.3 Land use

For larger scales in space, including not only cropped agricultural land, CS for arable crops interact with the corresponding systems for forestry and field horticulture. Some land use requirements (e.g. reduced nutrient leaching) may provide reason to replace CS for crops with an alternative land use (e.g. forestry). Similarly, an alternative land use is an outer boundary condition that CS in agriculture must adapt to e.g. cases where the yields are low and profit-ability is not high enough to be competitive with alternative land use (e.g. urbanisation). Profitability is affected by world market prices and farmers' land use is therefore linked to agriculture globally.

Modelling

Land use depends on a complex interaction between natural and socio-economic factors, from local to global level, due to the influence of "*multiple global drivers, turnover times of key ecological and social processes, connections between individual actions, institutional responses, and ecological changes*" (Engström 2016). Short-term future perspective land use modelling is often based on estimations of profitability, in which prices are input (e.g. ACCELERATES models; Abildtrup et al. 2006). In a longer perspective, land use modelling is often based on principles of a more physical character, such as the balance between plant production (e.g. food supply) and the need for food (consumption, demand) (e.g. ATEAM model; Rounsevell et al. 2005). This principle is also used in the PLUM (parsimonious land-use) model (Engström et al. 2016), which is based on the assumption that consumption and production of food are balanced on a global level (or set equal to over- or underproduction, if that is the case). Corresponding balances are calculated for each nation, and imbalances are first adjusted by exports and imports of food products between countries, and then by adjusting crop land area so as to achieve a global balance. Engström et al. (2016) also list a number of other land use change (LUC) models on the global scale, using alternative approaches to mimic the use of agricultural land, e.g. including interactions between society, the biosphere and the climate system or integration of the use of water for food production in global food security. Bioenergy is also increasingly considered a driver of global LUC assessments and due to the great complexity of land use functioning a variety of methodological approaches is applied, with some models being neither spatially explicit nor dynamic.

Cropping system link to land use

In simulations of global land use, calculations of yields are crucial and influence the land area needed for cropping. This influences CS and vice versa. It is important to identify this link for CS research and how to handle it, for instance to determine how assessments of cropping systems would be influenced if LUC models predicted less cereal land area in Sweden in coming years, e.g. as projected in one of two possible global LUC scenarios for 2050 fulfilling the requirement of global food supply (Engström et al. 2016) and a proposed planetary boundary of maximum cropland area (15% of total ice-free land area; Rockström et al. 2009). This would possibly have considerably more impact than how changes to cropping systems in Sweden would influence global land use modelling. How to consider those links between CS research and land use on a larger scale depends on how the boundaries of CS are defined.

2.4 Predictions/assessments

A fundamental basis for the design of CS and for linking CS research to practice is that there are ways to make predictions and assessments. Predictions aim to compute something for the future, while assessments aim to give value to something that might have happened but has not been observed. Both predictions and assessments involve extrapolations. The generalisations assumed can be regarded as based on analogies, e.g. something known from experience is often assumed to remain the same in the extrapolated situation. The analogy is applied on different levels of integration of the functions of the system, e.g. on a management level where yield is assumed to be a function of N fertilisation schedule. Alternatively, the analogy is applied on an eco-physiological process level where yield is a function of growth rate, which in turn is a function of plant N uptake, which in turn depends on fertilisation, and so on. Research aiming at increased understanding contributes models based on universal functions, providing predictions that are understandable from current knowledge of the system. Those predictions most often assess effects of many different growing conditions that are not covered by the relatively few physical experiments that are available.

Specific questions that need to be answered concerning predictions and assessments of CS are that they should be relevant to design and practice, such as how well different theories/models predict the impacts of various factors on CS, and the benefit of model use for design and practice. There is also a need to examine the contexts in which different models can be used.

Predictions may have the character of forecasts or scenarios, where forecasts are often limited to a shorter period in which conditions (inputs) will not change significantly compared with those assumed in the calculations (e.g. a weather forecast for the following day). Agricultural models for the near future or a small space perspective often have a less strict mechanistic structure than models for a more distant future or larger area. One reason may be related to the greater requirement for accuracy in the outputs on small scale; detailed mechanistic models require many inputs and include many computational steps that can generate uncertainties. The limit for when detailed mechanistic models are useful is unclear and is changing as research advances. For example, mechanistic models estimating evaporation (e.g. Penman 1948) have been widely used for many years to forecast the impact of weather on water conditions and irrigation needs, rather than statistical models based on weather variables. Examples of variables that are often predicted in the short term, within one growing season, are crop phenology, the presence of pests and the need for pest control, plant water supply, nitrogen status and production, the need for fertilisation, irrigation etc. Everything from simple models (in terms of few equations; e.g. harvested protein as a function of remote sensing before flowering; cf. Pettersson and Eckersten 2007) to detailed models (e.g. DSS with linked mechanistic crop and soil models; Jones et al. 2003) have been used for these estimates.

Scenarios normally refer to extended periods during which many alternative conditions in the input data may arise. For long-term predictions (e.g. more than one crop rotation), the farmer can select one of the alternative scenarios and change design accordingly. Consequently, the other scenarios can never be compared with observations and thus do not meet the basic requirement for science. Nevertheless, they constitute a transparent methodology for how scientific knowledge contributes to practice (cf. Eckersten et al. 2001a, 2007a; Rounsevell et al. 2005; Wolf et al. 2015).

Integrating/linking models

Statistical models can be a complement to mechanistic models, for example by generating probability distribution functions of the inputs to be used in Monte Carlo simulations by the mechanistic model (e.g. Höglind et al. 2016; Gärdenäs et al. 2017). Statistical models can also be an alternative to mechanistic models, for example by replacing extensive mechanistic calculations with fewer statistically generated algorithms, e.g. for soil temperature predictions (Persson et al. 2017a; to be used for predictions of e.g. crop winter survival, Bergjord Olesen et al. 2017). Expert judgements are a third type of model predictions. They can be regarded as similar to mechanistic models in the sense that they are based on the functioning of the system, but with the difference that they are not transparent, seldom repeatable and cannot be given a proper measure of validity. For the predictions of complex systems within the socio-economy (which is characterised by large uncertainties), simple statistical models have been found to be significantly more reliable than expert assessments, with one proposed explanation being that experts tend to reason in too complex a way (a tendency which we also know from the mechanistic models) and also can forget and change their perceptions (Kahneman 2015).

CS is a complex system and the effects of processes for plant pests and soil, and the farmer's actions need to be represented in the models used to design CS. All these processes interact. However, mechanistic models (extensively tested against observations) usually only mimic parts of this system and must be linked to each other to model the whole. It is unclear both conceptually and technically how this linking should best be done. In order to technically take into account the continuous development of models within research on understanding, there is a need to use a flexible model framework. DSS is often structured so as to enable the use of different models. Both static and dynamic models are used to manage the complexities of the cropping system. For technical reasons, different models are often linked in a static way, for example by a crop model producing a time-series of plant production and a soil model using this as an external driving variable and not (or only partly) taking into account any feedback loops between soil and plant production (e.g. for estimation of nutrient leaching at the regional level; Blombäck et al. 2013). It is not fully clear how important it is to explicitly consider these types of feedback, which thus need to be investigated (see section 2.6, Understanding). In order to also avoid technically difficult interconnection of models, simplified models are often used. For example, sometimes time steps of one year are used, in which variations in weather within the season are difficult to consider (e.g. Reckling et al. 2016a). There are complete frameworks that link models and can be manipulated to some extent (e.g. DSSAT, Jones et al. 2003; APSIM, Keating et al. 2003), and there are advanced generic modelling tools (e.g. Matlab, Eckersten et al. 2001b; see also Bergez et al. 2013) that can be used to link different models with the help of modelling expertise.

Uncertainties in the predictions

For predictions and assessments of CS, theories that have been developed and evaluated against observations in research on understanding (see section 2.6) are used. Predictions and estimates always involve some type of uncertainty arising for two main reasons: uncertainties in the input data (input, parameters, initial conditions, driving variables) and the processing of inputs to obtain the calculated outputs (i.e. the model structure; e.g. Montesinos-San Martin 2014; Montesinos-San Martin et al. 2015). Because of this, for a single site application, several alternative models or model applications are often used to obtain a measure of uncertainty (e.g. calculation of climate effects on crops; cf. Palosuo et al. 2011). How the various results should be combined and considered in a probability distribution is unclear, but in some way depends on the prediction accuracy of the respective model. Studies have found that the "ensemble mean" is often a better "predictor" of crop yield than any single prediction of an individual model application alone (Asseng et al. 2013).

When making predictions for an entire season, external driving variables, such as the weather, are so uncertain that precise forecasts are practically impossible. The predictions must be presented with some kind of measure of uncertainty. For example, strictly following the definition of climate, the next year's average weather can be assumed to be as in any of the previous 29 years and next year's production can only be specified with a certain probability. This means that estimates of production etc. need to be made for many more conditions (external driving factors) than justified by the observations against which the models have been validated. For example, the choice of crop rotations over several years should take into account this kind of uncertainty in the external driving factors (e.g. weather, prices etc.) and the results assessed (e.g. yield, N leaching, hygienic quality etc.) can only be assumed to occur with a certain probability, which in turn provides the basis for risk analysis of e.g. crop or profit failure.

Parameterisations, i.e. assessments of the value of model input parameters, have great significance for model outputs (predictions and projections). For statistically generated models, parameterisations interact with the formulation of the model structure (i.e. the equations), and parameter values are therefore difficult to set in accordance with specific measurable features of the system (e.g. DON infections in oats; Persson et al. 2017b). In contrast, the parameter values of mechanistic models represent functional characteristics of the system (e.g. maximum rate of photosynthesis), which does not affect the formulation (i.e. equation) of the process (e.g. light influence on photosynthesis). For a specific dataset, a period in which most of the variation in the observations can be assumed to have been caused by a limited number of processes can often be selected. The parameter values of these processes might then be determined separately for this period, and parameter values of other processes might be determined for other periods, etc. With step-wise parameterisations, the adaptation can focus on parameters of relevant processes, avoiding adjustment of those processes that are considered not to have affected the observations (e.g. avoiding parameters of the infiltration process not to be calibrated against water conditions during a dry period). For each step, there are often several parameter values that have to be determined. Initially, each parameter is assigned a value and an uncertainty range according to a probability distribution (prior parameterisation). Thereafter, a large number of simulations are made using alternative input parameter values randomly selected from the probability distributions. A parameterisation that provides simulated outputs which agree (to some degree) with observations is called 'posterior parameterisation' (e.g. Bayesian calibration; van Oijen et al. 2015b; evolutionary algorithm; Stratonovitch and Semenov 2010). Depending on how well the different processes can be isolated, these parameter values represent properties of the system. The step-wise parameterisations assume parameters to be independent. To compensate (to some degree) for this uncertainty, a posterior parameterisation including all selected parameters and observations (e.g. Gärdenäs et al. 2017), is determined as a final calibration step. A significant element of uncertainty in this procedure is the researcher's choice of parameter to be included in the calibrations and the initial values and distributions assumed, choices that depend on expert judgements on how the observations and the model functioning are related to one another. The influence of expert judgement on the parameterisation of eco-physiological process-based models may be one important reason why ensemble means have been found to provide more accurate predictions of crop yield than any of the predictions by the single models (e.g. Asseng et al. 2013). The degree of interdependency among parameters of mechanistic models is to a large extent unexplored and is an important matter for research on understanding to examine.

2.5 Scaling

How information and knowledge are used for a specific scale to express an opinion on a different scale is likely to be affected by what Kahneman (2015) characterises as a generally valid human phenomenon: “Man seems to be far more inclined to use observations on a small scale to draw conclusions about large-scale phenomena, while she finds it much more difficult to use information from a larger scale for the conclusions on a small scale”.

Predictions and assessments are always intended to be made for a specified scale. However, available data often refer to another scale and evaluations require additional estimates to be made. This applies not least to scientific experiments, for example in life cycle assessment (LCA) of the effects of a genetically modified (GM) crop on CS (e.g. Tidåker et al. 2016), the physical experiments of GM crops are limited to a few field conditions, whereas the LCA estimates refer to much larger scales both in space and time. Effects of experiments in the laboratory and some fields for some years need to be scaled up to cover more soil types, variable weather during e.g. a 30-year period, as part of alternative crop rotations etc. (for crops with alternative N use efficiency; cf. Eckersten et al. 2017a). Similarly, there is a need to scale down e.g. how climate change projections (e.g. given monthly for a 50 km by 50 km area) affect a CS within a single farm. Definitions of space and time affect CS boundaries to the socio-economy, e.g. a study on the effects of price changes on a single CS involves different definitions of boundary conditions than a study on the effects on several CS.

Conceptually, scaling is quite a complicated issue related to understanding and modelling of how the functioning of CS depends on spatial and temporal scales. However, in the research categorisation in this report, scaling refers to evaluations of spatial, rather than temporal, effects. Although, similarly to predictions and assessments, scaling involves some kind of extrapolation from a known situation to an unknown (non-observed) situation, it seems that statistical models are used more often than mechanistic models.

Examples

In assessment of the effects of e.g. a climate change scenario (with coarse resolution) on yield, nutrient leaching etc. for agricultural land in a region, the climate needs to be scaled down to the weather for each individual field. The yield assessments (calculations) must be made at the field level, because the calculation methodologies (models) are designed for this level and the relations between environmental factors, yield, N leaching etc. are non-linear. The question then becomes how the calculation errors are affected by the spatial scale of the input data used for weather (e.g. Zhu et al. 2015), soil characteristics (e.g. Coucheney et al. manuscript 2017), management and socio-economic factors. The similar problem applies to calculation of the effects of CS design on CS outputs. The error arising from aggregation of input data, called the ‘data aggregation effect’, needs to be investigated for each assessment method (model). Different ways to aggregate are used. When there are different soil types in an area, the type having the greatest spatial coverage or a soil type known to influence the output (e.g. nutrient leaching) particularly is often selected. An average soil type is hard to define and, above all, difficult to observe and test in physical experiments. For weather variables, however, average weather data for a large area are used, although this weather does not really exist. Various theories for aggregation (e.g. van Bussel 2011) need to be tested and applied in CS research.

Knowledge of scaling effects has practical relevance as regards e.g. estimating the error made when using climate change scenarios for a rough scale as inputs to the models used for estimating the crop yield at field level (e.g. Hoffman et al. 2015). This error should be compared with the effects of the errors that occur when using alternative downscaling methodologies of climate to local conditions (e.g. Semenov and Barrow 1997) causing errors in the estimated local weather, which in turn will cause errors in the calculations of yield at field level. For soils, knowledge of how the error depends on the distribution of soil types in a region (e.g. Coucheney et al. manuscript 2017) may allow determination (based on soil distribution data) of the spatial resolution at which modelling needs to be performed to reduce the error sufficiently to meet the desired accuracy.

2.6 Understanding

It is difficult to find well-defined measures of understanding, but the ability to predict how CS outputs respond to changing conditions is regarded an important measure of how well CS function is understood. This test is scientifically made by using some type of transparent model to anticipate a course of events that has already happened, but on the basis that the outcome is not known. The predictions are then compared with the result of the measurements that are available. The ability to predict also provides a link between research on understanding and the corresponding predictions/assessments and scaling research categories, which in turn provide tools and information needed by the research on design, practice and land use. There are many different models for predicting CS features. The number needed depends on the probability distributions of the outputs of the different models and how the user interprets those. It is the job of science to evaluate alternative models in terms of some type of objective measure that can be related to a ‘scale of understanding’ (e.g. by comparing their prediction ability). However, there is currently no such single-scale evaluation model that seems generally accepted and the methodologies used to rate understanding when analysing observations and experiments seem not to be well-defined.

CS depends on a large number of functions (processes) and a large number of interactions between those. It is difficult to describe these interactions, but the models used to simulate CS are generally forced to formulate some kind of structure. If this structure is transparent, analysis of the models describes how current knowledge perceives the functioning of CS. Alternatively, this can be expressed as follows: The mathematical and numerical formulation of causes and effects between different processes in a model are transparent images of the theories that have been compared with observations, and are for now the best way of describing our explanation of them.

Issues with an increased need for understanding

Research on understanding is controlled partly by the questions that this research generates itself and partly by issues generated by the other research categories listed above. Within the *design* research category (section 2.1), more knowledge is needed about how to optimise systems that are valued with several variables that are not immediately comparable (e.g. bio-physical conditions, socio-economic conditions, farm characteristics and crop management; López Porrero 2016). Questions to be answered are how these different variables should be compared, and what the targets for the optimisation should be. There is also a need for more knowledge about the importance of considering detailed subject-area knowledge for evaluating the outcome at CS level, e.g. how much extreme weather at different times influences crops (e.g. de Toro et al. 2015) and the design of the optimum crop rotation. How farmers can influence these effects (e.g. Aliteri et al. 2015) is a knowledge gap in insurance cases, where there is a need to estimate how much poor management may have contributed to the damage. The link to *practice* (section 2.2) requires better knowledge about the decision-making systems (DSS, role-play, etc.) that best suit the stakeholders (farmers, advisors, public authority etc.), and in what situations they should be used. Concerning how practice affects CS research, there is a need for a greater understanding of factors that affect the data that research can obtain from practical farming, and how innovative proposals on the design and management of CS can be understood in terms of existing scientific knowledge.

Concerning CS research in relation to *land use* (section 2.3), more knowledge is needed on how alternative use of agricultural land affects the design of CS. For example, what is the impact on CS if available arable land decreases due to e.g. increased competition from imported crop products making use of the land for cropping non-profitable? Conversely, how would land use affect CS if more arable land with less favourable soils must be taken into use to meet food demand? On what scale (within-farm, regional, national, European, global) is it feasible and in the interest of the CS research to answer these questions?

