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Simulations of plant productivity are affected by modelling approaches of farm management

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ABSTRACT

Despite their wide range of applications, process-based plant (crop and grassland) growth models often fail to reproduce yields, particularly at farm, regional and larger scales. This is largely due to inadequate information about field management activities needed as input to these models. A promising approach to overcome this limitation is to link plant growth models with farm management models which allow the simulation of management activities considering farmers' aims and constraints. Different approaches to model farm management are available, but tangible results to justify the choice for a specific approach are lacking. The objective of this work was to compare the effects of different approaches of modelling farm management on the simulation of grassland mechanized harvest dates and yields. Simulations were run with each approach for two grassland-based beef farms and 3 years and compared with available data over 156 harvest events. Our results show significant differences in the accuracy of simulated harvest dates depending on the approach to model farm management. Approaches using fixed dates or optimal phenological stages determined by expert knowledge performed less accurate than the one using calibrated phenological stages. Best results were achieved with a detailed farm management model. The accuracy of simulated yields was less affected by the chosen farm management modelling approach. However, this differed depending on the climate and the timing of harvest, allowing to rank approaches according to their ability to simulate harvest dates and yields. We conclude that further investigation is required to generalize these findings to other farm types including arable farming, and to support the analysis, modelling and calibration of farmers' management decision processes.

1. Introduction

Since the early 1970s, agricultural systems analysis and modelling has increasingly been used to improve our understanding of biophysical and human processes and their relationships involved in the use of natural resources (soils, crops, grasslands, etc.) at different scales (field, farm, region, etc.) (van Ittersum et al., 2003). Most such efforts have been concentrated on developing and applying dynamic process-based plant (crop and grassland) growth models. Based on promising results obtained on site-specific field experiments performed in one or few years, such models have also been used to extrapolate model results in time and space – most commonly done by aggregating inputs or outputs. More recent attempts have tried to integrate these models or their outputs, i.e. simulated yields, into higher level models representing farms (e.g. Matthews et al., 2006) or regions (e.g. Gimona et al., 2006). However, it has also been shown, that plant growth models do not always perform very well in reproducing yields when applied at new sites (Ewert et al., 1999; Palosuo et al., 2011) and at farm (Ewert et al., 2002), and regional scale (Reidsma et al., 2009).

A number of critical issues to the limited performance of plant growth models, e.g. model calibration (Guillaume et al., 2011), have already been studied. Another issue relates to inappropriate consideration of factors and processes determining yield variability over space and time (Challinor et al., 2009). In particular, it has been pointed out that the consideration of farm management has to be improved (e.g. Martin et al., 2011a; Reidsma et al., 2009; Woodward et al., 2008). Indeed, in most plant growth models, the system simulated is seen as a set of biophysical processes that can be controlled with unlimited resources (labour, machinery) and instantaneous operations assuming that the farmer can intervene on his fields whenever and wherever he wants. In grasslands, such modelling assumption may lead to an overestimation of harvested yields. Indeed, a delay of harvesting time due e.g. to weather constraints or lack of machinery available can result in yield reduction and additionally to losses of forage nutritive value (Fig. 1).

A promising approach to overcome these limitations and to provide more accurate management information is to link plant

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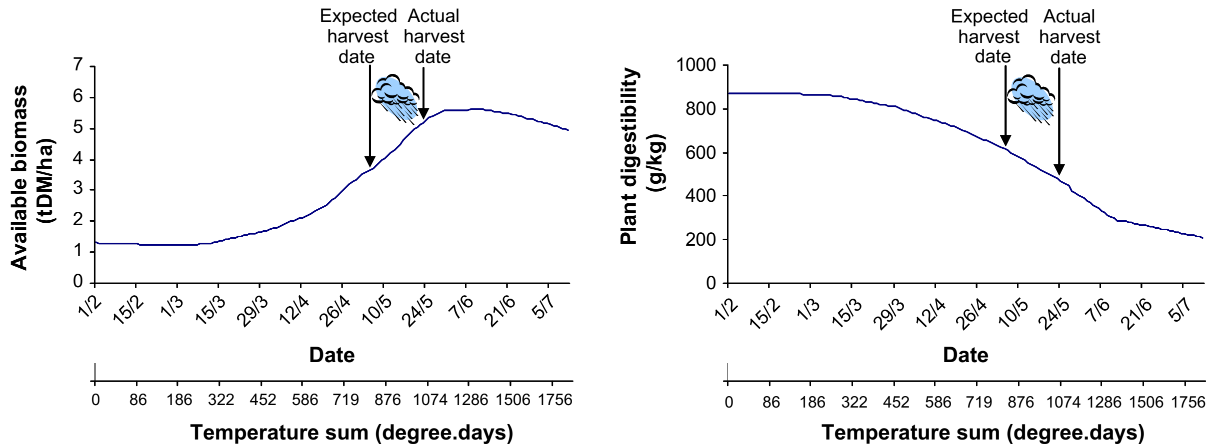

