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Testing the ability of a simple grassland model to simulate the seasonal effects of drought on herbage growth

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ABSTRACT

The purpose of the present investigation was to examine the ability of the simple mechanistic model published by Jouven et al. (2006a) to simulate the effects of drought on the seasonal patterns of growth in managed grasslands. Data collected in Switzerland were used for reference. Different representations of the effects of water stress on transpiration and growth were tested, but otherwise all simulations were run using the standard model configuration. Results indicated that the model was able to correctly simulate the seasonality of growth across sites and years, as well as variations in soil water availability. Overall, the effects of drought on growth were realistically reproduced by the model. This was specifically the case with respect to the exceptional conditions characterizing the summer of 2003. On the other hand, there was a tendency for overestimating the impacts during conditions of moderate water stress. Replacing the original formulation of the water stress response with alternate schemes was not sufficient to bypass the problem. This suggests that it could be worth examining ways to represent drought avoidance or enhanced drought tolerance in the model. The failure to simulate a delayed start of growth in the spring of 2011 further indicate the necessity to address in a mechanistic way spring regrowth. Concerning future model developments, we argue that the inclusion of a root/soil compartment should be addressed with high priority to be able to account for the interactions between water and nutrient cycling.

1. Introduction

Grasslands and rangelands cover 50% of the arable lands in Europe (EEA, 2012) providing most of the energy and proteins required for milk and meat production. Understanding the responses of grassland ecosystems to climate variability and change is therefore important to secure grassland functions and production services (Hopkins and Del Prado, 2007). At the farm scale an efficient management of grasslands is necessary to attain a balance between forage production and consumption (e.g., Duru et al., 2010; Mosimann et al., 2012). In practice, however, ensuring forage availability throughout the year is often difficult. A better hold on seasonal variations in herbage growth can help reducing this vulnerability and improve the performance of grassland-based livestock systems (Sautier et al., 2013).

Grasslands are sensitive to water stress (Knapp et al., 2001). Even in temperate regions, reduced grassland productivity from inadequate moisture supply have been observed in the past (Haddad et al., 2002; Brookshire and Weaver, 2015). The incidence of drought on herbage production is likely to increase in the future (Tubiello et al., 2007), given that in Southern, Western and Central Europe climate change is expected to lead to decreased summer precipitation (Calanca, 2007).

In recent years, the response of grassland ecosystems to drought has been addressed several times in manipulation experiments with rain shelters (Jentsch et al., 2007). But drawing general conclusions has so far been difficult (Kreyling and Beier, 2013). Responses have namely been found to depend on targeted plant community (e.g., Kahmen et al., 2005; Kreyling et al., 2008), nitrogen availability (Bloor and Bardgett, 2012; Xi et al., 2015) and other aspects of management (Vogel et al., 2012; Zwicke et al., 2013). Differences in intensity and timing of simulated droughts also contribute to explain the disparity of outcomes (De Boeck et al., 2010; Vicca et al., 2012).

The impacts of drought have also been examined by means of numerical simulation. In a few cases model-based investigations have been looking the seasonal patterns of growth (Woordward, 2001; Li et al., 2011), but in general the analysis has focused only on

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variations in annual production. Also, models published so far have targeted monospecific swards (Schapendonk et al., 1998; McCall and Bishop-Hurley, 2003), idealized mixtures of perennial ryegrass and white clover (Thornley, 1998; Topp and Doyle, 2004; Lazzarotto et al., 2009), or single species in competition (Blackburn and Kothmann, 1989), discounting the need to tackle complex communities (Duru et al., 2009).

The model published by Jouven et al. (2006a) (dubbed *ModVege* in the following) is a simple mechanistic model that predicts herbage quantity and quality in managed, multi-species grasslands. The approach chosen for the development of *ModVege* rests on the assumption that the behaviour of the community can be explained by the average traits of the dominant grasses. Following Cruz et al. (2002), the model addresses four basic functional groups of grasses that can be combined in different proportions to simulate a broad range of grassland communities (Jouven et al., 2006a).

Like the model published by Duru et al. (2009), *ModVege* is a purely source-driven model, in which potential growth is expressed as a function of the intercepted photosynthetic active radiation. Environmental limitations are associated with water shortage, high levels of radiation and extreme temperatures. Herbage growth is further controlled by the overall availability of nutrients through the introduction of a so-called nutrition index (Bélanger et al., 1992). However, since there is no model component to simulate nutrient availability in a dynamic way, the nutrient index is considered as a fixed, site specific parameter (Jouven et al., 2006a).

