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A simulation framework for the design of grassland-based beef-cattle farms

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ABSTRACT

Grassland-based beef-cattle farms are dynamic systems that are difficult to manage, particularly because of their sensitivity to uncontrollable environmental factors such as weather. The design of farms and management strategies capable of coping with a wide range of conditions is thus a challenging issue. The SEDIVER discrete-event simulation framework presented in this article has been developed to support the construction of dynamic simulation models of grassland-based beef-cattle farms for evaluation and empirical design purposes. The originality of the models built with SEDIVER lies in the explicit representation of: (i) management strategies as the planning and coordination of activities in time and space through which the farmer controls the biophysical processes occurring within the system and (ii) the diversity in plant, animals, grassland and farmland, and the management opportunities and difficulties that this might induce. An application example illustrates the kind of simulation-based investigations enabled by SEDIVER. A grassland-based beef-cattle farm in France is examined for two contrasted management strategies: the first one corresponding to the actual practice and the second one paying increased attention to and exploiting plant and grassland diversity. The simulation results showed that the second one could roughly double fodder yields and thus ensure farm self-sufficiency for fodder. Thanks to the capacity of a SEDIVER-based model to take practical production considerations into account, it is possible to increase the realism of farm simulations and the credibility and relevance of the farming systems which can thus be designed.

Software availability

Software name: SEDIVER (version 3.6)
Contact address: Jean-Pierre Rellier, rellier@toulouse.inra.fr
Year first available: 2009
Hardware and Operating System: SEDIVER runs on Linux and Microsoft Windows platforms. The DIESE library pre-compiled for Linux or for Windows respectively must be installed on the selected platform. On Microsoft Windows platforms, the distribution free Linux-like environment Cygwin must first be installed (see http://www.cygwin.com for current availability).
Software required: A Java runtime environment to inspect/develop the SEDIVER framework and generate the corresponding C++ source code, a standard C++ compiler to generate the executable simulator from the source code and the DIESE library.
Programming language: The functional parts of the SEDIVER framework are written in C++. The input files contain specifications written in a specific language documented in the DIESE package. Interpreters for this language are included in the DIESE library.
Availability: The material can be downloaded from http://carlit.toulouse.inra.fr/diese/. It comprises the DIESE package (libraries and documentation) which can be downloaded from the 'Télécharger' page, and the SEDIVER framework and a set of input/output files which can be downloaded from the 'Applications' page.

1. Introduction

In less-favourable areas, beef-cattle production involves the management of a wide diversity of semi-natural grasslands. Herbage production is highly variable in space and time (Pleasants et al., 1995) due to between-field differences in vegetation types, soil conditions and topography and also to weather variability within and between years. Similarly, beef-cattle feeding requirements change over time and between beef-cattle classes (INRA, 2007). Farmers need to be able to take decisions for planned

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management that in turn is able to take situation-dependent factors into account in order to achieve the most efficient use of production resources (grasslands, labour, etc.) over space and time to meet their objectives through a sustainable production system. The design of grassland-based beef-cattle farms capable of coping efficiently with a wide range of conditions (including climate variability and climate change and changing socio-economic conditions, etc.) is thus a challenging issue. This includes changes in the production resources of farms or in farmers' management.

In such systems, we believe that there is great potential for farmers to improve their efficiency through better use of plant (within-field), grassland (between-field), animal and farmland diversity. Diversity adds potential flexibility that can be used in organizational and operational decision-making to cope with variations in uncontrollable factors, such as climate (e.g. White et al., 2004; Andrieu et al., 2007; Martin et al., 2009). For instance, grassland diversity means that particular fields may be suitable for various forms of use, matching the feeding requirements of different beef-cattle classes (e.g. cows vs. heifers) characterized by specific and fluctuating animal intake rates (White et al., 2004). In addition to this organizational flexibility, within-field plant diversity makes it possible to take advantage of operational flexibility in grassland management (Martin et al., 2009), i.e. the extent to which the use of a given grassland may be brought forward or held in reserve at various times of the year.