Fig. 1. Illustration of possible consequences of a delay (expressed in days – upper abscissa – and in degree days – lower abscissa) in the timing of harvest due e.g. to weather constraints on harvested quantity of forage (left) and nutritive value of harvested forage (right). The curves are averaged outputs of multi-year (1989, 1991, 1999, 2000, 2002) simulations using the grassland models of Duru et al. (2008, 2009) for early and productive species such as Lolium perenne, grown at 650 m a.s.l. in Central Pyrenees (42°50 N, 1°17 E).

growth models with farm management models into dynamic farm-scale simulation models (Bergez et al., 2010). Farm management models should then allow consideration of farmers' aims as well as their spatial, temporal and resource (labour, machinery) constraints. For grassland-based beef-cattle farms, which is the main focus of this study, it is particularly important to accurately estimate harvest dates in order to accurately simulate harvestable yields (Martin et al., 2011b).

Compared to the long experience with biophysical processes modelling, the modelling of farm management is still in an early stage (Bergez et al., 2010). The simplest approaches implement a sequence of technical actions on fixed dates as static inputs of the simulation model (e.g. Cacho et al., 1995). A commonly used and more elaborate representation are rule-based models (e.g. Chatelin et al., 2005; Romera et al., 2004) that dynamically relate the decisions made and derived actions to the conditions encountered, for instance to the phenological stage of a crop. This allows the generation of different timings (i.e. dates) of activities depending on the conditions encountered. Still, there is no powerful means to create links between rules so as to control the order in which they are used. Farm management raises the problem of coordinating activities because these require resources which are either limited or constrained by temporal availability and also because future activities need to be anticipated in relation to present ones. A recent and more sophisticated approach (Martin-Clouaire and Rellier, 2009) to this coordination problem is to organize activities in plans that are flexible and adaptable to changing conditions in so-called activity-based models.

A number of scholars share the idea that linking plant growth models with farm management models into dynamic farm-scale simulation models can improve the accuracy of simulated yields (Martin et al., 2011a; Reidsma et al., 2009; Woodward et al., 2008), which, to our knowledge, never has been tested. Accordingly, the aim of the present study is to compare the impact of several approaches for modelling farm management on the accuracy of simulated dates and yields of grassland mechanized harvests in grassland-based beef farms. We focus on tactical farm management, i.e. management with a time horizon of decision issues of less than 1 year e.g. whether to harvest this field once or twice, and operational farm management, i.e. management with a time horizon of decision issues of less than 1 month e.g. whether to harvest today, tomorrow or next week. The approaches compared differ mainly in the detail used to model farm management. Simulations are compared with observed data from 156 harvest events obtained on several years on two grassland-based beef farms in France. We also evaluate the sensitivity of the results to two factors influencing yields, i.e. climate and farmers' production objective which determine the timing of mechanized harvests. Better understanding of the required level of detail to model farm management will help to improve simulations of crop and grassland productivity at various levels (field, farm, region).

2. Material and methods

2.1. Model description

This work uses the SEDIVER (Simulation-based Experimentation on livestock systems with plant, grassland, animal and farmland DIVERsity) framework for the simulation of grassland-based beef-cattle farms (Martin et al., 2011a). This framework enables to represent the structure, functioning and dynamics of farms. Farms are seen as two linked systems, a biophysical system and a farm management system (Fig. 2). The farm management system gathers information about the state of the biophysical system, e.g. herbage height on a given field, and processes this information to decide to implement activities, e.g. mechanized harvest of that

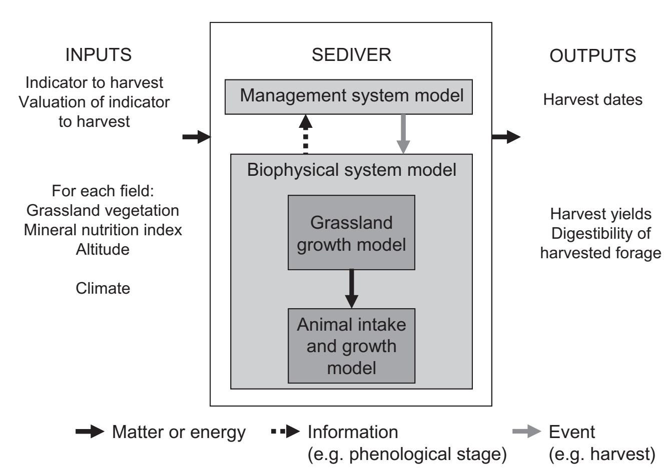

Fig. 2. Simplified representation of the SEDIVER framework for simulation of grassland-based beef farms adapted from Martin et al. (2011a), and key inputs and outputs considered in this work.