With regard to *predictions and assessments* (section 2.4), perhaps one of the main gaps in knowledge concerns the importance of the dynamics of models and the way processes in the models link to each other. Most models have been tested against outputs that are the result of interactions between several processes within the model or several models combined, while inner logic feedbacks are often taken for granted or based on quite a limited amount of experiments, and not tested and validated against explicit observations under variable conditions. This knowledge is central to link processes within models in a proper way. Another knowledge gap is how to describe the uncertainties in predictions. The theories behind the predictions are uncertain and predictions and assessments made with several alternative models need to be combined in a probability distribution, in which the outputs of single models need to be weighted in relation to their prediction abilities, although it is not quite clear how. Applications of models also involve uncertainties, and it is unclear how much of these can be estimated according to transparent protocols or subjective assessments. The structure of the prediction method (i.e. equations, rules etc. of models and frameworks) is strictly linked to our understanding of how CS works. Parameterisation of mechanistic models is part of this approach and central to expressing understanding in quantitative terms, which is a prerequisite for understanding the relative importance of different processes in different contexts. This is perhaps especially true for CS, where very many processes interact. The corresponding interpretation of the parameterisation of statistical models is more unclear, since their model structures are not strictly based on the mechanistic functioning of CS. However, when statistical models are based on indices calculated with mechanistic models, their parameterisation might be linked to processes of the system (e.g. models for pests; cf. Rossi et al. 2003; Del Ponte et al. 2005; Persson et al. 2017b).

Scaling (section 2.5) is a largely unexplored field and, similarly to predictions/assessments, is strongly linked to conceptual modelling. Which processes to consider and how to link them to best mimic observations depend on scale, and are the main subjects of research in CS modelling. In e.g. crop modelling, this has long been a matter of major concern, where e.g. the “big leaf” model is often used in favour of a multi-layered canopy model when simulating transpiration and photosynthesis. Most often the scaling is made by assuming experimental results at the field level to be, in a vague way, almost directly applicable to the regional or national level. However, assuming an analogy between the CS outputs of field experiments from a limited number of site conditions and the CS outputs of the whole of Sweden's arable land under climate variability appears questionable. Scaling in space interacts with time. For example, if a soil-borne virus occurs in one place, how likely is it that the virus is present or occurring at other places at a later point in time, and which measures related to CS could be taken to reduce and delay the spread (cf. Eckersten et al. 2015)? The scaling problem is further accentuated by very variable weather in a climate that is changing systematically. How to quantify this type of uncertainty is of great interest for CS research and its applicability to cropping in practice (e.g. for maize yields; cf. Nkurunziza et al. 2014).

Subject areas of importance for cropping system research (examples)

The need for research on understanding spans a wide range of research areas. Clermont-Dauphin et al. (2014) mention the need for using information from different sources such as “laboratory studies on the ecological functions of soil biodiversity, surveys on farmers’ ranking of farming practices and processes to be included in site-specific models, and on-station experiments to test hypotheses and acquire additional reference material”. They also note that: “many studies that suggest a positive relationship between soil biodiversity and ecosystem services” and “to take advantage of soil biodiversity services one would need to manage not only the interactions between various practices, but also the trade-off between the technical and socio-economic constraints on cropping systems". In addition, all these factors depend on the biophysical conditions and physiology of plants.

Within each subject area, there are a very large number of issues of understanding that are of great importance for CS design and its implementation in practice. One example concerns mid-successional legume-grain intercrop agroecosystems, for which Crews et al. (2016) listed (by means of a review and conceptual analysis) a number of mechanisms for which there are research challenges to achieve improved control of the CS: "For the mechanism called perennial vegetation cover → there is a challenge of avoiding soil loss in the establishment year; for SOM mineralisation and root allocation → the challenge concerns how N is immobilised in proportion to C; for nitrate uptake efficiencies by perennial roots → the challenge is to estimate and control nitrate loss in the establishment year; for legume fixation of N and N mineralisation → the challenge is to estimate and provide adequate soil N supply through microbial mineralisation at grain-fill; for legume fixation of N → the challenge is managing competition between grain and legume species; and for N_2O emissions → the challenge is to control highly labile soil C that may favour N_2O emissions."

3. Cropping system application, an example

In this chapter, activities and objectives of CS research are highlighted using an example of a CS design study. Based on the main research question of the study concerned (concerning crop rotation optimisation), follow-up questions in the research categories predictions/assessments, scaling, understanding and cropping in practice, and how this may be affected by, or affect, land use scenarios, are formulated. The chapter then examines how questions might be answered by some of the approaches presented in this literature review (see Appendix). The example (taken from Reckling et al. 2016b) relates to the design of crop rotations including legumes in Västra Götaland (VG) in south-west Sweden under current conditions (with relevance for the near future) based on estimates of effects on production and environmental factors (Table 2). Since objects and objectives of those other studies differ from the example of legumes in VG, the answers to the questions should be regarded as speculative and probably need further processing to be realistic.

Table 2. Question: How can a crop rotation with legumes with optimal outputs on N use, N losses and gross margins be designed (Reckling et al. 2016b)?

Design (Chapter C1 in Appendix)

C1)How is the design procedure structured?
Reckling et al. (2016a, 2016b): Multi-criteria assessment is used to select innovative cropping systems with low trade-offs between economic and environmental impacts. A framework with three steps is used: (i) generate crop rotations, (ii) evaluate crop production activities using environmental and economic indicators (new indicators can be easily added) and (iii) design cropping systems by combining generated rotations with evaluated crop production activities, and assess their impacts. To design new systems, a selection procedure according to different aims is provided, e.g. to identify economic-environmental best performing systems. Specifically, optimal cropping systems could then be selected according to three criteria: "(i) gross margin is $\geq$ system with the highest gross margin minus 50 EUR, (ii) nitrate leaching $\leq$ system with the highest gross margin, and (iii) nitrous oxide emission $\leq$ system with highest gross margin".
Colnenne-David and Doré (2014): A four-step design methodology is used: (i) define and rank constraints, (ii) design innovative CS prototypes, (iii) assess outputs of CS that best fulfil constraints in an iterative process using models, and (iv) make a long-term field experiment with the final designed CS.
Naudin et al. (2015): Information needed for each selected crop (or cover crop) is: (i) crop adaptation to biophysical conditions, (ii) agroecological functions of crops, (iii) crop production, (iv) compatibility for intercropping and (v) agroecological functions of the overall cropping system. This information is stored in a database for crops, cover crops, agronomic units and relationships between them. Thereafter crop sequences are selected in five steps: (i) plant choice in relation to agronomic units, (ii) whether or not a plant can be intercropped or grown in sequence, (iii) application of five cover crop sequence rules, (iv) select possible combinations and grouping similar cropping systems and (v) selection according to farmers' preferences.
Bergez et al. (2010): A four-step process is used: (a) generation, (b) simulation, (c) evaluation and d) comparison and choice.
Rossing et al. (1997): First, a diagnosis of the CS is made and the problem is formulated. Then a working hypothesis is formulated in which risk is assessed with the help of decision rules in three steps: (i) apply the inputs for climate, cropping history, decision rules and soil type, (ii) simulate 30 years (decision simulator and crop simulator) and (iii) process outputs to get frequency distribution among years.
Cerf et al. (2012): A two-step design is used: (i) diagnosis of uses to identify the diversity of situations in which the tools will help to solve the problem, (ii) characterise the users' use of the existing tools for taking decisions, and identify how new tools might fit in, or need to be modified.
Blombäck et al. (2013): Responsibilities of actors are defined. Stakeholder (S) represents society and chosen agronomic measures to be applied, Modellers (M) mimic the functioning of natural processes by assessing the response to the measures, and the Input/Output group transforms information between S and M. In an iterative procedure among the groups, proposed measures evaluated to have most significant effects are selected.
Li et al. (2015): An optimisation model for crop rotation scheduling is applied with the objective of maximising the profits of farmers, while minimising the differences in profits between farmers. The model is applied for a group of 80 farmers in the area.
Vereijken (1997): The actors are divided into two groups: a farm group (10-15 pilot farms) and a research group. The design comprises four steps: (i) define objectives (values of interest) and rate their importance, (ii) define quantitative parameters representing the objectives and farming methods used to implement them, (iii) design a prototype (theoretically) and (iv) test and refine the prototype in field experiments.
Gaba et al. (2015): (i) A set of priority services defined by biophysical, social and economic factors is defined in consultation with stakeholders, (ii) plant species that can sustain the services targeted are identified based on expert knowledge, literature or databases and (iii) agroecosystem functioning is optimised by means of management to satisfy the targeted services.
Jonsson et al. (2014): Crop sequences in neighbouring fields are synchronised so as to stimulate biological control of aphids by predators in adjacent fields.

Predictions/assessments (methods) (Chapter C4 in Appendix)

C4a) How are crop rotations generated?
Reckling et al. (2016a): Crops are selected and combined with soil types and rotational rules using crop sequence and frequency restrictions derived from experiments and defined by experts and thereafter combined to current and alternative crop rotations, which are finally checked for their plausibility by agronomists and advisors. The number of selected crops, the rotational restrictions and the orientation of the systems (arable or mixed farms) influence the number of crop rotations generated.
NLeCCS/FyrisNP (Blombäck et al. 2013): Crop sequences are generated by assuming crop rates over time to be the same as the spatial proportions of crops observed for a given year. The order of the crops is random except that some crop rotation restrictions should be met. The management of the crops is applied according to regional statistics.
Li et al. (2015): A heuristic algorithm (a rude algorithm or model, not fully deterministic; might be an interpretation) is used in six computational steps considering four constraints and five crop sequence rules. The constraints are to (i) ensure that a crop can be planted by a farmer no more than one time, (ii) guarantee that the planting area of each crop is more than the minimal requirement of the crop, (iii) ensure that the production period of a farmer is no more than the length of rotation, and (iv) limit the difference of profits per acre between all farmers. Crop sequence rules concern (i) crops with same profit and from same botanic family…, (ii) Cucurbitaceae cannot ….., (iii) leaf vegetables should be …., (iv) deep-rooting vegetables should be ….., and (v) crops sensitive to soil acidity should be ….. Crops chosen by each farmer are given by the computational steps listed above (although it is difficult to fully interpret those steps in 'physical' terms). Outputs are crop sequence of each farm, from which distributions of profits between farms can be calculated.
Vereijken (1997): First, the crop rotations (MCR) are generated by making a list of crops in diminishing order in terms of marketability and profitability. The crops are then assigned a rating from -5 to +5 as concerns physical properties (e.g. cover, rooting compaction and structure) and chemical properties (e.g. N uptake and N transfer). The MCR is designed targeting a maximum sum of these values, following a number of constraints: (i) start with the first crop on the profitability list; (ii) reduce the share of each crop in order to preserve biological soil fertility; (iii) select a crop with a high rating of soil cover or soil structure to preserve physical soil fertility; (iv) select a crop with a high rating of N transfer as pre-crop to a crop with high N need, and vice versa, to conserve chemical soil fertility; (v) select crops to adapt to limited labour capacity or market demand; and (vi) ensure that crop successions are agriculturally (logistically) feasible.
PRACT (Naudin et al. 2015): A list of cropping systems is generated from a database of 28 crops and/or catch crops including information on four categories: crops, cover crops, agronomic units and the relationships between these three components.
APSIM (APSIM 2016): Guided by two training examples of crop rotation simulations, different crop sequences are designed based on around 10 crops of interest for the VG region. The outputs are grouped into crop, soil, surface organic matter and fertilisation category, of which crop and soil include a huge amount of output variables to be used for the evaluations.

C4b) How are N use, N losses and gross margin assessed?
Reckling et al. (2016a, 2016b): N use, N losses and gross margin are assessed for each cropping system generated based on the pre-crop and site-specific management (fertilisation, pesticide application, tillage etc.) and yield, using simple static relationships. For each crop sequence, rotational (pre-crop) effects are included based on experiments and defined by experts. N_2O emissions, gross margin and nitrate-N leaching are calculated according to IPCC, Defra and Bachinger and Zander (2007), respectively. In order to perform a multi-criteria assessment, the indicators N use, N losses, gross margins and others are normalised by dividing by their respective regional average value in present conditions.
NLeCCS/FyrisNP (Blombäck et al. 2013): "Firstly, daily nutrient leaching on a hectare basis from arable fields is simulated with the NLeCCS (Nutrient Leaching Coefficient Calculation System) system, using the SOILNDB-model, for a 20-year period of weather and for combinations of soils and crops in the region. Secondly, the monthly nutrient load of each catchment is simulated with the FyrisNP model, summarising gross load of different land usages added by loads from point sources, but reduced by retention being a function of water area, discharge and water temperature." Statistical yields are input.
MONICA (Nendel et al. 2011): "The model (MOdel for NItrogen and Carbon in Agroecosystems; originating from HERMES model) is used to simulate daily crop growth, water and nitrogen uptake, and the soil

dynamics. Simulations of organic matter turn-over, nitrification and denitrification are taken from the DAISY model (Hansen et al. 1991). The crop growth module approach used is based on the SUCROS model (van Keulen et al. 1982). The impact of extreme heat on crop growth and yield formation is considered according to Challinor et al. (2005), and maintenance respiration is assessed separately for day and night using AGROSIM algorithms (Mirschel and Wenkel, 2007). Root dry matter is distributed over depth according to Pedersen et al. (2010), with the rooting depth increasing linearly with the thermal sum. Water and N stress reduce crop growth and accelerate crop ontogenesis at specific development stages."

Li et al. (2015): The profits of farms are outputs from the optimisation of crop rotations aimed at minimising profit differences between farms.

Vereijken (1997): Available N reserves are estimated as the soil mineral N content in the 0-100 cm layer prior to the period of precipitation surplus. N losses are the mineral N concentration of drainage water times the precipitation surplus. Net economic surplus is total returns minus all costs (all labour hours paid equal).

APSIM (APSIM 2016): Seasonal crop yields, N use and N losses for single fields are simulated by selecting among 43 crop types (Standard Toolbox/Crops). The functioning of each crop type is given in one single source code file. In a documentation file, there is a brief description of the functioning (e.g. in the CERES-Wheat phenology module, water or nitrogen stresses result in delayed phenology).

DSSAT (Jones et al. 2016): Seasonal crop yields are simulated with the CROPGRO model (or another crop model attached to DSSAT) dynamically linked to soil water, temperature, C and N model (e.g. CENTURY model) simulating N leaching of a one-dimensional multilayered soil profile, continuously during the whole crop rotation. N use is estimated by relating the simulated outputs to fertiliser input data at field level.

SOIL/SOILN (Eckersten et al. 2017b): Similar to DSSAT, but based on two models; SOIL simulating soil heat (considering frozen soil) and water conditions provides inputs to SOILN simulating biomass, C and N of crop and soil. The two models interact by running iterative loops on crop rotation level. CoupModel (Jansson and Karlberg 2004; Jansson 2012) does similar simulations but with modified versions of the two models interacting daily.

LPJ-GUESS (Smith et al. 2001; 2014): The outputs of LPJ-GUESS are yield and NPP for cropland (maize and wheat), and NPP for natural vegetation areas in terms of two types of grassland species (C3 and C4) and 10 types of forest species for biome patches within each grid cell. The inputs of LPJ-GUESS are drivers (climate (CRU; Harris et al. 2014), atmospheric CO_2 and N deposition (Smith et al. 2014)), parameters of soil texture (FAO, 1991; Sitch et al. 2003), crops and plants, and management variables.

SIRIUS model (Jamieson et al. 1998): Crop biomass and N yield and N leaching are simulated for single years. The model needs daily weather inputs on air temperature max and min, global radiation, precipitation, wind speed and vapour pressure.

WOFOST model (e.g. Boogaard et al. 2013): Crop potential aboveground biomass is simulated for single years. Weather inputs are the same as for the Sirius model except given (technically) in a slight different way. Weather could also be given as monthly values. In tests for a 10-year period (1988-1997), the average potential crop yield of a site in the VG region varied between 9.9 and 11.5 ton dry matter per ha among four wheat cultivars and the coefficient of variation (1 std/mean) was 12-13% (extremes were -18% and +28% of periodic mean, respectively; unpublished data).

Jonsson et al. (2014): The gross margin would be influenced by the need for pest control applications. The potential negative effects of a reduction in pest control on yield can be estimated as a function of cropping system of neighbouring fields. The negative effects would increase with the proportion of surrounding CS comprising annual crops.

Torssell et al. (2007). For mixed grass-clover swards, yields of grass and clover are simulated as a function of fertilisation level and daily weather. For grass leys N use is also simulated, but calibration to site conditions is needed for fields with low or no fertiliser supply (Eckersten et al. 2007b).

Van Ittersum et al. (2013): Crop models are used to provide crop yield assessment at three levels: (i) potential yields only limited by the temperature and solar radiation climate, (ii) the same as for potential yield except that water supply is limited to actual precipitation amounts, and (iii) actual yield including all yield-limiting factors in practical farming (see also the Global Yield Gap Atlas Project; GYGA 2016).

