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Modelling grass yields in northern climates – a comparison of three growth models for timothy

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ABSTRACT

During the past few years, several studies have compared the performance of crop simulation models to assess the uncertainties in model-based climate change impact assessments and other modelling studies. Many of these studies have concentrated on cereal crops, while fewer model comparisons have been conducted for grasses. We compared the predictions for timothy grass (*Phleum pratense* L.) yields for first and second cuts along with the dynamics of above-ground biomass for the grass simulation models BASGRA and CATIMO, and the soil-crop model STICS. The models were calibrated and evaluated using field data from seven sites across Northern Europe and Canada with different climates, soil conditions and management practices. Altogether the models were compared using data on timothy grass from 33 combinations of sites, cultivars and management regimes. Model performances with two calibration approaches, cultivar-specific and generic calibrations, were compared. All the models studied estimated the dynamics of above-ground biomass and the leaf area index satisfactorily, but tended to underestimate the first cut yield. Cultivar-specific calibration resulted in more accurate first cut yield predictions than the generic calibration achieving root mean square errors approximately one third lower for the cultivar-specific calibration. For the second cut, the difference between the calibration methods was small. The results indicate that detailed soil process descriptions improved the overall model performance and the model responses to management, such as nitrogen applications. The results also suggest that taking the genetic variability into account between cultivars of timothy grass also improves the yield estimates. Calibrations using both spring and summer growth data simultaneously revealed that processes determining the growth in these two periods require further attention in model development.

1. Introduction

Process-based crop simulation models that simulate crop growth, development, and yields, while taking into account the interactions between the crop genotype, management and environmental factors are increasingly used to support decision making and planning in agriculture, including aspects related to animal feed and forage production (Kipling et al., 2016). Several studies have recently been published on the comparison of the performance of crop simulation models under different environmental conditions in an effort to improve crop models and climate impact assessment projections and to gain an understanding of the uncertainties related to these assessments (see, e.g. Asseng et al., 2013; Asseng et al., 2015; Bassu et al., 2014; Pirttioja et al., 2015). In addition, there have been model-based evaluations of adaptation options to climate change (Ruiz-Ramos et al., 2017; Chenu et al., 2017).

To date, model comparisons and model ensemble studies have mostly focused on cereal crops and fewer model comparisons have been published for perennial forage grasses. Still, many crop models or crop modules of farm system models, e.g. STICS (Jégo et al., 2013) and APSIM (Keating et al., 2003), can also simulate forage grasses. There are also separate forage grass models (e.g. BASGRA, Höglind et al., 2016; CATIMO, Bonesmo and Bélanger, 2002a) that have comparable process descriptions to those in cereal crop models, such as radiation interception and use efficiency. Forage grass production systems, however, have specific characteristics that should be taken into account

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in simulation models. Almost all above-ground biomass is harvested several times during growing seasons and consequently the status of the plants after cuttings and regrowth are key issues for forage grass models (Jing et al., 2013). Another important aspect is the dynamically changing feed quality during forage development (Bonesmo and Bélanger, 2002b; Gustavsson and Martinsson, 2001). Finally, grass leys are typically perennial, which makes it essential to simulate the growth initiation in the spring (Bélanger et al., 2008) and thus, makes it important to develop the models to simulate relevant processes related to over-wintering particularly for forage grasses at high latitudes, where there is virtually no cold-season growth (Höglind et al., 2016).

To our knowledge, those forage grass model comparisons that have been conducted (e.g. Hurtado-Uria et al., 2013) were restricted to regions with rather homogeneous climate conditions, without testing their performance and suitability over a wide range of climate conditions. Even though the forage grass modules of current farm system models and the separate forage grass models that are referred to above are considered process-based, they all include several empirically derived functions. Therefore, one could assume that the predictability of such forage grass models or modules would vary with climatic and other environmental conditions. Hence, a comparison of crop simulation models across a wide range of conditions is a key to strengthening the understanding of the effects of different model process descriptions, i.e. model structures, on yield and quality related output variables. Moreover, varying the genetic variability and climate and soil conditions within the calibration and evaluation datasets could provide knowledge about the calibration procedures as well as knowledge about model application strategies. Persson et al. (2014) found that the observed dry matter yield for one variety (cv Grindstad) was more accurately predicted by LINGRA model (the predecessor of the BASGRA model) when the parameters were calibrated against data from several locations within a region with heterogeneous climate and soil conditions than when the parameters were calibrated against data from only one location. However, to the best of our knowledge no study has been published where the effects varying the genetic variability in calibration datasets on grassland dry matter yield were evaluated. Such a study providing knowledge about model sensitivity to genetic variability could be used to arrange field trial data for model calibration. It could also give useful information about how to calibrate and apply grassland models for genetically heterogeneous conditions, such as in estimations of regional or national grassland productivity.