Simulation (McCown, 2002) is an obvious tool for the study of grassland-based production systems as their complexity makes analytical evaluation or optimization more difficult. However, its potential usefulness as a tool for the empirical design of agricultural systems with extension services and farmers depends on the conceptual richness of its modelling functions. To ensure that the systems designed and evaluated by simulation are credible and relevant to stakeholders' needs, day-to-day farm operations need to be integrated in the model (Keating and McCown, 2001) in order to deal with the practical questions farmers have to answer such as "what should I do, where, when and how?" The model might then focus on the variability of biophysical processes over time and in space, the generated opportunities and constraints on grassland use and the way the farmer copes with them when planning and coordinating farming activities. Besides, developing credible farm-scale simulation models is a costly task that requires considerable agronomic knowledge and modelling skills. To make the simulation approach more accessible and to increase the reusability of previous modelling efforts, the simulation methodology needs to support the modelling process by providing generic knowledge patterns and functions which are suitable for dynamic simulation.

These considerations prompted the development of SEDIVER (Simulation-based Experimentation on livestock systems with plant, grassland, animal and farmland DIVERsity), a discrete-event simulation framework for supporting the construction of farm-scale dynamic models capable of reproducing the interactions on grassland-based beef-cattle farms between the biophysical and management processes in response to external factors such as weather. The purpose of this article is to present both this framework and an example of its application that illustrates the kinds of investigation enabled. In Section 2, the modelling approach and the ontology of agricultural production systems on which it relies are briefly described. Section 3 describes the domain-specific concepts underlying SEDIVER. An example is provided in Section 4 to illustrate how the modelling capabilities of SEDIVER are applied in a case study to compare the performance of a novel management strategy with the one already being used. Section 5 discusses the results obtained and situates SEDIVER with respect to related simulation models. Section 6 summarizes the main points and suggests possible future developments.

2. Ontology-based modelling

In Section 2.1 we outline our approach to the study of grassland-based beef-cattle production systems. The backbone of the approach is a production system ontology introduced in Section 2.2.

2.1. Approach overview

SEDIVER is a dynamic farm-scale simulation framework for supporting the design and evaluation of grassland-based beef-cattle production systems, which pays special attention to the management strategies used in these systems. It is intended for use by researchers, occasionally working with farm advisors and/or farmers, to investigate the relevance and performances of a given management strategy regarding the system settings and objectives under various climatic conditions. SEDIVER was actually built as a more specialised tool based on DIESE. DIESE, which offers a more abstract framework (Fig. 1), provides an ontology of single-manager production systems and an execution environment implementing a discrete-event simulation engine (Martin-Clouaire and Rellier, 2006, 2009). Basically, this ontology, which is described in Section 2.2, provides schemata for defining useful concepts for the domain of interest such as the entities composing it, their properties and the causal relationships that drive the change of state of these entities. The ontology is based on concepts that are relevant to all production systems such as, for instance, the manager and the operating and biophysical systems of which a production system consists (Figs. 2 and 3a), or the concept of activity controlled by the manager. Formally, in DIESE, the concepts are expressed in a frame-like representation implemented in C++. The simulation machinery and services (e.g. the interface and functions) provided by DIESE directly process the models declared with this language.

In SEDIVER, described in Section 3, a set of concepts specific to grassland-based beef-cattle production systems (see Fig. 2) have been introduced such as the entities, fields or herds, and processes such as herbage growth or animal intake. In other words, the development of SEDIVER has involved declaring the domain classes, their relations and attributes, data structures and system parameters by using the classes and services of the DIESE modelling framework. The classes created inherit from DIESE classes that carry the ontological background. The SEDIVER classes are generic to the domain in the sense that they provide the description primitives applicable to any production system in that domain. The genericity is of course bounded by the scope of the intended studies to be carried out with these systems. With SEDIVER, the focus is on the study of management strategies for efficient exploitation of plant, animal, grassland, and farmland diversity in grassland-based beef-cattle production systems. This explains the emphasis put on modelling (i) the heterogeneous nature of the biophysical processes occurring in the system and the subsequent constraints on herbage use, and ii) the farmer's management behaviour on a daily scale to coordinate the production activities (Fig. 4) that are constrained by this diversity over time and space.

Given the DIESE framework, specialised through the addition of the SEDIVER body of knowledge, a model of a given farm is made by specializing the domain classes provided by the framework (Fig. 2). Fig. 5 shows the declaration of part of the management strategy to be simulated. To run a simulation, the DIESE user needs to specify the size of the smallest possible increment of time (i.e. clock unit) − valued as the smallest step of the processes involved − and the duration of the simulated period. Some data files corresponding to the external factors influencing the system of interest have to be