Predictions/Assessments (databases) (Chapter C4.3 in Appendix)

C4.3) How are inputs achieved? *Reckling et al. (2016a):* Input data are taken from a combination of regional statistics, structured expert surveys, literature and experiments to capture all restriction values required for the crop rotation generator, to identify the set of crops for the rotations and to evaluate the impacts of cropping systems. *NLeCCS/FyrisNP (Blombäck et al. 2013):* Inputs are "*long time series of daily meteorological data (SMHI), and agricultural statistics of crops and area distribution, standard yields, normal fertilisation rates and crop management for a specific year*". Parameterisations of C, N, water and heat processes of 10 soil types are taken from a database of the NLeCCS computation framework. *MONICA (Nendel et al. 2011):* Inputs of the model are crop and soil parameters, soil data and daily management and weather data. Some crop and soil parameters are estimated by calibration to observations (Braunschweig and Hohenfinow experimental data) of total above-ground dry matter, dry matter yield, above-ground crop N content, marketable yield N content, soil moisture, leaf dry matter, leaf area index, crop height, ground coverage and soil mineral nitrogen. Management, weather and soil data are observed at the site. Parameters are available for the following crops: oil radish, potato, silage maize, silage summer barley, silage winter rye, Sudan grass, sugar beet, winter barley, winter oilseed rape, winter rye and winter wheat. *Li et al. (2015):* Inputs are crop, botanic family, planting time, minimum planting area, profits per acre and farm land area. The profits of single crops are based on the selling orders of 2013. "*The product manager proposes the rotation schedules for all farmers. The process of planting is controlled by the company to which the farmers are contracted.*" Inputs are available for pak choi, radish, garland, lettuce, sweetcorn, amaranth, Chinese watermelon, coriander, cucumber, hot pepper, celery, broccoli, broad bean, garlic bolt and tomato. *DSSAT (Jones et al. 2016); SOIL/SOILN (Eckersten et al. 2017b); CoupModel (Jansson and Karlberg, 2004):* Inputs of weather, soil, crop water and management are the same as for the NLeCCS framework (see above), whereas crop parameterisations are taken from previous model applications for winter wheat, spring barley, catch crop etc. *APSIM (APSIM 2016):* Daily weather inputs (global radiation, air temperature (max and min), rain, evaporation), are taken from a database (http://www.ffe.slu.se/FF/GMAP.cfm?APPL=V) of SMHI and Lant-Met weather stations. An example of technical operations needed in this type of data handling would be: Data in xlm-files are checked for errors, variable rearranged according to APSIM-met file format and converted into a "," denominated csv-file. Thereafter, the "," is replaced by a space bar and a heading added as a first line. The file is then renamed a met-file. After being loaded to APSIM, the variables are easily plotted and obvious errors detected. APSIM includes parameter sets for 43 crop types (Standard Toolbox/Crops), of which barley, field pea, lucerne, lupin, maize, oats and wheat, AgPasture and maize-wheat intercrop and weeds might be of potential use for the VG region. For the different crop types several varieties are available (e.g. for wheat around 100 and for barley around 50). Soil types to select among are categorised in terms of country/continent (Australia, Bangladesh, Indonesia, Africa and South Africa), in turn categorised in sub-regions within which there are several generic soil types to choose among. Achieving proper crop parameter values is possible by selecting among the existing crop varieties within APSIM, which are parts of the crop-specific source-code files. In a similar way, soil types are selected among existing types in APSIM. This selection would possibly benefit from comparison with databases used by NLeCCS/FyrisNP applications (Blombäck et al. 2011). Input values that can be specified interactively in APSIM for each field application are: management values for sowing criteria (rainfall etc.) and parameters (crop, cultivar, density etc.), fertilisation (when, amounts etc.); parameters for soil water (porosity profile etc.) and soil chemistry (e.g. pH); and initial values for surface residues, soil water, N and organic matter. *WOFOST model (e.g. Boogaard et al. 2013):* There are 58 available parameter sets covering 23 crops: wheat, barley, potato, oil seed rape, sugar beet, cassava, chick pea, cow pea, cotton, faba bean, groundnuts, grain maize, maize, millet, mung bean, pigeon pea, rice, sorghum, soybean, sunflower, sweet potato and tobacco. There are 15 parameter sets available categorising different soil water characteristics.

Scaling (Chapter C5 in Appendix)

C5) How are scales defined and scaling assessed? *Reckling et al. (2016a):* First, single crop production activities are assessed at the field level, then combined with generated rotations and aggregated for cropping systems at regional scale. Results are regarded as valid on regional scale. Comparison with observed annual yield variations at farm level is not regarded as relevant, since regional input data are used. *NLeCCS/FyrisNP (Blombäck et al. 2013):* 1-2 weather stations per region are used (e.g. Såtenäs). All crops are distributed in the same proportions for all soil types. Soils are aggregated into 10 types, i.e. sand, sandy loam, loam, silt loam, sandy clay loam, clay loam, silty clay loam, silty clay and clay in areal proportions of 0, 0, 34, 32, 3, 0, 19, 6, 2 and 3, respectively (Johnsson et al. 2008). Simulations are made for each soil type and regional averages are estimated by weighting the simulated outputs in relation to relative area of soil type. *DSSAT (Jones et al. 2016); SOIL/SOILN (Eckersten et al. 2017b); CoupModel (Coucheney et al. manuscript 2017; Hoffman et al. 2015):* Simulations of yield and N losses on a hectare basis are made on a grid scale of 1 km x 1 km, using inputs on gridded daily weather from SMHI, selection of areal-dominant soil type in each grid and regional statistics on management operations per crop and soil type. One field for each grid is simulated and averaged for the whole region. Using coarser resolution would cause data aggregation errors in the simulated outputs, which might be estimated using maps of soil type, knowing the model's response to certain key soil types (e.g. shallow soils). The N leaching simulations would determine the maximum grid size allowed to achieve an acceptable data aggregation error. *APSIM (APSIM 2016):* Each simulation application (representing a physical site for a specified period) consists of four modules: met (weather etc.), clock (simulation period), summary-file (simulation inputs, log and results) and paddock (crop, soil, management, selected and plotted outputs). Such a simulation application is easily copied into a new one, thus representing another field or period. Several such applications can be run in parallel (although probably not communicating with each other) using the option Factorials.

Understanding (Chapter C6 in Appendix)

C6a) How valid are the assessments (predictions)? *Reckling et al. (2016a):* The framework is validated by evaluations by experts and contacts with local advisory services, at three stages of the assessments: (i) The crop rotations generated are compared with typical crop sequences and crop proportions, and the integration of legumes checked for their agronomic acceptability. (ii) Agronomic performance and environmental indicators at the single crop scale are compared with data from field experiments and the literature. (iii) Assessed cropping systems at the regional scale are compared with the impacts of cropping systems with high and low shares of cereals and with and without legumes, using experts and available experiments. *NLeCCS/FyrisNP (Blombäck et al. 2013):* Predictions of N leaching from field and N concentrations in streams are compared and calibrated against field experiments and environmental monitoring programmes in the area. Runoff assessments are adjusted to SMHI calculations (using the S-Hype model; Lindström et al. 2010) on catchment level. Changes to the model concept can technically be introduced by the staff at SLU who host the model. *MONICA (Nendel et al. 2011):* "The mean bias error (MBE; Addiscott and Whitmore, 1987) is used to identify over- or under-predictions (ideal = 0). The mean absolute error (MAE, Shaeffer, 1980) is used as a measure of the average magnitude of prediction errors. A normalised value of MAE (nMAE) is achieved by dividing by the mean of the observations. The mean squared error (MSE) is split into a systematic (MSEs) and an unsystematic error component (MSEu). The root mean square error (RMSE; which is very sensitive to outliers and dependent on sample size) is used to allow for comparison with earlier modelling works. Willmott's index of agreement (d; range 0-1; Willmott and Wicks, 1980) is used as a measure similar to the correlation coefficient, although more accurate. The modelling efficiency (ME; Nash and Sutcliffe, 1970) is analogous to d-index, but with a different range ($-\infty$ to 1; optimal being 1 and zero indicating the model predictions being no better estimator than the observed mean). In tests against seven field experiments in Germany, calibrations yielded a median nMAE of 0.20 across all observed target variables (n = 42) and a median d of 0.9, and median ME of 0.75. Uncalibrated simulations yielded a median nMAE of 0.27 across all observed target variables (n = 85) and a median d of 0.76, and median ME of 0.30." *Li et al. (2015):* In accordance with observed data in China, crop sequences are adapted so that the

simulated gap of profits per acre between farmers and the simulated average profit become no more than 10% (assuming no fallow periods and the crop sequence to be restarted after 12 months).
DSSAT (Jones et al. 2016); SOIL/SOILN (Eckersten et al. 2017b); CoupModel (Jansson and Karlberg, 2004): The applications of mechanistic crop-soil models acquire detailed observations in time and space to identify a limited amount of explanations of differences between predicted and observed values. The validity of the assessments (predictions) in region VG would rely strongly on tests against experimental observations and the generality of the parameterisations, which depends on the way models have been parameterised in those experiments,.
APSIM (APSIM 2016): To calibrate for crop varieties that are currently not included in APSIM or to adjust existing cultivars to new observations, parameter values need to be changed. These changes are done inside the crop-specific source-code file, which includes both functioning (equations) of the crop type concern and the parameterisation of its cultivars (e.g. in …\Apsim78-r3867\Model\Wheat.xml). Simulation outputs are exported to an Excel file for comparison with observations. To simulate potential growth not limited by water or N, the management and/or weather inputs are changed (e.g. to applying high N fertilisation and increasing precipitation). The APSIM predictions of the potential yield of the wheat cultivar Avalon were compared with the corresponding Avalon predictions by the Sirius model (Jamieson et al. 1998) for a site in Skåne. In 2015, APSIM predicted maturity to occur several weeks earlier than Sirius and essentially lower yield and harvest index. In 2016, both models predicted maturity to be several weeks earlier compared with 2015, and the relative reduction in yield to be ~10% (unpublished data). Compared with observed values of the cultivar Ellvis on this site in 2015, the predicted anthesis date of Avalon was more than a week later and the maturity date more than two weeks later.
SIRIUS model (Jamieson et al. 1998; Stratonovitch and Semenov 2015): Crop parameters are calibrated against field observations for anthesis and maturity dates, yield, aboveground biomass and corresponding N content. Usually 12 crop parameters are under consideration for adjustment to different cultivars, but there are another 23 parameters defining each crop. For simulating soil water and N conditions, nine soil-specific parameters are defined, of which three depend on depth. There is a routine for optimisation of parameter values to fit simulated outputs on crop variables and soil N content to observations.
WOFOST model (e.g. Boogaard et al. 2013): Crop parameters are calibrated as for the Sirius model except for the N conditions, which are simulated in less detail. There are 43 parameters defining biomass simulations, another six for water and eight for N, phosphorus (P) and potassium (K) crop conditions. For simulating soil water, nine parameters need to be defined quantitatively; two depend on depth and five refer to soil workability.
SIRIUS (Jamieson et al. 1998) and WOFOST (e.g. Boogaard et al. 2013) models: The two models were calibrated against observed potential yield of the wheat cultivar Ceverin for a site in the VG region in 2015. Using these parameter sets for the following year in 2016, the two models predicted anthesis to occur 1-2 weeks earlier, and maturity 4-9 days earlier than in 2015. The change in predicted yield compared with 2015 was -5 to +1%, and the harvest index increased by 1 %-unit for both models (unpublished data). These ranges reflect the uncertainties in the predictions caused by differences in model structure and model calibration. The calibrations were made by adjusting three to five of the crop parameters of the pre-defined cultivar parameter set (among those attached to the model framework) regarded to be closest (geo-graphically) to the site concerned. The calibration was made step-wise, starting with the phenological process.
CoupModel (Jansson 2012): Conceptual changes to the model code can (on request) be introduced by the model developers.

C6b) What are the major scientific questions remaining to be resolved to achieve accurate assessments?
Reckling et al. (2016a): What is the effect of not explicitly considering within-season variations or variations between years?
NLeCCS/FyrisNP (Blombäck et al. 2013): How well does the simple method used for estimating plant N demand variation between years resemble real variations, or variations assessed with a weather-driven crop growth model? How well does the space-time analogy used for generating crop sequences resemble effects on N leaching of actual crop sequences in practical agriculture?
MONICA (Nendel et al. 2011): "*The simulation of single crops in a rotation can fail for different reasons. The next task should be to broaden the MONICA crop parameter sets to account for the differences in crop varieties with respect to, for example, their growth and yield characteristics.*" "The model often underperforms for variables related to nitrogen."

Li et al. (2015): The proposed approach needs to be tested for real-world situations. The crop-specific constraints used for the CR assessments (i.e. crop repetition, planting area, production period, difference in profits between farmers) need further investigations.
SOIL/SOILN (Eckersten et al. 2007b): What are the reasons for the relatively large differences between crop parameters for N uptake depending on the site for which the parameterisation is made?
LPJ-GUESS (Smith et al. 2001; 2014): How well do assessments for a 50 km x 50 km grid resemble fields on single farms? What is the need for introducing downscaling methods, and how might that be done?
APSIM (APSIM 2016): Crop cultivar and soil parameters would need to be adjusted to those of crops and soils in the VG region.

Practice (Chapter C2 in Appendix)

C2a) How is information/knowledge from practice used in the design?
Reckling et al. (2016a): Alternative crop rotations are checked for their plausibility by agronomists. The framework is validated in contacts with local advisors.
Li et al. (2015): Data on a company are used as input. Business strategies (maximising profits while minimising the differences in profits between farmers) are implemented in the model.
SOIL/SOILN (Eckersten et al. 2017b): The model parameters for N use (e.g. daily root N uptake efficiency of soil mineral N) need to be calibrated against frequent observations on plant dry matter and N, and soil mineral N in farmers' fields cropped with genetically modified spring barley.

C2b) How is the designed crop rotation implemented in practice?
Reckling et al. (2016a): Designed cropping systems with legumes are tested by farmers. European farmers that aim to integrate legumes into their rotations as a result of the greening in the current CAP can use the economic-environmental best-performing rotations modelled for their region.
APSIM (APSIM 2016): When the APSIM model has been adapted to observed values (i.e. after calibration to cultivars, soils, weather and management of the VG region), the model provides quite a handy DSS tool for evaluating effects of alternative CS designs. A rough evaluation is that it fits advisors' rather than farmers' skills and that it would be a useful tool in teaching agronomists.
Vereijken (1997): The prototype is disseminated by means of field experiments on 10-15 farms (in addition to the 10-15 pilot farms), together covering the range of variable soil, climate and management conditions within the region. Improved farm-specific prototypes are developed from the various farm situations and the theoretical prototype.

Land use (Chapter C3 in Appendix)

C3a) How do the projections of future cropland/grassland areas globally and continentally influence areas of Sweden and the design of legume-based crop rotations in Västra Götaland?
Eckersten et al. (2007a): The ACCELERATES model (Rounsevell et al. 2005) project, with only a few exceptions, shows positive effects on productivity for sites in the whole of Europe with large climate and technological changes in future. Under these conditions, the area of crop land in Sweden is projected to increase by 20% from 2000 to 2050, but with a small climate change it may instead decrease by 70% due to decreased competitiveness on the world market (for 15 European countries the corresponding average change ranged from -27% to + 5%). For the ATEAM model based on mass balances between production and demand (see section on *Land use* above), the corresponding projections (Abildtrup et al. 2006) are regarded as mainly reliable on European level. Depending on the assumed development of society, crop land area from 2000 to 2020 is projected to decrease by between 28% and 11% (corresponding decreases in the area of grassland are 24% and 20%, respectively). These modelled changes in land use are based on modelled projections of yields. Depending on assumptions of societal development, crop yields are projected to increase from 2000 to 2020, due to technological development, by +4 to +68% (ACCELERATES) and +19 to + 37% (ATEAM). For ATEAM the corresponding projections of yield changes due only to climate change impacts are comparatively small (-5 to + 3%).
PLUM (Engström et al. 2016b; Sallaba et al. manuscript 2016): Outputs from global land use modelling with the PLUM model give the area of cropland and grassland for the whole of Sweden, scaled down to 50 km x 50 km grid level of the VG region. The simulations are based on a balance between estimated food and feed supply and food and feed demand as influenced by trade and policy strategies within the EU and elsewhere, of which the N supply is based on simulations of yield and NPP for 50 km x 50 km grids by the

LPJ-GUESS model (Smith et al. 2014), and data and assumptions about changes in yield gap, in turn mimicked by a meta model (BME, Engström et al. 2016b). The outputs of PLUM then reflect effects of balances between supply and demand within each grid for food and feed.

The main question of how the outputs from these land use projections would influence the design of CS in terms of generation of crop rotations (e.g. Reckling et al. 2016a) and the assessments of N use, N losses and gross margin of the VG region still remains to be answered.

C3b) How does the design of legume-based crop rotations for Västra Götaland influence the projections of future cropland/grassland areas of Sweden?
Which inputs to land use modelling are influenced by CS design? The outputs from CS design are crop types, the order in which crops are cultivated, tillage, fertilisation and crop protection measures, N use, N losses and gross margin, at field level regionally averaged by one or several site categories (e.g. soil type).
ACCELERATES (Abildtrup et al. 2006): The input data (parameters) to the model are: Divergence/convergence; costs of fertilisers, seeds, pesticides, machinery, fuel and labour; Areal-based subsidies and price of grain, maize, oilseeds and protein crops; Price of sugar beet, roots and tubers, meat, milk and water; Fallow subsidies and quotas; LFA subsidies; Yield (as a function of technology change); Irrigation and efficiency; Restriction of chemical pesticides; Farm size; Negative effects of crop rotation (see e.g. Eckersten et al. 2007a).
ATEAM (Rounsevell et al. 2005): The input data (parameters) to the ATEAM model are demand (consumption) for arable products and grassland products, production (as a function of climate and [CO2]), Productivity (as a function of technology) and Overproduction (%).
LPJ-GUESS (Smith et al. 2014; Sallaba et al. manuscript 2016): How would the outputs from CS design influence the LPJ-GUESS simulations at a 50 km x 50 km grid scale and the PLUM simulations of food supply? The inputs of LPJ-GUESS are drivers (climate, atmospheric CO_2 and N deposition), parameters of soil texture (FAO, 1991; Sitch et al. 2003), crops and plants, and management variables. The yield and NPP simulations of the LPJ-GUESS model would need to consider properties and management of new crops, rescaled from the scale of design to the grid scale. The BME metamodel of LPJ-GUESS would be redeveloped accordingly to feed the PLUM model with gridded NPP supply data.
PLUM (Engström et al. 2016b): The inputs of the PLUM model are gross domestic product (GDP), population and lifestyle. From these inputs a 'consumer module' calculates total crop use, a 'crop module' calculates crop production and cropland, which provide inputs to a 'trade module' calculating crop production demand of Sweden. These demand estimates then feed back into the cropland estimates of the 'crop module' in the following year. The increase or decrease in cropland area within Sweden is input to a 'land use module' estimating the resulting area of grassland and forest land. The 'trade module' functioning is based on the principle that balances between supply (including import and export) and demand for crop production within each country (Sweden) for food, feed and grazing are fulfilled, and that the corresponding balances on global level are also fulfilled. These balances might, theoretically, be estimated for single grids as well.

4. Conclusions

Research on CS is complicated as it spans scales from days to centuries and from fields of a single farm to the global level. It also includes different scientific subject areas and stakeholders with different interests. Each CS study should be clearly defined as regards content and links to relevant research areas, in order to make it comparable with other CS studies. We propose that CS research focuses on integrating the key aspects that control CS design, which includes utilisation of knowledge and methodologies of subject-area research.

Based on this review, CS research is proposed to be divided into six categories (design, practice, land use, predictions/assessments, scaling and understanding). Each study on CS normally spans several of these categories simultaneously. Research within design and practice contributes directly to cropping in practice. Research within land use helps to link CS in agriculture to CS in horticulture and forestry and studies at European and global scale. Research within the other three categories should provide the necessary scientific basis for applications in the former categories.