In spite of this shortcoming, *ModVege* has been shown to perform well under various environmental settings and for different management regimes (Jouven et al., 2006b; Hurtado-Uria et al., 2013). Detailed investigations by Jouven et al. (2006b) have nevertheless revealed that the model tends to over-predict herbage production in years characterized by unfavorable conditions.

The purpose of the present investigation was to examine the capability of *ModVege* to reproduce the effects of droughts on the seasonal patterns of herbage growth in managed grasslands. Data from three grassland sites located in Western Switzerland (Mosimann, 2005; Mosimann et al., 2012) and one site located on the Swiss Central Plateau (Ammann et al., 2009) were used as a benchmark. The sites are characterized by contrasting environmental conditions and productivity levels.

In line with the idea that the default model setup should enable the simulation of a wide spectrum of productive grassland systems (Jouven et al., 2006a), the model was run using its standard setup and without specific calibration. A few modifications were nevertheless introduced to widen the scope of the analysis. In particular we slightly revised the algorithm for computing potential and actual evapotranspiration and tested two alternate formulations of the water-stress response function.

2. Materials and methods

2.1. Study area and sites

The geographic area covered by our investigation is shown in Fig. 1. As seen in Table 1, growing-season (March–October) rainfall totals for the three sites in the core of the study region decrease from about 600 mm at 400 m a.s.l. to about 900 mm at 1200 m a.s.l. Mean daily temperature decreases from 14 °C at 400 m a.s.l. to 9 °C at 1200 m a.s.l., corresponding to an average lapse rate of 0.62 °C/100 m. At Oensingen, on the Swiss Plateau, growing-season rainfall totals are close to 800 mm in average, whereas the daily mean air temperature is of nearly 13 °C.

Comparison of the rainfall amounts with estimates of the reference evapotranspiration (Allen et al., 1998) suggests that growing-season water requirements are satisfied in normal years at Posieux, La Frêtaz and Oensingen, but only hardly met at Changins, stressing the relative aridity of this site.

2.2. Data

2.2.1. Monitoring network

The first set of data was collected in the context of a long-term grassland monitoring program, put in place in western Switzerland in the year 2000 (Mosimann, 2005; Mosimann et al., 2012). As of today, the program has monitored a total of 219 plots distributed across 44 sites (Fig. 1). Situated on the outer border of the monitored area, the three sites of Changins, Posieux and La Frêtaz were selected to represent the variety of environmental conditions imposed on herbage growth across the network (Table 1). The sites are further characterized by different types of vegetation and soil (Table 1).

For monitoring, growth rates were estimated following Mosimann (2001), using an experimental setup adapted from Corral and Fenlon (1978). This information was supplemented with botanical surveys conducted with linear relevés following Daget and Poissonet (1971). Soil water conditions were monitored at Changins during 2010–2012 in the framework of a manipulation experiment conducted at this site by Mosimann et al. (2013). As described in this reference, the available data refer to measurements of the soil water potential with Watermark©-probes. Conversion of this data into volumetric soil water content was achieved following Saxton et al. (1986).

Altogether, the monitoring data span the whole period between 2000 and 2013. However, none of the three sites offers a complete record. Also, at Changins and Posieux data from different years do not necessarily refer to the same plot, introducing an additional level of uncertainty that has yet to be quantified.

2.2.2. Rain-shelter experiment at La Frêtaz

The second set of data refer to a drought experiment that was conducted during 2012 at La Frêtaz. The experimental setup consisted of two plots, one exposed to natural rainfall to provide a control, the second covered with a rain shelter for a 10 weeks period lasting from the mid of June to the end of August. The precipitation anomaly induced by the shelter was of −310 mm, corresponding to about 20% of the annual precipitation (1497 mm), or 35% of the 897 mm falling between April and September 2012 on the control plot. As with the monitoring programme, herbage growth was again measured using a procedure adapted from Corral and Fenlon (1978).

2.2.3. The Oensingen field experiment

For evaluating the model performance relatively to the simulation of actual evapotranspiration and soil moisture dynamics, data from an experiment carried out at Oensingen (Fig. 1) between 2001 and 2011 were employed. The scope of this experiment was to determine the total carbon and nitrogen budget of a managed, productive grassland (Ammann et al., 2009). Site characteristics and experimental setup are described in great detail in Ammann et al. (2007, 2009),) and are not further specified here, except for a few key figures that are reported in Table 1. Actual evapotranspiration was measured by means of the eddy-covariance technique, whereas volumetric soil water content was monitored using the frequency domain reflectometry (FDR) technique at 5, 10, 30 and 50 cm depth (Ammann et al., 2007). These data are complemented by weekly observations of the leaf-area index (LAI), which was measured non-destructively with an optical LAI-2000 instrument (Li-Cor, Lincoln, USA).