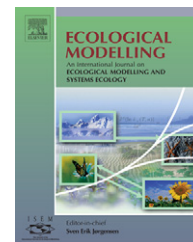


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## Modelling above-ground herbage mass for a wide range of grassland community types

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### ABSTRACT

Whereas it is recognized that management of plant diversity can be the key to reconciling production and environmental aims, most grassland models are tailored for high-value grass species. We proposed to adapt a mono-specific grass model to take into account specific features of species-rich permanent grasslands, especially over the reproductive phase. To this end, we used the concept of plant functional type (PFT), i.e. the grouping of plant species according to plant traits determined by the response of plant species to different management practices (land use and fertilization) and characterizing of agronomic properties of the corresponding species. In the model, weather and nutrient availability act upon rates of biophysical processes (radiation capture and use, plant senescence). These rates are modified over times due to PFT-specific parameters determined experimentally which represent the different strategies of plant species regarding growth. The integration of these parameters into the model made it possible to predict herbage biomass accumulation rate under different management practices for a wide range of plant communities differing in their PFT composition. The model was evaluated in two steps, first by analyzing separately the effects of PFT and an indicator of nutrient availability on herbage accumulation and then by conducting a sensitivity analysis. It was validated using two independent datasets; a cutting experiment running over the whole growing season to examine the consistency of the model outputs under different cutting regimes, and a monitoring of meadows and pastures in spring over a whole growth cycle to assess the model's ability to reproduce growth curves. Although a good fit was observed between the simulated and observed data, the few discrepancies noticed between field data and predicted values were attributed mainly to the potential presence of non-grass species. More specifically, we noticed that nutrient (mainly nitrogen) availability is the main driver of plant growth rate, and that PFT determines the times at which this rate changes in relation to the phenological characteristics of species present. We concluded that integration of the PFT concept into the initial mono-specific growth model is especially suited to evaluating the consequences of management practices on species-rich permanent grasslands to meet feed production targets.

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## 1. Introduction

The sustainability of temperate grasslands is increasingly seen as encompassing plant diversity on several scales (Bignal and McCracken, 2000). Whereas it is recognized that management of plant diversity at field, farm and landscape levels can be the key to reconciling production and environmental aims (White et al., 2004), most grassland models are tailored for high-value grass species (mono-specific swards). It is only recently that specific features of species-rich grasslands (natural grasslands or old sown grasslands) have begun to be taken into account in herbage growth models (McCall and Bishop-Hurley, 2003; Corson et al., 2006; Jouven et al., 2006). However, these models suffer from several omissions and misrepresentations. A major advance in the model of McCall and Bishop-Hurley (2003) was the introduction of a function to model the reproductive phase for different sward compositions so as to simulate herbage accumulation for yield before or after flowering stages, or after topping in spring as frequently observed in extensive livestock systems (Coléno et al., 2005). However, their model is not suited to easily take into account in a generic manner a range of plant communities differing in their composition. The model of Jouven et al. (2006) constituted an interesting first step in this direction by considering the functional composition of the plant community. However, there are three limitations: it did not evaluate the respective roles of nutrient availability and plant functional composition of the plant community such as are frequently observed (Duru et al., 2005); it did not evaluate whether there is a real gain in precision from taking into account the latter rather than just nutrient availability, particularly for simulated herbage accumulation rate over a short time scale during the reproductive period; it does not take account of phosphorus deficiency, although this is frequently observed in low-input grasslands (Janssens et al., 1998). Finally, the model of Corson et al. (2006) is very complex and data demanding, requiring high investments for calibration outside the region of initial application. These models have only partially succeeded in taking into account, in a simple manner, a wide range of plant community compositions and management practices (from early to late cutting, combination of grazing and cutting). Thus, it is necessary to have a sound and integrative model for evaluating the effect of management practices upon production of such grasslands. In this paper, we adapt an existing mono-specific grass model (Cros et al., 2003; Duru et al., 2007) for species-rich grasslands by introducing new features aimed at simulating the productivity of species-rich grasslands for a wide range of management practices, especially over the spring period. It raised one main challenge and a number of key modelling choices.

As such grasslands are generally made up of more than ten species; a major challenge is to simplify the expression of within-field plant diversity. The principle of parsimony (using no more complex a model or representation of reality than absolutely necessary), leads us to use the plant functional type (PFT) concept that “bridges the gap between plant physiology and community and ecosystem processes” (Diaz and Cabido, 1997). PFT groups species according to their responses

to the environment (response group) and/or their effects on ecosystem processes (effect group) (Lavorel and Garnier, 2002). In reference to the response group concept, we included the PFT concept in our model through the definition of a limited number of parameters applicable to a diversity of species-rich grasslands and management situations. A grassland community is composed of one or several PFTs (Duru et al., 2005). By relying on response plant traits, we assumed that the management practices lead to a stable functional composition of the plant community, keeping it in a dynamic equilibrium (Huston, 1994) over the years. A first step towards the integration of this concept into herbage growth and/or digestibility models of permanent grasslands can be found in the recent literature (Andrieu, 2004; Viegas et al., 2005; Jouven et al., 2006). To overcome the limitations identified, we used predefined grass plant functional types (PFT) established on a leaf dry matter content basis (Ansquer et al., 2004). We assumed that this plant trait encompasses all relevant variables and their specific PFT parameters needed for modelling resource capture, use and biomass allocation.

Key choices consisted in determining the level of detail suitable for the simulation of resource acquisition and use. This granularity choice results from a compromise between the target use of the model, the complexity of the modelling process and the available data, especially for each PFT. Morphogenesis processes are very different between species (Craine et al., 2002) and they remain poorly understood (Calvière and Duru, 1995) except for well-known species (e.g. *Lolium perenne* L.) (Barrett et al., 2005). For this reason, building a source- and sink-driven model would have been very difficult. In such models, daily crop growth rate is determined as the lower of the daily rate of either the sink or source activity (e.g. Schapendonk et al., 1998). Instead, we decided to build a source-driven model in which the interception of solar radiation is transformed into biomass and further partitioned (e.g. Brisson et al., 1998). Usually, dry matter partitioning is a function of the development stage of the crop (Van Ittersum and Rabbinge, 1997) such as in LINGRA to define leaf and tiller dynamics (Schapendonk et al., 1998). In this case, dry matter is being mostly allocated to storage organs when flowering is reached. For the purpose of our model, we chose to adopt a simpler empirical approach: associated with the appearance of leaves and sward growth, there is an increase of dry matter allocation to stems at the expanse of leaves (Lemaire et al., 1989). A relationship was established between the leaf dry matter percentage in the above-ground herbage mass and the standing herbage mass from the stem elongation phase until the flowering stage for a wide range of plant communities (Calvière and Duru, 1999). Most often, the expansion of leaf area, which is a necessary variable in the mechanistic modelling of herbage growth, is linked to the increase in leaf dry matter through the specific leaf area. For a single species observed at a given development stage, specific leaf area displays wide variations according to environmental conditions (Al Haj Khaled et al., 2005). Thus, considering its parameterization as hardly possible given the data available, we considered expansion of leaf area and leaf dry matter as uncoupled processes.

In a first part, we summarized the principles used in this model, and we further described new developments intro-

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