Knowledge gaps were found in all categories. The main needs of research may be to: (i) create assessable measures of what CS design aims at, and estimate and predict how such measures may vary over time and due to changes in driving factors, (ii) identify how knowledge of subject-area research can be integrated into CS design and evaluate and understand its importance at CS level, and (iii) develop the basis for uncertainty analysis by analysing effects of variations in conditions (inputs), theories (models) and applications of prediction/assessment tools.

To return to the question of why SLU largely lacks organised exploitation of subject-area research models in its CS research, one reason might be that many scientific questions remain unanswered regarding how, when and at what level of detail this knowledge significantly impacts upon the integrated level. Another reason may be limited opportunities to use such knowledge, e.g. subject-area knowledge-based models used in CS research may be lacking or not applicable on CS level.

What this mean for the development of a CS platform in concrete terms, such as frameworks for models and databases, is not evaluated here, but the Appendix lists several candidates. This review was limited by its scope and can therefore be regarded as a first attempt to clarify the structure of CS research rather than a definitive guide. Further work on the framework may therefore be needed.

5. Acknowledgements

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6. Contents of the Appendix

The Appendix largely comprises quotes from other publications and is therefore published internally in a separate document and only available from the author on request. Here only the contents of it are published. The sections of the Appendix are structured to follow the sequence in the main report:

Within each section of the Appendix, the text is structured according to the main questions addressed by the studies reviewed (answers to the questions are lacking in a few cases).

-K: Indicates that the information is taken from a seminar in Krusenberg (Uppsala) in January 2015, organised by the SLU Cropping System Committee.

(S), (SE) and (ES): Indicates that the answers are given in Swedish, mostly Swedish but also English, and mostly English but also Swedish, respectively.

Appendix A. Introduction
-How is a textbook in CS structured?

Appendix B. Cropping system (CS) definition (system description)
-Issues within classifications of CS (S)?
-How can the system description of CS be structured (S)?

B.1. System definition – CS outputs
-Which "Outputs" does CS generate (S)?

B.2. System definition - CS content
-What is a cropping system (S)?
-Which parts does CS consist of (S)?
-What is the system boundary of CS (SE)?
-K: How is CS defined?
-K: What are the components of CS and how are they linked?

B.3. System definition - Driving factors (Input)
-What are the main inputs of intensive farming practices?
-Which of the core principles of agroecology are inputs?
-What are the boundary conditions of CS in this study? What are the Inputs and Outputs of CS (SE)?
-K: Which factors influence farmers' fields?

B.4. Types of CS
-What types of CS are characterised in agricultural research?
-How can "the seven core principles of agroecology" be interpreted in a system description (ES)?
-Can intercropping be described as a CS within the CS named 'Agroecology' (ES)?
-K: Which factors make CS diverse?
-K: Which factors can be used to categorise CS?

B.5. Evaluation of CS
-Which "Outputs" are desirable, or undesirable?
-What factors have been used in evaluations of CS (ES)?
-Which factors differ between CS types and make them different?
-How can different CS be compared (SE)?

Evaluations
-Which of the core principles of agroecology are outputs?
-What are the main drawbacks of intensive farming practices?
-How does CS production capacity relate to supply demands (S)?

Appendix C1. Design of cropping systems
-Examples from the Introduction (Chapter 1) in the main report

Aims
-K: Why does CS need to meet several aspects to be innovative?
-K: Why is it essential to develop research on design of innovative cropping systems?
-K: What opportunities can analysis of CS provide?

Definitions
-How is resilience of an agroecosystem defined?
-How is risk of an agroecosystem defined?

Methods
-Innovation: What does it involve and how does it function?
-Prototyping: What are the five main steps in prototyping?
-What are the main steps in designing multi-crop systems?
-Which issues does 'Dialogical design' respond to?
-Which two-step methodology is used in 'Dialogical design'?
-How can models be used for CS design (ES)?
-What is the benefit of rule-based models for design?
-How can network flows be used to derive an optimal crop sequence?
-K: How can experts use models when they choose crop rotation?
-K: Which methodological steps are needed to design CS at catchment level?
-K: Which methods are available to analyse CS? What can agronomic models be used for? What are the limitations of agronomic models?
-K: Which actors should be included in a "design workshop" and how should it be organised?
-K: How can a "step-by-step design" be conducted and what can be the outcome?

Modelling
-How can model tools be used to design CS that target ambitious environmental goals, and how should the results be expressed?
-How can the spatio-temporal arrangements in a landscape be modelled?
-How were models evaluated as tools to be used for design 20-30 years ago?
-How can risk influence on crop rotations be modelled?
-K: Which ecosystem services can be aggregated into a few categories?

Assessments
-What may be the effects of policy on the distribution of CS types in a region?
-What are the possible combinations of crops and management in a conservative agricultural (CA) cropping system?
-How might the introduction of legumes in a crop rotation influence N use and losses and gross margins?
-K: To what extent can ecosystem services be affected by replacing the current spring barley crops with corresponding crops with improved uptake efficiency of soil N?
-K: To what extent can ecosystem services be affected by measures taken to reduce N leaching?
-K: How can economic outcomes be compared with biophysical outcomes at farm level?
-K: What is "Best Available Practice "(BAP) to reduce nutrient discharge?
-K: To what extent can BAP reduce nutrient leaching without reducing crop production?

Appendix C2. Cropping in practice

-Examples from the Introduction (Chapter 1) in the main report

Introduction of CS

-How can the core principles of agroecology be applied in practice?
-What is the first big step to take in introducing agroecology to agriculture?
-What socio-economic factors hinder the introduction of agroecology to agriculture?

Models and tools

-How can DSS be used for CS in practical cropping (ES)?
-How can designers of CS adapt DSS to the user's needs (S)?
-For what applications can a platform for modelling agro-ecosystems be used (ES)?
-How were models evaluated as useful tools for practical farming 20-30 years ago?
-K: What is the potential contribution of a tool for finding cost-effective options to adapt to climate change?

Assessments

-K: When and by how much should crops be fertilised?
-K: What is the probability of a certain financial outcome in alternative future climates?
-K: How does nutrient leaching depend on climate, crop rotation and soil conditions?

Dialogue

-Which working steps are included in "participatory scenario design"; examples?
-How are stakeholders involved in modelling N leaching (ES)?
-Which new scientific issues can dialogue with users create?
-K: Why and how should the "user" of CS be included in its design?
-K: Can actor interests be grouped?
-K: To what extent are ecosystem services affected by CS design being proposed by a stakeholder?
-K: What user features does a DSS have?
-K: Which stakeholders can benefit from a DSS?
-K: Which stakeholders are involved in designing CS to reduce N leaching from catchments?
-K: How can stakeholders make use of models when evaluating measures to reduce nutrient leaching?

Appendix C3. Land use

-Examples from the Introduction (Chapter 1) in the main document
-Which aspects are addressed in various global land use models?
-Which techniques are used in global land use modelling?

Appendix C4. Predictions/Assessments

-Examples from the Introduction (Chapter 1) in the main document

Concept

-Which analogies are assumed when extrapolating scientific knowledge of CS over time and space (S)?

Evaluations

-How can statistical methods be used to analyse the most sensitive parameters of a soil-crop model?
-How do site conditions influence calibrated ley parameter values?
-How well do crop models simulate ley production in the Nordic countries?
-K: With what accuracy can a process based soil-crop model be adapted to the observed biomass, C and N dynamics in field experiments?
-K: With what accuracy can a process-based soil-crop model be adapted to the observed P and N fluxes and concentrations in rivers?

Production

-Which CS performed best in targeting environmental goals while still being productive?
-How are the effects of winter conditions on ley yield simulated?
- To what biophysical threats and risks is Swedish crop production exposed (S)?

N and C assessments

-How might N and C dynamics change during development of a native grassland ecosystem?
-What are the effects of alternative N fertilisers on outputs of agro-environmental CS?

-Which measures have been assessed to contribute to reduced N losses from catchments?
-How might a spring barley crop with improved N use influence yield, N leaching and SOC and national environmental assessments?
-How can spatial variability in precision farming be modelled with DSSAT?
-K: What are the effects of modified crop traits on field biomass N and C dynamics?
-K: How does the optimum fertiliser dose depend on which CS output is targeted?
-K: How can the need for fertilisation vary from year to year?

Pests

-Is there an upper fraction of organic CS acreage above which the presence of harmful organisms is more likely?
-How much do different management options influence biological pest and weed control?
-How much might the biological control effect vary depending on CS in surrounding fields?
-How does multiplication rate of Carabids depend on CS?

Scenarios

-What do assessments based on mechanistic modelling project for future farm N losses and farm gross incomes for different sites in Europe?
-What are the relative influences of climate change, technology development and policy development on future farm N losses and farm gross income scenarios?
-How might the conditions for CS change in the future (S)?
-What is lacking in current approaches of climate change impact assessments to be used for crop rotation evaluations?
-K: How do uncertainties in climate change (CC) adaptation assessments propagate and provide a measure of risk?
-K: Which questions need to be answered in a risk assessment of cereal and milk production?

C4.1. Databases

-Which databases are available at SLU?
-Who are the users of the databases?
-How can the databases be linked to models?
-K: What should data be used for and what qualities should the data have?
-K: What data and models are used in DSS, and what are the outputs?

Appendix C5. Scaling

-Examples from the Introduction (Chapter 1) in the main document
-What is meant by "landscape agronomy"?
-K: How do types of research questions concerning the interaction between environment and society vary with the spatial scale under study?

Effects

-How is biodiversity affected by land use in the landscape?
-How might the effects of a spring barley crop with improved N use differ between scales?
-How can the distribution of alternative CS within a region be optimised for sustainability indicators?
-K: How much can measures targeted at identified high-risk areas affect the N budget on farms?
-K: In which areas is the presence of risk factors for "Beetle infestation in oilseed rape" comprehensive?
-K: What might be the effects of cultivar improvement on N leaching on regional or national level?

Scaling

-How can knowledge from experimental studies be utilised for local conditions in the field and the farm?
-How can regional pasture statistics be used to estimate within-season pasture growth curves?
-K: How can the effect of global climate change be downscaled to the local level, used to suggest adaptation of CS and estimate local impacts, and thereafter scaled up to regional and national level?
-K: How can the effects of management at field level on N loads in river outlets be modelled?
-K: Which computational steps are needed for deriving adaptation strategies at farm level to CC?
-K: Which calculation steps are needed to assess regional yields?
-K: How can spatial variation in growing conditions be used for predictions at the local level?

Appendix C6. Understanding the functioning of CS

-Examples from the Introduction (Chapter 1) in the main document

Cropping system

-How well can the N and C dynamics of the five successional stages towards grain-legume intercropping be predicted?
-Which ecological mechanisms are in focus when achieving benefits of mid-successional legume-grain intercrop agroecosystems?
-What are the "pre-crop benefits to yield and input requirements of subsequent crops in legume-based crop sequences"?
-K: What can a crop rotation experiment comprise?
-K: By how much are yield predictions improved when the crop rotation is taken into account in the simulation?
-K: How does the crop rotation affect the fertilisation effect on yield?
-K: What are the conclusions of testing crop models against crop rotation experiments?

Crop

-To which crop and soil processes is crop production most sensitive?
-How do crop parameters differ between wheat cultivars for different crop models?
-To what degree does shoot N fixation relate to shoot NPP?
-How does species A influence the environment of species B?
-K: Which processes are considered when assessing effects of modified crop functional traits?
-K: How can tests of crop model predictability be performed?
-K: For which crops are there tested models?

Soil

-How is subsoiling defined, and what are the effects on CS?
-What is the advantage and disadvantage for CS of including catch crops?

Pests

-How does the type of CS in the surrounding fields affect the presence of pests in a wheat field (S)?
-How well can the biological control effect be estimated as function of CS of surrounding fields?
-K: How does the number insecticide controls correlate with the percentage area of oilseed rape?
-K: How does the occurrence of pests relate to the type of CS in the landscape?

Biodiversity

-How does the type of CS affect biodiversity?
-Are mechanisms for regulating biodiversity and ecosystem services general?
-How much do soil food web indices differ between croplands of different N availability, and between cropland and grassland?

Socio-economics

-How does farm size influence productivity?
-Can net income be the reason for agro-environmental CS not being replaced by conventional CS?

Appendix D. Models and databases

D.1. Models

-Issues in model studies:
-How can models be used to evaluate differences in cultivar performance, and support breeders and best choices of cultivars for cropping systems (CS)?

Model concept

-K: For what purposes should models be used?
-How complex should a model be?
-K: How can a balance be achieved between detailed representation of processes in a model and statistical evaluations of its predictability?
-Which processes should be included in the model?
-How can a science-based risk analysis of crop production be structured (S)?
-Which models are used for different purposes?
-K: Which types of subject-area models are used in DSS?

Applications/Evaluations
-How can a model be evaluated for its decision support quality?
-How are models used for studying genotype, environment and CS interactions?
-How well can models simulate effects of differences in genes?
-What are the main limitations in model uses for defining breeding targets?
-K: What limitations have been found in current models used to predict crop yield?
Model frameworks
-How is a platform for modelling agro-ecosystems created (SE)?
-How is the DSSAT/CSM model framework structured and used?
-How is the APSIM model framework structured and used?
-K: How can scenarios for the economic outcome of a farm be calculated (MONICA/YIELDSTAT)?
-K: How can CS research regarding biophysical processes, ecosystem services and land use conflicts be integrated?
Input/Output
-How to estimate model parameters?
-How to identify cultivar parameters?
-How to estimate cultivar specific model parameters?
-What are the inputs and outputs of models in the MACSUR-Sweden project (ES)?
-K: What inputs does an agroecosystem model need, and what outputs does it deliver?

D.2. Databases
-Which databases are available at SLU?
-What is the purpose of the organisation of SLU data (S)?
-Which databases outside SLU are related to CS?

7. References

All references are given below, including those cited in the Appendix. References listed in smaller text (font 9) and indented immediately after a main reference are a secondary source taken from this main reference and not analysed in this review (different reference styles are used).

References (not allocated specifically)

Boogaard, H., Wolf, J., Supit, I., Niemeyer, S., Ittersum, M. 2013. A regional implementation of WOFOST for calculating yield gaps of autumn-sown wheat across the European Union. Field Crops Research. 143, 130-142.

Blombäck K, Johnsson H, Markensten H, Mårtensson K, Orback C, Persson K, Lindsjö A. 2011. Läckage av näringsämnen från svensk åkermark för år 2011 beräknat med PLC5-metodik Beräkningar av normalläckage av kväve och fosfor för 2011. Rapport till Jordbruksverket (99 pages).

Coucheney E, Eckersten H, Hoffmann H, Jansson P-E, Gaiser T, Ewert F, Lewan E. (manuscript 2017). Effects of soil variability on spatial aggregation errors for soil-crop modeling at a regional scale. Swedish University of Agricultural Sciences.

Eckersten H, Blombäck K, Kätterer T, Nyman P. 2001a) Modelling C, N, water and heat dynamics in winter wheat under climate change in southern Sweden. Agric Ecosyst Environm 86:221-235

GYGA. 2016. Global yield gap atlas. http://www.yieldgap.org/

Jamieson PD, Semenov MA, Brooking IR, Francis GS. 1998. Sirius: a mechanistic model of wheat response to environmental variation. European Journal of Agronomy 8, 161–179.

Johnsson H, Larsson M, Lindsjö A, Mårtensson K, Persson K, Torstensson G. 2008. Läckage av näringsämnen från svensk åkermark Beräkningar av normalläckage av kväve och fosfor för 1995 och 2005. Naturvårdsverket rapport nr 5823. 152 pp.

Krusenberg, 2015. SLU workshop on cropping and forestry systems at Krusenberg in January 19-21, 2015

SLU, 2015. Road map Cropping System Platform 20150930.docx

Stratonovitch P and Semenov MA. 2015. Heat tolerance around flowering in wheat identified as a key trait for increased yield potential in Europe under climate change. Journal of Experimental Botany. doi:10.1093/jxb/erv070

Van Ittersum, M., Cassman K.G., Grassini, P., Wolf, J. Tittonell, P., Hochman, Z. 2013. Yield gap analysis with local to global relevance — A Review. Field Crops Research. 143, 4-17.

References (CS Definition)

Altieri MA, Nicholls CI, Henao A, Lana MA. 2015. Agroecology and the design of climate change-resilient farming systems. Agron. Sustain. Dev. 35:869–890.

Behaderovic D 2016. En jämförande studie av konventionella och ekologiska odlingssystem på svenska växtodlingsgårdar – Har de närmat eller skiljt sig åt över tid? (A comparing study of conventional and organic cropping systems on Swedish cropping farms – Have they been influenced by each other or distanced over time?). Kandidatuppsats/Agronomprogrammet, SLU. 49 pages. (http://stud.epsilon.slu.se)

Bommarco R, Kleijn D, Potts SG. 2013. Ecological intensification: harnessing ecosystem services for food security. TREE 28:230–238. doi:10.1016/j.tree.2012.10.012

Clermont Dauphin C, Blanchart E, Loranger-Merciris G, Meynard JM. 2014. Cropping Systems to Improve Soil Biodiversity and Ecosystem Services: The Outlook and Lines of Research In: OzierLafontaine, H; LesueurJannoyer, M (eds.). Sustainable Agriculture Reviews 14: Agroecology and Global Change Book Series: Sustainable Agriculture Reviews Volume: 14 Pages: 117-158 (Only Abstract)

Fogelfors, H. (red). 2015. Vår mat. Odling av åker- och trädgårdsgrödor. Biologi, förutsättningar och historia. 1:1 uppl. Lund: Studentlitteratur AB. 614 sidor.

Gaba S, Françoise Lescourret, Simon Boudsocq, Jérôme Enjalbert, Philippe Hinsinger, Etienne-Pascal Journet, Marie-Laure Navas, Jacques Wery, Gaetan Louarn, Eric Malézieux, Elise Pelzer, Marion Prudent, Harry Ozier-Lafontaine . 2015. Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. Agron. Sustain. Dev. 35:607–623.

Haines-Young R, Potschin M. 2010. "The links between biodiversity, ecosystem services and human well-being," in ecosystemecology: a new synthesis, eds. D. Raffaelli, C. Frid. Cambridge University Press, Cambridge).

