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Review

Toward more efficient model development for farming systems research – An integrative review

E. Reinmuth *, S. Dabbert

Institute of Farm Management, Section Production Theory and Resource Economics (410a), Universität Hohenheim, 70593 Stuttgart, Germany

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ABSTRACT

Bio-economic simulation models are widely established in Farming Systems Research; they are used to investigate complex real-world phenomena in agricultural production. Such simulation models are largely designed and created by scientists from different disciplines who are not modeling experts. Thus, IT knowledge is required, but this area of expertise falls outside of most agricultural researchers' background. IT knowledge is essential for the maintenance, development, and applicability of simulation models. Often, bio-economic simulation models require a fair amount of time to ensure basic functionality before specific research questions can be answered. Researchers who contribute to the creation of a bio-economic simulation model often spend the majority of their time ensuring basic model functionality. This integrative literature review provides a few basic rules that are intended to ensure more efficient model development. There is an increased need for support from IT personnel who are not researchers in their own field but who can increase the quality of such models and their reusability in different contexts.

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* Corresponding author.
E-mail address: evelyn_reinmuth@uni-hohenheim.de (E. Reinmuth).

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1. Introduction

Farming Systems Research places the farm at the center, and everything in the analysis emanates from it. Farming Systems Research was revolutionized as a result of technical progress, and complex integrated bio-economic simulation models (Janssen and van Ittersum, 2007; Feola et al., 2012) were established as analysis tools. Definitions of integrated bio-economic simulation models are not precise, as this type of model is for the most part unique and resists labelling. Following Janssen and van Ittersum (2007) and Oriade and Dillon (1997), we define an integrated bio-economic simulation model as a model that has components, either parametrical or sub-model types, that are able to describe farmers' management processes according to the chosen context and scale or level of model resolution through computer simulation. An integrated model subsumes interdisciplinary modeling approaches (Dabbert et al., 1999; Oriade and Dillon, 1997; Rotmans and van Asselt, 1996), which can be of a bio-physical, (socio-) economic or institutional nature. Bio-economic simulation models are used in studies of system analysis or impact assessment (Thornton and Herrero, 2001). They are either used by scientists only or serve as a decision support system where scientists in cooperation with stakeholders (farmers for example) try to achieve decision support by modeling the consequences of decisions (Schreinemachers and Berger, 2011; Troost and Berger, 2014; Keating and McCown, 2001). This is a way to gain an understanding of complex real-world phenomena and systems (van Ittersum et al., 2008; Rotmans and van Asselt, 1996), which for the most part cannot be investigated in a laboratory (Schreinemachers and Berger, 2011) or can otherwise be achieved solely through long and costly experiments (Keating and McCown, 2001). "The necessity of a bio-economic model and integrated approaches comes from the fact that both systems (biology and economy) are interrelated (Prellezo et al., 2012, p. 423)."

Farming Systems Research with (integrated) bio-economic simulation models incorporates multiple research fields (Rotmans and van Asselt, 1996), from plant modeling to meteorology and the economic and social sciences. Covering so many disciplines is challenging when recruiting personnel (Dabbert et al., 1999). It is nearly impossible to find people who are experts in all of the required research fields. A specialist in a field of research is necessary to be able to produce results that are publishable in a scientific journal. The fact that results should be obtained via bio-economic modeling requires a commitment to interdisciplinary thinking and a willingness to gain skills that are specific or elementary to a discipline outside one's scientific expertise (Nicolson et al., 2002). As simulation models are computer based, basic knowledge of computational rules is essential. A successful simulation model depends on the application of rules that were established in the field of Information Technology. These rules relate to the establishment, documentation, maintenance, and application of simulation models.

The concept of using simulation models as a research tool dates back to the mid-sixties (Dillon et al., 1991). Tremendous technological progress has occurred since that time. However, the establishment of such a model is still a considerable undertaking that must not be underestimated (Fall and Fall, 2001). It is astonishing how many new models were developed rather than using established models and expanding or customizing them as Dillon et al. (1991) projected. Many of these modeling efforts are forgotten once there is no more funding or a specific research question is answered (van Ittersum et al., 2008; Janssen and van Ittersum, 2007). "A common problem with many models is that they are large, complicated, and poorly documented "black boxes", and consequently few if any researcher beyond the developers are able to use them (Antle and Stoorvogel, 2006, p. 41)." This is also a critical point with regard to replicability of results (Fall and Fall, 2001). Replicability of results, a fundamental aspect of the scientific method, depends heavily on compliance with software design principles in this context (Keating and McCown, 2001).

Models will only be of use for other scientists if their infrastructure offers a good basis for an efficient customization process. Most features that support user-friendliness and model flexibility require a great deal of work, which is seldom part of the research proposal (Holzworth et al., 2014) and does not necessarily lead to scientific or publishable results. Greater user-friendliness and flexibility are the result of high-quality software configuration management and an efficient documentation process. Knowledge about promoting these features in scientific software is gained from the development process. Preventing access to such knowledge can lead "to premature releases of science with users applying incomplete models to real world scenarios, something that risks incorrect analysis (Holzworth et al., 2014, p. 344)".

The crop growth modeler community (both bio-economic simulation models and stand-alone model frameworks) has already addressed this issue. Authors such as Porter et al. (1999) suggested that there is an increased need for research on approaches that support more effective model development as well as a documentation process.

We draw on their propositions when formulating the objective of this paper, for example, providing recommendations that are intended to support a more efficient development of bio-economic simulation models at all levels of complexity, thus making them attractive for re-use. There is certainly no standard or established methodology for formulating such recommendations. We use our own experience from active participation in such interdisciplinary modeling projects as the basis for an integrative literature review (Pautasso, 2013) to create this piece of inductive research. We found further support for our objectives in papers by Janssen and van Ittersum (2007), Nicolson et al. (2002), Keating and McCown (2001), and Dillon et al. (1991), which are in parts literature reviews themselves. Unlike these authors, we place greater emphasis on the practical, technical aspects of the software engineering process. By doing so, we aim to call attention to this issue among non IT-trained scientists who intend to build models for Farming Systems Research as well as to reviewers of these works. Given our limited experience, our recommendations are to be tested in terms of their usefulness to others.

The remainder of this paper is organized as follows. After classification of bio-economic simulation models according to their level of integration, we start by answering how such models should be designed. Then, we show how model improvements or developments at different stages should be managed. We further focus on the importance of testing. We provide a best evidence review of successful models that survived their initial stage and note why they are relevant for re-use. Finally, we explain why IT specialists should be hired to assist with model development and give a short list of mandatory recommendations for future modelers.

1.1. A classification

Simulation models come in all degrees of complexity, depending on the model focus. The implementation of one of the large model frameworks is determined based on research context (scope), expertise, time and financial constraints (Dillon et al., 1991). Often, data availability retards/hinders the generation of a solution by means of a complex bio-economic simulation model. In such cases, sub-models of large modeling frameworks are loosely coupled (Antle et al., 2001) with the parametrical function, where simulation output is used in the parametrical function. This is even more likely when the construct is only a means to investi-

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