Millennium Ecosystem Assessment. 2005. Ecosystems and human wellbeing: synthesis. World Resources Institute, Washington, DC Miranda Filho JB, Chaves LJ. 1991. Procedures for selecting composites based on prediction methods. Theor Appl Genet 81:265–271. doi: 10.1007/BF00215732

Kirchmann H, Kätterer T, Bergström B, Börjesson G, Bolinder MA, 2016. Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems. Review. Field Crops Research 186:99–106.

López Porrero, E J, 2016. Explaining yield gaps of cereals in temperate regions using an expert-based survey. MSc Internship Plant Production Systems (PPS-70424). Wageningen University. 51 pages.

Sebillotte, M., 1974. Agronomie et agriculture. Essai d'analyse des t^aches de l'agronome. Cah. ORSTOM 24, 3-25.

Ponti, Luigi; Altieri, Miguel A.; Gutierrez, Andrew Paul. 2007. Effects of crop diversification levels and fertilization reqimes on abundance of Brevicoryne brassicae (L.) and its parasitization by Diaeretiella rapae (M'Intosh) in broccoli. Agricultural and Forest Entomology. Volume: 9 Issue: 3 Pages: 209-214.

Vendermeer JH ed. 2011. The Ecology of Agroecosystems. (http://www.amazon.com/The-Ecology-Agroecosystems-John-Vandermeer/dp/0763771538#reader_0763771538)

Watts M (ed.), 2015. Replacing Chemicals with Biology: Phasing out highly hazardous pesticides with agroecology, 210pp. Copyright © Pesticide Action Network Asia and the Pacific. (http://pan-international.org/release/phasing-out-highly-hazardous-pesticides-with-agroecology-pesticide-action-network-releases-book-at-iccm4/)

References (Design)

Andriulo, A., Mary, B., and Guerif, J. 1999. Modelling soil carbon dynamic with various cropping sequences on the rolling pampas. Agronomie 19:365–379.

APSIM. 2016. APSIM model downloaded from web 20161120. Version 7.8, 2016-03-24, build number r387. (www.apsim.info)

Aubry, C., Chatelin, M.H., Poussin, J.C., Attonaty, J.M., Meynard, J.M., Ge´rard, C. and Robert, D., 1992. De´cible´: a decision support system for wheat management. In: Book of Abstracts, 4e`me Congre`s d'Informatique agricole, Versailles, SAF, Paris.

Bachinger J, Zander P, 2007. ROTOR, a tool for generating and evaluating crop rotations for organic farming systems. Europ. J. Agronomy 26 130–143.

Blazy J-M, Ozier-Lafontaine H, Doré T, Thomas A, Wery J. 2009. A methodological framework that accounts for farm diversity in the prototyping of crop management systems. Application to banana based systems in Guadeloupe. AgriSyst 101(1–2):30–41. doi:10.1016/j.agsy.2009.02.004

Cerf M, Jeuffroy M-H, Prost L, Meynard JM. 2012. Participatory design of agricultural decision support tools: taking account of the use situations. Agronomy for Sustainable Development Volume: 32 Issue: 4 Pages: 899-910.

Chopin P, Thierry Doré, Loïc Guindé, Jean-Marc Blazy, 2015. MOSAICA: A multi-scale bioeconomic model for the design and ex ante assessment of cropping system mosaics. Agricultural Systems 140:26-39

Harold, A.L., Murray, T., 2002. The Delphi Method, Techniques and Applications. New Jersey Institute of Technologyhttp://is.njit.edu/pubs/delphibook/ (Accessed 24 September 2014).

Bergez, J.-E., Garcia, F., Leenhardt, D., Maton, L., Castelletti, A., Sessa, R.S., 2007. Chapter 7 optimising irrigation management at the plot scale to participate at the regional scale water resource management. Topics on System Analysis and Integrated Water Resources Management. Elsevier, Oxford, pp. 141–160 http://dx.doi.org/10.1016/B978-008044967-8/50007-5.

Ronfort, C., Souchere, V., Martin, P., Sebillotte, C., Castellazzi, M.S., Barbottin, A., Meynard, J.M., Laignel, B., 2011. Methodology for land use change scenario assessment for runoff impacts: a case study in a north-western European Loess belt region (Pays de Caux, France). Catena 86, 36–48. http://dx.doi.org/10.1016/j.catena.2011.02.004.

Rusch, A., Valantin-Morison, M., Roger-Estrade, J., Sarthou, J.-P., 2012. Using landscape indicators to predict high pest infestations and successful natural pest control at the regional scale. Landsc. Urban Plan. 105, 62–73. http://dx.doi.org/10.1016/j.landurbplan. 2011.11.021.

Thenail, C., Joannon, A., Capitaine, M., Souchère, V., Mignolet, C., Schermann, N., Di Pietro, F., Pons, Y., Gaucherel, C., Viaud, V., Baudry, J., 2009. The contribution of crop-rotation organization in farms to crop-mosaic patterning at local landscape scales. Agric. Ecosyst. Environ. 131, 207–219. http://dx.doi.org/10.1016/j.agee.2009.01.015.

Colnenne-David C, Doré T, 2014. Designing innovative productive cropping systems with quantified and ambitious environmental goals. Renewable Agriculture and Food Systems: 30(6); 487–502.

Coleman, K. and Jenkinson, D.S. 1999. A model for the turnover of carbon in soil; Model description and windows users guide, IACR—Rothamsted. p. 47.

Crews TE, Blesh J, Culman SW, Hayes RC, Jensen ES, Mack MC, Peoples MB, Schipanski MB, 2016. Going where no grains have gone before: From early to mid-sucession. Agriculture, Ecosystems and Environment, 223, 223-238.

Detlefsen NK, Jensen AL, 2007. Modelling optimal crop sequences using network flows. Agricultural Systems 94:566–572.

Doré T, Clermont-Dauphin C, Crozat Y, David C, Jeuffroy M, Loyce C, Makowski D, Malézieux E, Meynard JM, Valantin-Morison M. 2008. Methodological progress in on-farm regional agronomic diagnosis. A review. Agron Sustain Dev 28(1):151–161. doi:10.1051/agro:2007031

Huyghe, C.; Meynard, J.-M. 2014. Innovation: what does it involve and how does it function? Fourrages Issue: 217 Pages: 5-12 (Only abstract).

Li J, Rodriguez D, Zhang D, Ma K, 2015. Crop rotation model for contract farming with constraints on similar profits. Computers and Electronics in Agriculture 119:12–18

Louarn G, Corre-Hellou G et al. 2010. Déterminants écologiques et physiologiques de la productivité et de la stabilité des associations graminées-légumineuses. Innov Agronom 11:79–99.

Meynard, JM. 1994. In: Biarnes, A (ed). Conference: Seminar on Dynamics of Farmlands - Viewpoints of Agronomists Location: Montpellier, France (Only Abstract).

Meynard, J.M. and David, G., 1992. Diagnostic sur l’e´laboration du rendement des cultures. Cahiers Agric., 1: 9–19.

Naudin, K, O. Husson, E. Scopel, S. Auzoux, S. Giner, K.E. Giller, 2015. PRACT (Prototyping Rotation and Association with Cover crop and no Till) – a tool for designing conservation agriculture systems. Europ. J. Agronomy 69: 21–31.

Nicholls CI, Altieri MA. 2013. Agroecologia y cambio climatico: metodologias para evaluar la resiliencia socio-ecologica en comunidades rurales. Red IberoAmericana de Agroecologia para el desarrollo de sistemas agricolas resilientes al cambio climatico (REDAGRES). Gama Grafica, Lima, p 91.

Ridier A , Chaib K, Roussy C. 2016. Dynamic Stochastic Programming model of crop rotation choice to test the adoption of long rotation under price and production risks. European Journal of Operational Research 252:270–279.

Rossing, WAH; Meynard, JM; vanIttersum, MK, 1997. Model-based explorations to support development of sustainable farming systems: case studies from France and the Netherlands. European Journal of Agronomy Volume: 7 Issue: 1-3 Pages: 271-283.

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

References (Practice)

Asseng S, Ewert F, Rosenzweig C, Jones JW, Hatfield JL, Ruane AC, Boote KJ, Thorburn PJ, Rötter RP, Cammarano D, Brisson N, Basso B, Martre P, Aggarwal PK, Angulo C, Bertuzzi P, Biernath C, Challinor AJ, Doltra J, Gayler S, Goldberg R, Grant R, Heng L, Hooker J, Hunt LA, Ingwersen J, Izaurralde RC, Kersebaum KC, Müller C, Naresh Kumar S, Nendel C, O'Leary G, Olesen JE, Osborne TM, Palosuo T, Priesack E, Ripoche D, Semenov MA, Shcherbak I, Steduto P, Stöckle C, Stratonovitch P, Streck T, Supit I, Tao F, Travasso M, Waha K, Wallach D, White JW, Williams JR, Wolf J. 2013. Uncertainties in assessing food security under climate change. Nature Climate Change 3, 827–832.

Börjesson T, Persson T., Eckersten H, Pettersson C-G, Elen O, Hjelkrem A-G.R. 2015. Prediktering av Deoxynivalenol (DON) i havre under västsvenska förhållanden med hjälp avväder- gröd- och skötseldata. Slutrapport 2015-07-01 till SLF. (see also Persson et al. 2017b).

de Toro A., Eckersten H., Nkurunziza L., von Rosen D., 2015. Effects of extreme weather on yield of major arable crops in Sweden, Dep of Energy and Technology, Swedish University of Agricultural Sciences (SLU), Uppsala. 301 pages.

Dupas R, Parnaudeau V, Reau R, Jeuffroy M-H, Durand P, Gascuel-Odoux C. 2015. Integrating local knowledge and biophysical modeling to assess nitrate losses from cropping systems in drinking water protection areas. Environmental Modelling & Software Volume: 69 Pages: 101-110.

Benoit, M., Rizzo, D., Marraccini, E., Moonen, A.C., Galli, M., Lardon, S., Rapey, H., Thenail, C., Bonari, E., 2012. Landscape agronomy: a new field for addressing agricultural landscape dynamics. Landsc. Ecol. 27 (10), 1385-1394. http://dx.doi.org/10.1007/s10980-012-9802-8.

Eckersten, H.; Kornher, A., 2012. Klimatförändringars effekter på jordbrukets växtproduktion i Sverige – scenarier och beräkningssystem. (Climate change impacts on crop production in Sweden – scenarios and computational framework). Report No 14, Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden. 62 pp (In Swedish with English summary). http://pub.epsilon.slu.se/8590/1/eckersten_h_120208.pdf

Hossard L, Jeuffroy M-H, Pelzer E, Pinochet X, Souchere V. 2013, A participatory approach to design spatial scenarios of cropping systems and assess their effects on phoma stem canker management at a regional scale. Environmental Modelling & Software Volume: 48 Pages: 17-26.

Lillunen, A., Härjämäki, K., Riiko,K., Yli-Renko,M., Kulmala, A., Koskinen, J., Lundström, E., Kaasinen, S. 2011. TEHO-hanke 5/2011 Kotopellolta Rantalohkolle - Tehoa maatalouden vesiensuojeluun. TEHO-hankkeen (2008 - 2011) loppuraportti, TEHO-projects final report. p.152.

Makowski D, Taverne M, Bolomier J, Ducarne M. 2005. Comparison of risk indicators for sclerotinia control in oilseed rape. Crop Prot 24:527–531. doi:10.1016/j.cropro.2004.10.003

Moore AD, Holzworth DP, Herrmann NI, Brown HE, de Voil PG, Snow VO, Zurcher EJ, Huth NI. 2014. Modelling the manager: Representing rule-based management in farming systems simulation models. Environmental Modelling & Software 62:399-410.

Christian, K.R., Freer, M., Donnelly, J.R., Davidson, J.L., Armstrong, J.S., 1978. Simulation of Grazing Systems. Pudoc, Wageningen.

Hammer, G.L., Holzworth, D.P., Stone, R., 1996. The value of skill in seasonal climate forecasting to wheat crop management in a region with high climatic variability. Aust. J. Agric. Res. 47 (5), 717-737.

Johnson, I.R., Chapman, D.F., Snow, V.O., Eckard, R.J., Parsons, A.J., Lambert, M.G., Cullen, B.R., 2008. DairyMod and EcoMod: biophysical pasture-simulation models for Australia and New Zealand. Aust. J. Exp. Agric. 48 (5), 621-631.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., Huth, N.I., 1995. APSIM - an agricultural production system simulation model for operational research. Math. Comput. Simul. 39 (3e4), 225-231.

Moore, A.D., Salmon, L., Dove, H. 2004. The whole-farm impact of including dualpurpose winter wheat and forage brassica crops in a grazing system: a simulation analysis. In: Fischer, R.A., Turner, N.C., Angus, J.F., McIntyre, C.L., Robertson, M.J., Borrell, A.K., Lloyd, D. (Eds.), New Directions for a Diverse Planet. Proceedings of the 4th International Crop Science Congress. The Regional Institute Ltd, Brisbane, Australia.

Romera, A.J., Morris, S.T., Hodgson, J., Striling,W.D.,Woodward, S.J.R., 2004. A model for simulating rule-based management of cow-calf systems. Comput. Electron. Agric. 42 (2), 67-86.

Rotz, C.A., Buckmaster, D.R., Comerford, J.W., 2005. A beef herd model for simulating feed intake, animal performance, and manure excretion in farm systems. J. Animal Sci. 83 (1), 231-242.

Shaffer, M.J., Bartling, P.N.S., Ascough II, J.C., 2001. Object-oriented simulation of integrated whole farms: GPFARM framework. Comput. Electron. Agric. 28 (1), 29-49.

Palosuo T, Kersebaum KC, Anguloc C, Hlavinka P, Moriondo M, Olesen JE, Patil RH, Ruget F, Rumbaur C, Takáč J, Trnka M, Bindi M, Çaldağ B, Ewert F, Ferrise R, Mirschel W, Şaylan L, Šiška B, Rötter R, 2011. Simulation of winter wheat yield and its variability in different climates of Europe: A comparison of eight crop growth models. European Journal of Agronomy. 35:103–114.

Parnaudeau, V., Reau, R., Dubrulle, P., 2012. Un outil d'evaluation des fuites d'azote vers l'environnement a l'echelle du systeme de culture: le logiciel Syst'N. Innov. Agron. 21, 59-70.

Penaud A, Duroueix F. 2009. Stratégie fongicide du colza: la clé d'une protection réussie et rentable pour 2009. Perspect Agr 354:56–61.

Persson T, Eckersten H, Elen O, Hjelkrem A-GR, Markgren J, Söderström M, Börjesson T. 2017b. Predicting deoxynivalenol in oats under conditions representing Scandinavian production regions. Food Additives and Contaminants. http://www.tandfonline.com/doi/full/10.1080/19440049.2017.1305125

Prost L, Jeuffroy MH. 2007. Replacing the nitrogen nutrition index by the chlorophyll meter to assess wheat N status. Agron Sustain Dev 27:321–330. doi:10.1051/agro:2007032

Prost L, Makowski D, Jeuffroy MH. 2008. Comparison of stepwise selection and Bayesian model averaging for yield gap analysis. Ecol Model 219:66–76. doi:10.1016/j.ecolmodel.2008.07.026

References (Land use)

Abildtrup, J., Audsley, E., Fekete-Farkas, M., Giupponi, C., Gylling, M., Rosato, P., and Rounsevell, M. 2006. Socio-economic scenario development for the assessment of climate change impacts on agricultural land use: a pairwise comparison approach. Environmental Science & Policy 9 (2), 101-115.

Audsley, E., Pearn, K. R., Simota, C., Cojocaru, G., Koutsidou, E., Rousevell, M. D. A., Trnka, M., and Alexandrov, V. 2006. What can scenario modelling tell us about future European scale agricultural land use, and what not? Environmental Science & Policy 9 (2), 148-162.

Eckersten H, Andersson L, Holstein F, Mannerstedt Fogelfors B, Lewan E, Sigvald R, Torssell B, 2007a. Bedömningar av klimatförändringars effekter på växtproduktion inom jordbruket i Sverige (Evaluation of climate change effects on crop production in Sweden). Bilaga 24 i: Sverige inför klimatförändringarna - hot och möjligheter, SOU 2007:60, Bilagedel B, bilaga B 23-27: 26-277. (summary in English). (http://www.regeringen.se/sb/d/8704/a/89334).

Engström K. 2016. Pathways to future cropland - Assessing uncertainties in socio-economic processes by applying a global land-use model. Doctoral Thesis, Faculty of Science, Lund University, Sweden. 51pp, ISBN 978-91-85793-61-7.

Engström, K., Olin, S., Rounsevell, M., Arneth, A. (manuscript 2016) Food supply and bioenergy production within the planetary boundary of global cropland. (manuscript in Engström 2016). Lund University.

Engström, K., Olin, S., Rounsevell, M. D. A., Brogaard, S., van Vuuren, D. P., Alexander, P., Murray-Rust, D., and Arneth, A. 2016b. Assessing uncertainties in global cropland futures using a conditional probabilistic modelling framework, Earth System Dynamics Discussions, 2016, 1-33.

Engström K, *, Mark D.A. Rounsevell, Dave Murray-Rust, Catherine Hardacre, Peter Alexander, Xufeng Cui, Paul I. Palmer, Almut Arneth, 2016. Applying Occam's razor to global agricultural land use change. Environmental Modelling & Software 75:212-229.

Baldos, U.L.C., Hertel, T.W., 2013. Looking back to move forward on model validation: insights from a global model of agricultural land use. Environ. Res. Lett. 8, 034024.

Heistermann, M., Müller, C., Ronneberger, K., 2006. Land in sight? Achievements, deficits and potentials of continental to global scale land-use modeling. Agric. Ecosyst. Environ. 114, 141-158.

Hurtt, G.C., Chini, L.P., Frolking, S., Betts, R.A., Feddema, J., Fischer, G., Fisk, J.P., Hibbard, K., Houghton, R.A., Janetos, A., Jones, C.D., Kindermann, G., Kinoshita, T., Klein Goldewijk, K., Riahi, K., Shevliakova, E., Smith, S., Stehfest, E., Thomson, A., Thornton, P., Vuuren, D.P., Wang, Y.P., 2011. Harmonization of land-use scenarios for the period 1500e2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. Clim. Change 109, 117-161.

Lambin, E.F., Rounsevell, M.D.A., Geist, H.J., 2000. Are agricultural land-use models able to predict changes in land-use intensity? Agric. Ecosyst. Environ. 82, 321-331.

Letourneau, A., Verburg, P.H., Stehfest, E., 2012. A land-use systems approach to represent land-use dynamics at continental and global scales. Environ. Model. Softw. 33, 61-79.

Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp, A., Lucht, W., 2008. Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach. Agric. Econ. 39, 325-338.

Parker, D.C., Hessl, A., Davis, S.C., 2008. Complexity, land-use modeling, and the human dimension: fundamental challenges for mapping unknown outcome spaces. Geoforum 39, 789-804.

Rosegrant, M.W., Ringler, C., Zhu, T., Tokgoz, S., Bhandary, P., 2013.Water and food in the bioeconomy: challenges and opportunities for development. Agric. Econ. 44, 139-150.

Schaldach, R., Priess, J.A., 2008. Integrated models of the land system: a review of modelling approaches on the regional to global. Living Rev. Landsc. Res. 2.

Schmitz, C., van Meijl, H., Kyle, P., Nelson, G.C., Fujimori, S., Gurgel, A., Havlik, P., Heyhoe, E., d'Croz, D.M., Popp, A., Sands, R., Tabeau, A., van der Mensbrugghe, D., von Lampe, M., Wise, M., Blanc, E., Hasegawa, T., Kavallari, A., Valin, H., 2014. Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. Agric. Econ. 45, 69-84.

van Asselen, S., Verburg, P.H., 2013. Land cover change or land-use intensification: simulating land system change with a global-scale land change model. Glob. Change Biol. 19, 3648-3667.

van Tongeren, F., van Meijl, H., Surry, Y., 2001. Global models applied to agricultural and trade policies: a review and assessment. Agric. Econ. 26, 149-172.

Harris, I., Jones, P. D., Osborn, T. J., and Lister, D. H. 2014. Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset, International Journal of Climatology, 34, 623-642.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A. 2009. A safe operating space for humanity. Nature 461, 472-475.

Rounsevell, M. D. A., Berry, P. M., and Harrison, P. A. 2006. Future environmental change impacts on rural land use and biodiversity: a synthesis of the ACCELERATES project. Environmental Science & Policy 9 (2), 93-100.

Rounsevell, M. D. A., Ewert, F., Reginster, I., Leemans, R., and Carter, T. R. 2005. Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. Agriculture Ecosystems & Environment 107 (2-3), 117-135.

Sallaba, F., Olin, S., Engström, K., Abdi, A.M., Boke-Olén, N., Lehsten, V., Ardö, J., Seaquist, J. (manuscript 2016) Exploring NPP supply and demand in the Sahel at regional, country and local level for climate and socio-economic pathways. (manuscript in Engström 2016). Lund University.

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., Sykes, M. T., Thonicke, K., and Venevsky, S. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Global Change Biology, 9, 161-185.

References (Predictions/Assessments)

Bergjord Olsen AK, Persson P, de Wit A, Nkurunziza L, Sindhøj E, Eckersten H. 2017. Estimating winter survival of winter wheat by simulations of plant frost tolerance. Journal of Agronomy and Crop Science (accepted for publication 29 August 2017).

Blazy J-M, Barlagne C, Sierra J. 2015. Environmental and economic impacts of agri-environmental schemes designed in French West Indies to enhance soil C sequestration and reduce pollution risks. A modelling approach. Agricultural Systems 140:11–18.

Blombäck K., Duus Børgesen C., Eckersten H., Giéczewski, M., Piniewski, M., Sundin S., Tattari S., Väisänen S., Eds., 2013. Productive agriculture adapted to reduced nutrient losses in future climate - Model and stakeholder based scenarios of Baltic Sea catchments. (http://www.balticcompass.org/_blog/Project_Reports/post/future-nutrient-load-scenarios/)

Blombäck K, Eckersten H, Lewan E, 2003. Simulations of soil carbon and nitrogen dynamics during seven years in a catch crop experiment. Agr. Syst. 76 (1): 95-114.

Carlsson C. 2014. Definition av verksamhetsområdet för Tilda. Version 1.0, 2014-05-16, IT-byrån, SLU.

Collentine D., Eckersten H., Norman Haldén A., Ryd Ottoson J., Salomon E., Sundin S., Tattari S., Braun J., Kuussaari, M., 2013. Consequences of future nutrient load scenarios on multiple benefits of agricultural production. Department of Crop Production Ecology, Report No. 17, Swedish University of Agricultural Sciences. Uppsala. 65pp (ISBN 978-91-576-9178-1) (http://pub.epsilon.slu.se/10864/1/eckersten_h_131022.pdf)

Eckersten H., Bolinder M.A., Johnsson H., Kätterer T., Mårtensson K., Collentine D., Tidåker P., Marstorp H., 2017a. Nitrogen leaching and soil organic carbon sequestration of a Barley crop with improved N use efficiency – A regional case study. Acta Agriculturae Scandinavica, 67, 615-627, http://dx.doi.org/10.1080/09064710.2017.1324041.

Eckersten H, Djurle A, Albihn A, Andersson L, Båge R, de Toro A, Gärdenäs A, Hultgren J, Kvarnheden A, Lewan E, Nkurunziza L, Rosén K, Spörndly R, Vågsholm I, von Rosen D, Yuen J , Magnusson U., 2015. Framtida risker och hot mot svensk spannmåls- respektive mjölkproduktion; en analys av forskningsbehov för att bedöma risker. SLU, Framtidens lantbruk - djur växter och markanvändning, 154 sidor (www.slu.se/framtidenslantbruk).

Eckersten H., Marstorp H., Johnsson H., Collentine D., Kätterer T. 2017b. Ecosystem C and N dynamics affected by a modified spring barley trait with increased nitrogen use - a simulation case study. Acta Agriculturae Scandinavica (accepted for publication September 20, 2017). http://dx.doi.org/10.1080/09064710.2017.1385835

Eckersten, H., Noronha-Sannervik, A., Nyman, P., Torssell, B., 2001b. Modelling mass flows in soil plant systems using Matlab/Simulink. In: Björneå, T.I., Ed. Nordic MATLAB Conference – Program & Proceedings. October 17-18, Oslo, Norway. ISBN 82-995955-0-9. pp II:44-49.

Eckersten, H., Torssell, B., Kornher, Boström, U., 2007b. Modelling biomass, water and nitrogen in grass ley: Estimation of N uptake parameters. European J. Agronomy 27:89-101.

FAO. 1991. The Digitized Soil Map of the World (Release 1.0). World Soil Resources Report 67/1, Food and Agriculture Organization of the United Nations, Rome.

Gärdenäs AI, Berglund SL, Bengtsson SB, Rosén K, 2017. The grain storage of wet-deposited caesium and strontium by spring wheat — A modelling study based on a field experiment. Science of the Total Environment 574:1313–1325.

Gosme M, de Villemandy M, Bazot M, Jeuffroy M-H. 2012. Local and neighbourhood effects of organic and conventional wheat management on aphids, weeds, and foliar diseases. Agriculture Ecosystems & Environment Volume: 161 Pages: 121-129.

Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M., 2005. Cluster Analysis Basics and Extensions. R package version 1.14.2.

Hallbäcken, L. Hägglund, A. 2008. Utredning gällande databaser vid NL-fakulteten SLU; Inst. f. markvetenskap, Inst. f. växtproduktionsekologi, Inst. f. ekologi. Delprojekt 1- Nulägesbeskrivning. 87 sidor.

Höglind M, Van Oijen M, Cameron D, Persson T. 2016. Process-based simulation of growth and overwintering of grassland using the BASGRA model. Ecological Modelling 335:1–15.

Van Oijen, M., Höglind, M., Hanslin, H.M., Caldwell, N., 2005a. Process-based modeling of timothy regrowth. Agron. J. 97, 1295–1303.

Van Oijen, M., Rougier, J., Smith, R., 2005b. Bayesian calibration of process-basedforest models: bridging the gap between models and data. Tree Physiol. 25,915–927.

Van Oijen, M., Reyer, C., Bohn, F.J., Cameron, D.R., Deckmyn, G., Flechsig, M.,Härkönen, S., Hartig, F., Huth, A., Kiviste, A., Lasch, P., Mäkelä, A., Mette, T.,Minunno, F., Rammer, W., 2013. Bayesian calibration, comparison and averaging of six forest models, using data from Scots pine stands across Europe. For. Ecol. Manag. 289:255–268.

Jeuffroy M-H, Gate P, Machet J-M, Recous S. 2013. Nitrogen management in arable crops: Can available knowledge and tools reconcile agronomic and environmental needs? Cahiers Agricultures Volume: 22 Issue: 4 Pages: 249-257 (In French).

Kahneman D. 2015. Tänka snabbt och långsamt. Bokförlaget Volante Stockholm. 677 sidor ISBN 978-91-7503-242-9 (Översättning av Kahneman D 2011, Thinkig fast and slow; Bokman Inc)

Legrand A, Gaucherel C, Baudry J, Meynard J-M. 2011. Long-term effects of organic, conventional, and integrated crop systems on Carabids. Agronomy for Sustainable Development Volume: 31 Issue: 3 Pages: 515-524.

LifWatch 2016. Svenska LifeWatch - En e-infrastruktur för biodiversitetsdata (http://www.slu.se/site/svenska-lifewatch).

Montesino-San Martin, M., Olesen, J.E., Porter, J.R. 2015. Can crop-climate models be accurate and precise? A case study for crop production in Denmark. Agricultural and Forest Meteorology, 202:51-60.

Nendel C, Berg M, Kersebaum KC, Mirschel W, Specka X, Wegehenkel M, Wenkel KO, Wieland R, 2011. The MONICA model: Testing predictability for crop growth, soil moisture and nitrogen dynamics. Ecological Modelling 222, 1614–1625.

Addiscott, T.M., Whitmore, A.P., 1987. Computer-simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. J. Agric. Sci. 109, 141–157.

Challinor, A.J., Wheeler, T.R., Craufurd, P.Q., Slingo, J.M., 2005. Simulation of the impact of high temperature stress on annual crop yields. Agric. For. Meteorol. 135, 180–189.

Hansen, S., Jensen, H.E., Nielsen, N.E., Svendsen, H., 1991. Simulation of nitrogen dynamics and biomass production in winter-wheat using the Danish simulationmodel DAISY. Fert. Res. 27, 245–259.

Mirschel, W., Wenkel, K.-O., 2007. Modelling soil–crop interactions with AGROSIM model family. In: Kersebaum, K.C., Hecker, J.-M., Mirschel, W., Wegehenkel, M. (Eds.), Modelling Water and Nutrient Dynamics in Soil Crop Systems. Springer, Stuttgart, pp. 59–74.

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models, part I – a discussion of principles. J. Hydrol. 10, 282–290.

Pedersen, A., Zhang, K.F., Thorup-Kristensen, K., Jensen, L.S., 2010. Modelling diverse root density dynamics and deep nitrogen uptake – a simple approach. Plant Soil 326, 493–510.

Shaeffer, D.L., 1980. Model evaluation methodology applicable to environmental assessment models. Ecol. Model. 8, 275–295.

van Keulen, H., Penning de Vries, F.W.T., Drees, E.M., 1982. A summary model for crop growth. In: Penning de Vries, F.W.T., van Laar, H.H. (Eds.), Simulation of Plant Growth and Crop Production. PUDOC, Wageningen, pp. 87–97.

Willmott, C.J., Wicks, D.E., 1980. An empirical method for the spatial interpolation of monthly precipitation within California. Phys. Geogr. 1, 59–73.

Penman, H.L. 1948): Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London A (194), S. 120-145.

Persson T, Bergjord Olsen AK, Nkurunziza L, Sindhoj E, Eckersten H. 2017a. Estimation of Crown Temperature of Winter Wheat and the Effect on Simulation of Frost Tolerance. J Agro Crop Sci ISSN 0931-2250. 203:161-176.

Persson T, Höglind M, Gustavsson A-M, Halling M, Jauhiainen L, Niemeläinen O, Thorvaldsson G, Virkajärvi P. 2014. Evaluation of the LINGRA timothy model under Nordic conditions. Field Crops Research 161:87–97.

Höglind M, Schapendonk A,Van Oijen M . 2001. Timothy growth in Scandinavia : combining quantitative information and simulation modelling. New Phytol. 151:355–367.

Schapendonk A, Stol W, van Kraalingen DWG, Bouman BAM. 1998. LINGRA, a sink/source model to simulate grassland productivity in Europe. Eur. J. Agron. 9, 87–100.

Thorsen SM, Roer AG, Van Oijen, M. 2010. Modelling the dynamics of snow cover, soil frost and surface ice in Norwegian grasslands. Polar Res. 29:110–126.

Pirttioja, N., Carter, T.R., Fronzek, S., Bindi, M., Hoffmann, H., Palosuo, T., Ruiz-Ramos, M., Tao, F., Trnka, M., Acutis, M., Asseng, S., Baranowski, P., Basso, B., Bodin, P., Buis, S., Cammarano, D., Deligios, P., Destain, M.-F., Dumont, B., Ewert, F., Ferrise, R., François, L., Gaiser, T., Hlavinka, P., Jacquemin, I., Kersebaum, K.C., Kollas, C., Krzyszczak, J., Lorite, I.J., Minet, J., Minguez, M.I., Montesino, M., Moriondo, M., Müller, C., Nendel, C., Öztürk, I., Perego, A., Rodríguez, A., Ruane, A.C., Ruget, F., Sanna, M., Semenov, M.A., Slawinski, C., Stratonovitch, P., Supit, I., Waha, K., Wang, E., Wu, L., Zhao, Z., Rötter, R.P. 2015. Temperature and precipitation effects on wheat yield across a European transect: a crop model ensemble analysis using impact response surfaces. Climate Research 65: 87-105.

Preissel S, Reckling M, Schläfke N, Zander P, 2015. Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. Field Crops Research 175:64–79.

Pettersson, C.G., H. Eckersten, H. 2007. Prediction of grain protein in spring malting barley grown in northern Europe. European J. Agronomy 27:205-214.

Reckling M, Hecker J-M, Bergkvist G, Watson CA, Zander P, Schläfke N, Stoddard FL, Eory V, Topp CFE, Maire J, Bachinger J, 2016a. A cropping system assessment framework—Evaluating effects of introducing legumes into crop rotations. Eur.J.Agron. 76,186–197.doi:10.1016/j.eja.2015.11.005

Reckling M, Bergkvist G, Watson CA, Stoddard FL, Zander PM, Walker RL, Pristeri A, Toncea I, Bachinger J, 2016b. Trade-Offs between Economic and Environmental Impacts of Introducing Legumes into Cropping Systems. Front. Plant Sci., http://dx.doi.org/10.3389/fpls.2016.00669

Kollas,C.,Kersebaum,K.C.,Nendel,C.,Manevski,K.,Müller,C., Palosuo,T.,etal. 2015. Crop rotation modelling – A European model intercomparison. Eur.J. Agron. 70,98–111.doi:10.1016/j.eja.2015.06.007

Smith, B., Prentice, I.C., Sykes, M.T. 2001. Representation of vegetation dynamics in modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space. Global Ecology and Biogeography 10: 621-637.

Smith, B., Wårlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J., and Zaehle, S. 2014. Implications of incorporating N cycling and N limitations on primary production in an individual-based dynamic vegetation model, Biogeosciences, 11, 2027-2054.

Specka X, Nendel C, Wieland R, 2015. Analysing the parameter sensitivity of the agro-ecosystem model MONICA for different crops. Europ. J. Agronomy 71:73–87.

Cukier, R.I., Fortuin, C.M., Shuler, K.E., Petschek, A.G., Schaibly, J.H., 1973. Study ofthe sensitivity of coupled reaction systems to uncertainties in rate coefficients.I. Theory. J. Chem. Phys. 59, 3873–3878, http://dx.doi.org/10.1063/1.1680571.

Morris, M.D., 1991. Factorial sampling plans for preliminary computational experiments. Technometrics 33, 161–174.

Stratonovitch P, Semenov MA. 2010. Calibration of a crop simulation model using an evolutionary algorithm with self-adaptation. Procedia-Social and Behavioral Sciences, 2, 7749-7750.

Thorp KR, DeJonge KC, Kaleita AL, Batchelor WD, Paz JO. 2008. Methodology for the use of DSSAT models for precision agriculture decision support. computers and electronics in agriculture 64:276–285

Tidåker P., Bergkvist G., Bolinder M., Eckersten H., Johnsson H., Kätterer T., Weih M. 2016. Estimating the environmental footprint of barley with improved nitrogen uptake efficiency - a Swedish scenario study. European Journal of Agronomy 80: 45–54.

Torssell, B., Eckersten, H., Kornher, A., Nyman, P., Boström, U., 2007. Modelling carbon dynamics in mixed grass-red clover swards. Agricultural Systems Vol.94 issue 2: 273-280.

Wolf, J., 2012. LINTUL5: Simple Generic Model for Simulation of Crop Growth Under Potential, Water Limited and Nitrogen, Phosphorus and Potassium Limited Conditions. Plant Production Systems Group. Wageningen University, Wageningen (63 pp. See: http://models.pps.wur.nl/models?page=1).

Wolf J, Kanellopoulos A, Kros J, Webber H, Zhao G, Britz W, Reinds GJ, Ewert F, de Vries W, 2015. Combined analysis of climate, technological and price changes on future arable farming systems in Europe. Agricultural Systems 140:56–73.

Britz, W., Witzke, P., 2012. CAPRI model documentation 2012. (See: http://www.caprimodel.org/docs/capri_documentation.pdf). http://www.capri-model.org/dokuwiki/doku.php

Gaiser, T., Perkons, U., Küpper, P.M., Kautz, T., Uteau-Puschmann, D., Ewert, F., Enders, A., Krauss, G., 2013.Modeling biopore effects on root growth and biomass production on soils with pronounced sub-soil clay accumulation. Ecol. Model. 256, 6–15.

de Vries, W., Leip, A., Reinds, G.J., Kros, J., Lesschen, J.P., Bouwman, A.F., 2011. Comparison of land nitrogen budgets for European agriculture by various modeling approaches. Environ. Pollut. 159, 3253–3267.

Janssen, S., Louhichi, K., Kanellopoulos, A., Zander, P., Flichman, G., Hengsdijk, H., Meuter, E., Andersen, E., Belhouchette, H., Blanco, M., Borkowski, N., Heckelei, T., Hecker, M., Li, H., Oude Lansink, A., Stokstad, G., Thorne, P., van Keulen, H., van Ittersum, M.K., 2010. A generic bio-economic farm model for environmental and economic assessment of agricultural systems. Environ. Manag. 46, 862–877.

Kros, J., Frumeau, K.F.A., Hensen, A., de Vries,W., 2011. Integrated analysis of the effects of agricultural management on environmental quality at landscape scale. Environ. Pollut. 159, 3170–3181.

Louhichi, K., Kanellopoulos, A., Janssen, S., Flichman, G., Blanco, M., Hengsdijk, H., Heckelei, T., Berentsen, P., Oude Lansink, A., van Ittersum, M.K., 2010. FSSIM, a bioeconomic farm model for simulating the response of EU farming systems to agricultural and environmental policies. Agric. Syst. 103, 585–597.

References (Scaling)

Benoit, M., Rizzo, D., Marraccini, E., Moonen, A.C., Galli, M., Lardon, S., Rapey, H., Thenail, C., Bonari, E., 2012. Landscape agronomy: a new field for addressing agricultural landscape dynamics. Landsc. Ecol. 27 (10), 1385-1394. http://dx.doi.org/10.1007/s10980-012-9802-8.

Guamán Sarango V, 2016. Biological and mechanical subsoiling in potato production – a participatory research approach. Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala. Acta Universitatis agriculturae Sueciae 2015:135. ISSN 1652-6880, ISBN (print version) 978-91-576-8468-4

Hoffmann H, Zhao G, Van Bussel LGJ, Enders A, Specka X, Sosa C, Yeluripati J, Tao F, Constantin C, Raynal H, Teixeira E, Grosz B, Doro L, Zhao Z, Wang E, Nendel C, Kersebaum K-C, Haas E, Kiese R, Klatt S, Eckersten H, Vanuytrecht E, Kuhnert M, Lewan E, Rötter R, Roggero PP, Wallach D, Cammarano D, Asseng S, Krauss G, Siebert S, Gaiser T, Ewert F., 2015. Variability of effects of spatial climate data aggregation on regional yield simulation by crop models. Climate Research 65, 53-69.

Semenov MA, Barrow EM. 1997. Use of a stochastic weather generator in the development of climate change scenarios. Climate Change 35:397-414.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecol. Lett. 8, 857–874.

Vogeler I, Cichota R, Beautrais J. 2016. Linking Land Use Capability classes and APSIM to estimate pasture growth for regional land use planning. Soil Research, 54, 94–110 http://dx.doi.org/10.1071/SR15018

Li FY, Snow VO, Holzworth DP. 2011. Modelling seasonal and geographical pattern of pasture production in New Zealand - validating a pasture model in APSIM. New Zealand Journal of Agricultural Research 54,331–352. doi:10.1080/00288233.2011.613403

van Bussel LGJ. 2011. From field to globe: Upscaling of crop growth modelling Thesis, Wageningen University, Wageningen, The Netherlands, 212 pages. ISBN 978-94-6173-015-2 (http://edepot.wur.nl/180295)

Winqvist C, Ahnstrom J, Bengtsson J, 2012. Effects of organic farming on biodiversity and ecosystem services: taking landscape complexity into account. Ann. N.Y. Acad. Sci. 1249: 191–203.

Zhao G, Hoffmann H, Van Bussel LGJ, Enders A, Specka X, Sosa C, Yeluripati J, Tao F, Constantin J, Raynal H, Teixeira E, Grosz B, Doro L, Zhao Z, Nendel C, Kiese R, Eckersten H, Haas E, Vanuytrecht E, Wang E, Kuhnert M, Trombi G, Moriondo M, Bindi M, Lewan E, Bach M, Kersebaum K-C, Rötter R, Roggero PP, Wallach D, Cammarano D, Asseng S, Krauss G, Siebert S, Gaiser T, Ewert F., 2015. Effect of weather data aggregation on regional crop simulation for different crops, production conditions, and response variables. Climate Research 65, 141-157.

References (Understanding)

Ahmed M, Akram MN, Asim M, Aslam M, Hassan F, Higgins S, Stöckle CO, Hoogenboom G. 2016. Calibration and validation of APSIM-Wheat and CERES-Wheat for spring wheat under rainfed conditions: Models evaluation and application. Computers and Electronics in Agriculture 123:384–401.

Zheng, B., Chenu, K., Doherty, A., Doherty, T., Chapman, L., 2014. The APSIM-Wheat Module. APSRU Toowoomba, Australia, pp. 1–44.

Anonymous, 2001. Review on the possible interactions of pests, diseases and weeds in cereals grown in organic and conventional agriculture (No. OF0194). Ministry of Agriculture, Fisheries and Food, U.K.

Dabney, S.M., Delgado, J.A.,, Reeves, D.W. 2001. Using cover crops to improve soil and water quality. Communications in Soil Sciences and Plant Analysis, 32, 1221-1250.

Del Ponte, E.M., Fernandes, J.M.C., Pavan, V., 2005. A Risk Infection Simulation Model for Fusarium Head Blight of Wheat. Fitopatologia Brasileira 30, 634-642.

Everitt BS, Landau S, Leese M, Stahl D. 2011. Cluster analysis, 5th edn. Wiley, New York

Lindström, G., Pers, C.P., Rosberg, R., Strömqvist, J., Arheimer, B. 2010. Development and test of the HYPE (Hydrological Predictions for the Environment) model – A water quality model for different spatial scales. Hydrology Research 41.3-4:295-319.

Nave, Stefanie; Jacquet, Florence; Jeuffroy, Marie-Helene, 2013.Why wheat farmers could reduce chemical inputs: evidence from social, economic, and agronomic analysis. Agronomy for Sustainable Development Volume: 33 Issue: 4 Pages: 795-807.

Nkurunziza L, Kornher A, Hetta M, Halling M, Weih M, Eckersten H 2014. Crop genotype-environment modelling to evaluate forage maize cultivars under climate variability. Acta Agriculturae Scandinavica, Section B - Soil & Plant Science, Vol. 64, No. 1, 56-70 http://dx.doi.org/10.1080/09064710.2014.885076

Pelzer E, Hombert N, Jeuffroy M-H, Makowski D. 2014. Meta-Analysis of the Effect of Nitrogen Fertilization on Annual Cereal-Legume Intercrop Production. Agronomy Journal, Vol:106 Issue: 5 Pages: 1775-1786

Rossi, V., Giosue, S., Pattori, E., Spanna, F., Del Vecchio, A., 2003. A model estimating the risk of Fusarium head blight on wheat. Bulletin OEPP/EPPO 33, 421-425.

Voisin A-S, Guéguen J, Huyghe C, Jeuffroy M-H, Magrini M-B, Meynard J-M, Mougel C, Pellerin S, Pelzer E. 2014. Legumes for feed, food, biomaterials and bioenergy in Europe: a review. Agronomy For Sustainable Development Volume: 34 Issue: 2 Pages: 361-380.

Zander P, Amjath-Babu TS, Preissel S, Reckling M, Bues A, Schläfke N, Kuhlman T, Bachinger J, Uthes S, Stoddard F, Murphy-Bokern D, Watson C. 2016. Grain legume decline and potential recovery in European agriculture: a review. Agron. Sustain. Dev. 36:26. DOI 10.1007/s13593-016-0365-y

References (Models and databases)

Bergez J-E, Chabrier P, Gary C, Jeuffroy M-H, Makowski D, Quesnel G, Ramat E, Raynal H, Rousse N, Wallach D, Debaeke P, Durand P, Duru M, Dury J, Faverdin P, Gascuel-Odoux C, Garcia F. 2013. An open platform to build, evaluate and simulate integrated models of farming and agro-ecosystems. Environmental Modelling & Software Volume: 39 Special Issue: SI Pages: 39-49.

Casadebaig, P., Guilioni, L., Lecoeur, J., Christophe, A., Champolivier, L., Debaeke, P., 2011. SUNFLO, a model to simulate genotype-specific performance of sunflower .

Debaeke, P., Champolivier, L., Jouffret, P., Lecomte, V., Salvi, F., Thibierge, J., Vogrincic, C., 2010. A Model to Simulate Sunflower Oilseed Production on the Supplying Area of an Agricultural Cooperative. Proc. 11th ESA Congress. AGRO2010, Montpellier. 873-874.

Le Gal, P.Y., Merot, A., Moulin, C.H., Navarrete, M., Wery, J., 2010. A modelling framework to support farmers in designing agricultural production systems. Environmental Modelling & Software 25, 258-268.

Martin-Clouaire, R., Rellier, J.P., 2009. Modelling and simulating work practices in agriculture. IJMSO 4, 42-53.

Moreau, P., Salmon-Monviola, J., Durand, P., Ramat, E., Baratte, C., Faverdin, P., Gascuel-Odoux, C., Ruiz, L., 2010. Designing innovative farming systems in catchments to limit diffuse pollution: development of a coupled model to assess farmer strategies in mitigation options implementation. In: Proc. 11th ESA Congress. AGRO2010. Montpellier.

Quesnel, G., Duboz, R., Ramat, E., 2009. The virtual laboratory environment - an operational framework for multi-modelling, simulation and analysis of complex dynamical systems. Simulation Modelling Practice and Theory 17, 641-653.

Zeigler, B.P., Praehofer, H., Gon Kim, T., 2000. Theory of Modelling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems. Academic Press, 510 pp.

Bindi, M., 2013. MACSUR, CropM WP1: progress report

Brown, H., Huth, N.I., Holzworth, D.P., Zyskowski, R.F., Teixeira, E.I., Hargraves, J.N.I., Moot, D., 2014. Plant modelling framework: software for building and running crop models on the apsim platform. Environ. Model. Softw. 62, 385-398.

Brun F, Wallach D, Makowski D, Jones JW. 2006. Working with Dynamic Crop Models: Evaluation, Analysis, Parameterization, and Applications. Ch6: Parameter Estimation with Classical Methods (Model Calibration). Book, Elsevier, 462 pp.

Eckersten H, Jansson P-E. 1991. Modelling water flow, nitrogen uptake and production for wheat. Fertilizer Research 27:313-329.

Eckersten m fl. 2012): ”En detaljerad bedömning av klimatförändringars effekter på Europeiskt jordbruk och livsmedelssäkerhet i samarbete med informella projekt”. Formas projekt inom ramen för EU-kunskapsnav MACSUR

Herrmann, A., Kornher, A.,, Taube, F. 2005b. A new harvest time prognosis tool for forage maize production in Germany. Agricultural and Forest Meteorology, 130, 95-111.

Holzworth, D., Huth, N., deVoil, P., Zurcher, E., Herrmann, N., McLean, G., Chenu, K., van Oosterom, E., Snow, V., Murphy, C., Moore, A., Brown, H., Whish, J., Verrall, S., Fainges, J., Bell, L., Peake, A., Poulton, P., Hochman, Z., Thorburn, P., Gaydon, D., Dalgliesh, N., Rodriguez, D., Cox, H., Chapman, S., Doherty, A., Teixeira, E., Sharp, J., Cichota, R., Vogeler, I., Li, F., Wang, E., Hammer, G., Robertson, M., Dimes, J., Carberry, P., Hargreaves, J., MacLeod, N.C.M., Harsdorf, J.,Wedgewood, S., Keating, B., 2014. APSIM - evolution towards a new generation of agriculutral systems simulation. Environ. Model. Softw. 62:327-350.

Chapman, S., Cooper, M., Podlich, D.W., Hammer, G., 2003. Evaluating plant breeding strategies by simulating gene action and dryland environment effects. Agron. J. 95, 99-113.

Chenu, K., Deihimfard, R., Chapman, S.C., 2013a. Large-scale characterization of drought pattern: a continent-wide modelling approach applied to the Australian wheat belt spatial and temporal trends. New Phytol. 198 (3), 801-820.

Chenu, K., Doherty, A., Rebetzke, G.J., Chapman, S.C., 2013b. StressMaster: a web application for dynamic modelling of the environment to assist in crop improvement for drought adaptation. In: Sievänen, R., Nikinmaa, E., Godin, C., Lintunen, A., Nygren, P. (Eds.), 7th International Conference on Functional- Structural Plant Model, pp. 357-359. Saariselkä, Finland.

Hammer, G.L., Chapman, S., van Oosterom, E., Podlich, D.W., 2005. Trait physiology and crop modelling as a framework to link phenotypic complexity to underlying genetic systems. Aust. J. Agric. Res. 56 (9), 947-960.

Messina, C.D., Podlich, D., Dong, Z., Samples, M., Cooper, M., 2011. Yield-trait performance landscapes: from theory to application in breeding maize for drought tolerance. J. Exp. Bot. 62 (3), 855-868.

Hossard L, Souchere V, Pelzer E, Pinochet X, Jeuffroy M-H. 2015. Meta-modelling of the impacts of regional cropping system scenarios for phoma stem canker control. European Journal of Agronomy Volume: 68 Pages: 1-12.

Jansson, P.-E., 2012. CoupModel: Model Use, Calibration, and Validation. Trans. ASABE 55, 931 1337–1346. doi:10.13031/2013.42245

Jansson P-E and Karlberg L. 2004. Coupled heat and mass transfer model for soil-plant-atmosphere systems. Royal Inst. of Technology, Dept. of Civil and Environmental Engineering, Stockholm. 427 pp. http://www2.lwr.kth.se/Vara%20Datorprogram/CoupModel/coupmanual.pdf

Johnsson H, Bergström L, Jansson P-E. 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. Agric. Ecosyst. Environ. 18:333-356.

MACSUR, 2013. ”Modelling European Agriculture with Climate Change for Food Security”. FACCE-JPI knowledge-hub. (http://www.macsur.eu/)

Montesino-San Martin, M. 2014. Uncertainties in Agricultural Impact Assessments of Climate Change. University of Copenhagen. Department of Plant and Environmental Sciences, Denmark, (PhD thesis) 88 pp.

Montesino-San Martin, M., Olesen, J.E., Porter, J.R. 2014. A genotype, environment and management (GxExM) analysis of adaptation in winter wheat to climate change in Denmark. Agricultural and Forest Meteorology, 187, 1-13 p.

Nkurunziza L, Halling M, Weih M, Eckersten H. 2014a. Can data series from variety testing be used to predict yields in leys? International Journal of Agri Science Vol. 4(11): 486-489.

Torssell B, Eckersten H, Anbari S, Lundkvist A, Verwijst T. 2015. Modelling below-ground shoot elongation and emergence time of Sonchus arvensis shoots. Acta Agric Scand, Sect B – Soil & Plant Sci. 65:582–588.

Torssell, B, Eckersten H, Lundkvist, A, Verwijst, T. Modelling Sonchus arvensis root biomass allocation to below-ground shoot and fine root growth. Acta Agriculturae Scandinavica, Sect B – Soil & Plant Sci. 66:476–482.

References (Models and databases) from Jeuffroy et al. (2014)

Jeuffroy, Marie-Helene; Casadebaig, Pierre; Debaeke, Philippe; Loyce C, Meynard J-M, 2014. Agronomic model uses to predict cultivar performance in various environments and cropping systems. A review. Agronomy for Sustainable Development Volume: 34 Issue: 1 Pages: 121-137.

Agüera F, Villalobos FJ, Orgaz F. 1997. Evaluation of sunflower (Heliantus annuus, L.) genotypes differing in early vigour using a simulation model. Eur J Agr 7:109–118. doi:10.1016/S1161-0301(97)00023-3

Asseng S, Turner NC, Botwright T, Condon AG. 2003. Evaluating the impact of a trait for increased specific leaf area on wheat yields using a crop simulation model. Agron J 95:10–19. doi:10.2134/agronj2003.1000

Bannayan M, Crout MJ, Hoogenboom G. 2003. Application of the CERES-wheat model for within season prediction of winter wheat yield in the United Kingdom. Agron J 95:114–125. doi:10.2134/ agronj2003.1140

Barbottin A. 2004. Utilisation d'un modèle de culture pour évaluer le comportement des génotypes: Pertinence de l'utilisation d'Azodyn pour analyser la variabilité du rendement et de la teneur en protéines du blé tendre. Thèse de Doctorat, INA P-G, Paris.

Barbottin A, Lecomte C, Bouchard C, Jeuffroy MH. 2005. Nitrogen remobilisation during grain filling in wheat: genotypic and environmental effects. Crop Sci 45:1141–1150. doi:10.2135/ cropsci2003.0361

Barbottin A, Le Bail M, Jeuffroy MH. 2006. The Azodyn crop model as a decision support tool for choosing cultivars. Agron Sustain Dev 26:107–115. doi:10.1051/agro:2006003

Becker HC, Leon J. 1988. Stability analysis in plant-breeding. Plant Breed 101:1–23. doi:10.1111/j.1439-0523.1988.tb00261.x

Boote KJ, Jones JW, Pickering NB. 1996. Potential uses and limitations of crop models. Agron J 88:704–716. doi:10.2134/agronj1996 00021962008800050005x
Boote KJ, Kropff MJ, Bindraban PS. 2001. Physiology and modelling of traits in crop plants: implications for genetic improvement.Agric Syst 70:395–420. doi:10.1016/S0308-521X(01)00053-1
Boote KJ, Jones JW, Batchelor WD, Nafziger ED, Myers O. 2003. Genetic coefficients in the CROPGRO-soybean model: links to field performance and genomics. Agron J 95:32–51. doi:10.2134/agronj2003.3200
Brisson N, Ruget F, Gate P, Lorgeou J, Nicoullaud B, Tayot X, Plenet D, Jeuffroy MH, Bouthier A, Ripoche D, Mary B, Justes E. 2002. STICS: a generic model for simulating crops and their water and nitrogen balances. II. Model validation for wheat and maize.Agronomie 22:69–92. doi:10.1051/agro:2001005
Chapman S, Cooper M, Podlich D, Hammer GL. 2003. Evaluating plant breeding strategies by simulating gene action and dryland environment effects. Agron J 95:99–113. doi:10.2134/agronj2003.9900
Colson J, Bouniols A, Jones JW. 1995. Soybean reproductive development: Adapting a model for European cultivars. Agron J 87:1129–1139. doi:10.2134/agronj1995.00021962008700060015x
Cox MC, Qualset CO, Rains DW. 1986. Genetic-variation for nitrogen assimilation and translocation in wheat. 3. Nitrogen translocation in relation to grain-yield and protein. Crop Sci 26:737–740. doi:10.2135/cropsci1986.0011183X002600040022x
Debaeke P, Casadebaig P, Mestries E, Palleau JP, Salvi F, Bertoux V, Uyttewaal V. 2011. Evaluer et valoriser les interactions variétémilieu- conduite en tournesol. Innovations Agronomiques 14:77–90.
Hammer GL, Goyne PJ, Woodruff DR. 1982. Phenology of sunflower cultivars. III. Models for prediction in field environments. Aust J Agric Res 33:251–261. doi:10.1071/AR9820263
Hoogenboom G, White JW, Acosta-Gallegos J, Gaudiel RG, Myers JR, Silbernagel MJ. 1997. Evaluation of a crop simulation model that incorporates gene action. Agron J 89:613–620. doi:10.2134/agronj1997.00021962008900040013x
Hunt LA, Reynolds MP, Sayre KD, Rajaram S, White JW, Yan W. 2003. Crop modeling and the identification of stable coefficient that may reflect significant groups of genes. Agron J 95:20–31.doi:10.2134/agronj2003.2000
Jeuffroy MH, Barré C, Bouchard C, Demotes-Mainard S, Devienne-Barret F, Girard ML, Recous S. 2000. Fonctionnement d'un peuplement de blé en conditions de nutrition azotée suboptimale.In: Bonhomme R, Maillard P (eds) Fonctionnement des peuplements végétaux sous contraintes environnementales.INRA, Paris, Les Colloques n°93, pp 289–304.
Jeuffroy MH, Barbottin A, Jones JW, Lecoeur J. 2006. Crop-models with genotype parameters. In: Wallach D, Makowski D, Jones JW (eds) Working with dynamic crop models—evaluation, analysis, parameterization and applications. Elsevier, Amsterdam (The Netherlands), pp 281–307.
Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT. 2003. The DSSAT cropping system model. Europ. J. Agronomy 18:235-265.
Lecomte C, Prost L, Cerf M, Meynard JM. 2010. Basis for designing a tool to evaluate new cultivars. Agron Sustain Dev 30:667–677.doi:10.1051/agro/2009042
Loyce C, Meynard JM, Bouchard C, Rolland B, Lonnet P, Bataillon P, Bernicot MH, Bonnefoy M, Charrier X, Debote B, Demarquet T, Duperrier B, Félix I, Heddadj D, Leblanc O, Leleu M, Mangin P, Méausoone M, Doussinault G. 2008. Interaction between cultivar and crop management effects on winter wheat diseases, lodging, and yield. Crop Prot 27:1131–1142. doi:10.1016/j.cropro.2008.02.001
Loyce C, Rellier JP, Meynard JM. 2002a. Management planning for winter wheat with multiple objectives (1): the BETHA system. Agric Syst 72(1):9–31. doi:10.1016/S0308-521X(01)00064-6
Makowski D, Hillier J, Wallach D, Andrieu B, Jeuffroy MH. 2006a. Parameter estimation for crop models. In: Makowski D, Jones JW, Wallach D (eds) Working with dynamic crop models. Elsevier, New York, pp 101–149.
Makowski D, Naud C, Jeuffroy MH, Barbottin A, Monod H. 2006b. Global sensitivity analysis for calculating the contribution of genetic parameters to the variance of crop model predictions. Reliab Eng Syst Saf 91:1142–1147. doi:10.1016/j.ress.2005.11.015
Mavromatis T, Boote KJ, Jones JW, Irmak A, Shinde D, Hoogenboom G. 2001. Developing genetic coefficients for crop simulation models with data from crop performance trials. Crop Sci 41:40–51. doi:10.2135/cropsci2001.41140x
Reymond M, Muller B, Leonardi A, Charcosset A, Tardieu F. 2003. Combining quantitative trait loci analysis and an ecophysiological model to analyze the genetic variability of the responses of maize leaf growth to temperature and water deficit. Plant Physiol 131:664–675.
Shorter R, Lawn RJ, Hammer GL. 1991. Improving genotypic adaptation in crops—a role for breeders, physiologists and modellers. Exp Agric 27:155–175. doi:10.1017/S0014479700018810
Sinclair TR, Muchow RC. 2001. System analysis of plant traits to increase grain yield on limited water supplies. Agron J 93:263–270. doi:10.2134/agronj2001.932263x
Travasso MI, Magrin GO. 1998. Utility of CERES-barley under Argentine conditions. Field Crops Res 57:329–333. doi:10.1016/S0378-4290(98)00079-3
Wallach D, Goffinet B. 1987. Mean squared error of prediction in models for studying ecological and agronomic systems. Biometrics 43:561–573.
Wallach D, Goffinet B. 1989. Mean squared error of prediction as a criterion for evaluating and comparing systems models. Ecol Model 44:299–306. doi:10.1016/0304-3800(89)90035-5
Wallach D, Goffinet B, Bergez JE, Debaeke P, Leenhardt D, Aubertot JN. 2001. Parameter estimation for crop models: a new approach and application to corn model. Agron J 93:757–766. doi:10.2134/agronj2001.934757x

White JW, Hoogenboom G. 1996. Simulating effects of genes for physiological traits in a process-oriented crop model. Agron J 88:416–422. doi:10.2134/agronj1996.00021962008800030009x

Villalobos FJ, Hall AJ, Richie JT, Orgaz F. 1996. OILCROP-SUN: a development, growth, and yield model of the sunflower crop. Agron J 88:403–415. doi:10.2134/agronj1996.00021962008800030008x

Yin X, Kropff MJ, Goudriaan J, Stam P. 2000. A model analysis of yield differences among recombinant inbreed lines in barley. Agron J 92:114–120. doi:10.2134/agronj2000.921114x

Yin X, Struik PC. 2010. Modelling the crop: from system dynamics to systems biology. J Exp Bot 61:2171–2183. doi:10.1093/jxb/erp375

Yin X, van Laar HH. 2005. Crop systems dynamics: an ecophysiological simulation model for genotype-by-environment interactions. Wageningen Academic Publishers, Wageningen

Zhang XY. 2005. Modélisation de la réponse des variétés de blé au niveau d'intensification. Influence de la pression de maladies foliaires, Thèse INA P-G, Paris

Zhang XY, Loyce C, Meynard JM, Savary S. 2006. Characterization of multiple disease systems and cultivar susceptibilities for the analysis of yield losses in winter wheat. Crop Prot 25:1013–1023.doi:10.1016/j.cropro.2006.01.013

References (Models and databases) DSSAT from Jones et al. (2003)

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT. 2003. The DSSAT cropping system model. Europ. J. Agronomy 18:235-265.

Batchelor, W.D., Jones, J.W., Boote, K.J., Pinnschmidt, H.O.,1993. Extending the use of crop models to study pest damage. Transactions of the ASAE 36 (2), 551-558.

Boote, K.J., Batchelor, W.D., Jones, J.W., Pinnschmidt, H., Bourgeois, G., 1993. Pest damage relations at the field level. In: Penning de Vries, F.W.T., et al. (Eds.), Systems Approaches for Agricultural Development. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Boote, K.J., Jones, J.W., Hoogenboom, G., 1998a. Simulation of crop growth: CROPGRO model. In: Peart, R.M., Curry, R.B. (Eds.), Agricultural Systems Modeling and Simulation (Chapter 18). Marcel Dekker, Inc, New York, pp. 651_/692.

Boote, K.J., Jones, J.W., Mishoe, J.W., Berger, R.D., 1983. Coupling pests to crop growth simulators to predict yield reductions. Phytopathology 73 (11), 1581-1587.

Geng, S., Penning de Vries, F.W.T., Supit, I., 1986. A simple method for generating daily rainfall data. Agricultural and Forest Meteorology 36, 363-376.

Geng, S., Auburn, J., Brandstetter, E., Li, B., 1988. A program to simulate meteorological variables. Documentation for SIMMETEO. Agronomy Report No. 204. University of California, Davis Crop Extension, Davis, CA.

Hoogenboom, G., White, J.W., Jones, J.W., Boote, K.J., 1994b. BEANGRO: A process-oriented dry bean model with a versatile user interface. Agronomy Journal 86, 182-190.

Jones, C.A., Dyke, P.T., Williams, J.R., Kiniry, J.R., Benson, V.W., Griggs, R.H., 1991. EPIC: an operational model for evaluation of agricultural sustainability. Agricultural Systems 37, 341-350.

Parton, W.J., Stewart, J.W.B., Cole, C.V., 1988. Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5, 109-131.

Parton, W.J., Ojima, D.S., Cole, C.V., Schimel, D.S., 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. In: Bryant, R.B., Arnold, R.W. (Eds.), Quantitative Modeling of Soil Forming Processes (Special Publication 39). SSSA, Madison, WI, pp. 147-167.

Richardson, C.W., 1981. Stochastic simulation of daily precipitation, temperature, and solar radiation. Water Resources Research 17 (1), 182-190.

Richardson, C.W., 1985. Weather simulation for crop management models. Transactions of the ASAE 28 (5), 1602/1606.

Ritchie, J.T., 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resources Research 8, 1204-1213.

Ritchie, J.T., Otter, S., 1985. Description and performance of CERES-Wheat: a user-oriented wheat yield model. In: ARS Wheat Yield Project. ARS-38. Natl Tech Info Serv, Springfield, Missouri, pp. 159-175.

Seligman, N.C., Van Keulen, H., 1981. PAPRAN: a simulation model of annual pasture production limited by rainfall and nitrogen. In: Frissel, M.J., Van Veen, J.A. (Eds.), Simulation of Nitrogen Behaviour of Soil _/Plant Systems. Centrum voor Landbouwpublikaties en Landbouwdocumentatie (PUDOC), Wageningen, Netherlands, pp. 192-221.

Williams, J.R., Jones, C.A., Dyke, P.T., 1984. A modeling approach to determining the relationships between erosion and soil productivity. Transactions of the ASAE 27, 129-144.

References (Models and databases) APSIM from Keating et al. (2003)

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM, Smith CJ. 2003. An overview of APSIM, a model designed for farming systems simulation- Europ. J. Agronomy 18:267-288.

Carberry, P.S., Abrecht, D.G., 1991. Tailoring crop models to the semi-arid tropics. In: Muchow, R.C., Bellamy, J.A. (Eds.), Climatic Risk in Crop Production: Models and Management for the Semiarid Tropics and Subtropics. CAB International, Wallingford, UK, pp. 157-182.

Carberry, P.S., Adiku, S.G.K., McCown, R.L., Keating, B.A., 1996a. Application of the APSIM cropping systems model to intercropping systems. In: Ito, C., Johansen, C., Adu-Gyamfi, K., Katayama, K., Kumar-Rao, J.V.D.K., Rego, T.J. (Eds.), Dynamics of roots and nitrogen in cropping systems of the semi-arid tropics. Japan Int. Res. Centre Agric. Sci., pp. 637-648.

Chapman, S.C., Hammer, G.L., Meinke, H., 1993. A sunflower simulation model: I. Model development. Agronomy J. 85, 725-735.

Hammer, G.L., Muchow, R.C., 1994. Assessing climatic risk to sorghum production in water-limited subtropical environments I. Development and testing of a simulation model. Field Crops Res. 36, 221-234.

Helyar, K.R., Porter, W.M., 1989. Soil acidification, its measurement and the processes involved. In: Robson, A.D. (Ed.), Soil Acidity and Plant Growth. Academic Press, Marrickville, Australia, pp. 61-101.

Jones, C.A., Kiniry, J.R. (Eds.), CERES-Maize: a simulation model of maize growth and development. Texas A&M University Press, College Station 1986, p. 194.

Littleboy, M., Silburn, D.M., Freebairn, D.M., Woodruff, D.R., Hammer, G.L., 1989. PERFECT*/A computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques. Queensland Department of Primary Industries Bulletin, QB89005.

Littleboy, M., Silburn, D.M., Freebairn, D.M., Woodruff, D.R., Hammer, G.L., Leslie, J.K., 1992. Impact of soil erosion on production in cropping systems. I. Development and validation of a simulation model. Aust. J. Soil Res. 30, 757_/774.

Probert, M.E., Keating, B.A., 2000. What soil constraints should be included in crop and forest models? Agric., Ecosyst. Environ. 82, 273-281.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C., Strong, W.M., 1998c. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. Agric. Syst. 56, 1-28.

Ritchie, J.T., 1972. A model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8, 1204-1213.

Seligman, N.G., van Keulen, H., 1981. PAPRAN: a simulation model of annual pasture production limited by rainfall and nitrogen. In: Frissel, M.J., van Veen, J.A. (Eds.), Simulation of Nitrogen Behavior of Soil-Plant Systems. PUDOC, Wageningen, The Netherlands, pp. 192-221.

References (Models and databases) from Eckersten et al. (2013)

Eckersten H, Bergkvist G, Yuen J, Kyllmar K, Kätterer T. 2013. Development of a framework for databases in soil, plant and environment for enhanced usability in agricultural crop production research. Grant application to Vetenskapsrådet March 2013. (available from Eckersten on request).

Anbari S, Lundkvist A, Verwijst T. 2011. Sprouting and shoot development of Sonchus arvensis in relation to initial root size. Weed Research 51, 142–150.

Andersson, L., Karlsson, L., Milberg, P. & Pye, A. 2012. Metod för detektering och uppföljning av förekomsten av arter som är potentiellt framtida ogräs och expanderande ogräs. Vässa växtskyddet för framtidens klimat – Hur vi förebygger och hanterar ökade problem i ett förändrat klimat. Jordbruksverket Rapport 2012:10.

Andrén, O., Kätterer, T. 1997. ICBM - the Introductory Carbon Balance Model for exploration of soil carbon balances. Ecol. Appl. 7(4): 1226-1236.

Andrén, O., Kätterer, T., Karlsson, T., Eriksson, J. 2008. Soil C balances in Swedish agricultural soils 1990-2004, with preliminary projections. Nutr. Cycl. Agroecosyst. 81:129–144.

Arnold, J.G., J.R. Williams, R. Srinivasan, K.W. King, and R.H.Griggs, 1995: SWAT - Soil and Water Assessment Tool: Draft UsersManual, USDA-ARS, Temple, TX.

Barré, P., Eglin, T., Christensen, B.T., Ciais, P., Houot, S., Kätterer, T., van Oort, F., Peylin, P., Poulton, P.R., Romanenkov, V., Chenu, C. 2010. Quantifying and isolating stable soil organic carbon using long-term bare fallow experiments. Biogeosciences 7: 3839–3850.

Blandon-Diaz, U., Forbes, G.A, Andrade-Piedra, J., and Yuen, J. 2011. Assessing the adequacy of the simulation model LATEBLIGHT under Nicaraguan conditions. Plant Disease 95:839-846.

Del Ponte E M, Maurício J C, Fernandes J M C, Pavan W, 2005. A Risk Infection Simulation Model for Fusarium Head Blight of Wheat. Fitopatologia Brasileira 30:634-642.

Eckersten H, Lundkvist A, Torssell B, Verwijst T. 2011. Modelling species competition in mixtures of perennial sow-thistle and spring barley based on shoot radiation use efficiency. Acta Agriculturae Scandinavica, Section B – Soil and Plant Science 61, 739–746.

FFE. 2016. http://www.slu.se/faltforsk

Fogelfors, H., Boström, U., Karlsson L., Lundkvist A., Mannerstedt Fogelfors B. 2007. Ogräsreglering i växtföljder med och utan djurhållning – långliggande växtföljdsförsök i ekologisk odling. www.slu.se/Global/externwebben/nl-fak/vaxtproduktionsekologi/Ekhaga%20Dok/071218_EKHAGAREDOVISNING.pdf

Hallgren, E., Palmer, M.W., Milberg, P. 1999. Data diving with cross-validation: an investigation of broad-scale gradients in Swedish weed communities. Journal of Ecology 87:1037-1051.

Jarvis, N.J., 1995. Simulation of soil water dynamics and herbicide persistence in a silt loam soil using the MACRO model. Ecol. Model., 81, 97-109.

Jansson P-E and Karlberg L. 2004. Coupled heat and mass transfer model for soil-plant-atmosphere systems. Royal Inst. of Technology, Dept. of Civil and Environmental Engineering, Stockholm. 427 pp. http://www2.lwr.kth.se/Vara%20Datorprogram/CoupModel/coupmanual.pdf

Johnsson H., M.H. Larsson, K. Mårtenssson, M. Hoffmann. 2002. SOILNDB: A decision support tool for assessing nitrogen leaching losses from arable land. Environmental Software & Modelling. 17, 505-517.

Klein M. 1994): Evaluation and Comparison of Pesticide Leaching models for Registration Purposes, Results of Simulations performed with the Pesticide Leaching Model, Journal of Environmental Science & Health, A29(6), 1197-1209.

Knisel, W.G., R.A. Leonard, and F.M. Davis., 1993. GLEAMS Version 2.1 Part I:Model Documentation. UGA-CPES-BAED, Pub. 5, Nov. 1993.

Kroes, J.G. and J. Roelsma 1998: ANIMO 3.5; user's guide for the ANIMO version 3.5 nutrient leaching model. Wageningen, SC-DLO, 1998. Techn. Doc. 46, 98 pp.

Kvarnäs, H., 1996. Modellering av näringsämnen i Fyrisåns avrinningsområde. Källfördelning och retention (in Swedish). Rapport från Fyrisåns vattenförbund 1996, 31 pages.

Larsson, M., Persson, K., Ulén, B., Lindsjö, A., Jarvis, N.J., 2007. A dual porosity model to quantify phosphorus losses from macroporous soils. Ecological Modeling 205:123-134.

Whitehead, P.G., Wilson, E.J. and Butterfield, D. 1998. A semi-distributed Integrated Nitrogen Model for Multiple source assessment in Catchments (INCA): Part I - Model Structure and Process Equations. Science of the Total Environment, 210/211: 547-558.

Widén-Nilsson, E., Hansson, K., Wallin, M., Djodjic, F., Orback, C., 2012. The FyrisNP model Version 3.2- User's manual - Technical description. Report 2012:8. Department of water and environment, Swedish University of Agricultural Sciences, Uppsala. 37pp.

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