Timothy (*Phleum pratense* L.) is one of the most important forage grass species in the cold temperate climate zone of the northern hemisphere, including Canada and the Nordic countries in Europe. Management of timothy swards varies considerably according to the climate and soil conditions where it is grown and with its end use. Timothy is grown either in pure stands or mixed with other grasses or leguminous species for three years or longer before it is ploughed up and reseeded or rotated with an annual crop. When used to feed dairy cows, timothy is often cut and harvested at the mid-heading stage to optimize the nutritive value and yield. When used as feed for beef cattle and sheep, timothy is usually cut at later stages, which generally results in higher yields but a lower nutritive value. The number of harvests per year usually varies from two to four depending on the cutting strategy, the cultivar-specific characteristics such as the development rate and its effect on nutrient composition, as well as the climate and weather conditions. In addition, plant characteristics, such as the maximum tiller height, pattern of development of vegetative and reproductive tillers and the leaf/stem ratio, vary between cultivars, which have been bred to meet different regional climate conditions and management practices (Virkajärvi et al., 2010). Considering the range of environmental conditions, alternative management strategies and the genetic variability of timothy, a model comparison with timothy data covering different environmental conditions, a wide set of different cultivars and alternative management options would provide material for critical testing of crop simulation models.

The overall aim of this study was to assess and compare the ability of simulation models to accurately simulate the growth and yield of the first and second annual cuts of timothy under different environmental conditions. To this end, the performance of two grass simulation models, BASGRA and CATIMO and the soil-crop model STICS were assessed with a comprehensive experimental dataset collected from across Northern Europe and Canada with varying management practices. The three models were calibrated either specifically for each cultivar (cultivar-specific calibration) or for a number of cultivars all together (generic calibrations) and the performance of the models with both calibrations was tested.

2. Materials and methods

2.1. Models

The three models simulating the growth and development of timothy as a function of weather, soil and crop management factors included in the comparison were: CATIMO (R-version 1.0; Bonesmo and Bélanger, 2002a,b; Jing et al., 2012, 2013), BASGRA (version 2014; Höglind et al., 2001; van Oijen et al., 2005; Höglind et al., 2016) and STICS (v8.4; Brisson et al., 1998, 2008; Jégo et al., 2013; Jing et al., 2017). All three models use the radiation use efficiency (RUE) approach instead of calculating the photosynthesis and respiration in detail and they use a simple leaf area index (LAI) to calculate light interception (Table 1). They all cover soil water and N effects in the simulation of

Table 1
Approaches used by the three models for the major processes determining crop growth and development.

Process	BASGRA	CATIMO	STICS
Leaf area development and light interception[a]	S	S	S
Light utilization[b]	RUE	RUE	RUE
Root distribution over depth[c]	–	–	Sig
Drought stress[d]	ETa/ETp	ETa/ETp	ETa/ETp
Water dynamics[e]	C	C	C
Evapo-transpiration[f]	PM	PM	P
Effect of nitrogen[g]	NSNS	RNC	RNC
Tillering dynamics[h]	C	–	–
Vernalisation[i]	SV	–	–
Start of spring growth[j]	5D	5Drm	1D
Regrowth dynamics[k]	SSDG	RDG	RDG
Soil C/N model[l]	CN, P(3)	N	CN, P(3), B

[a] Leaf area development and light interception: S = simple approach (e.g. leaf area index (LAI).
[b] Light utilization or biomass growth: RUE = simple (descriptive) radiation use efficiency approach.
[c] Root distribution over depth: Sig = sigmoidal.
[d] Drought stress: ETa/ETp = actual to potential evapotranspiration ratio.
[e] Water dynamics approach: C = capacity approach.
[f] Method to calculate evapotranspiration: P = Penman; PM = Penman–Monteith.
[g] Effect of nitrogen: RNC = relative nitrogen concentration as the ratio of the actual N concentration to the critical N concentration (Bélanger and Richards, 1997), NSNS = N source/N sink balance dependent growth.
[h] Tillering dynamics: C = Three different tiller categories (dependent on internal as well as external factors).
[i] Vernalisation: SV = simple approach (threshold temperature).
[j] 5D = the first day of 5 consecutive days above base temperature, 5Drm = the first day when the running mean of a five-day daily mean temperature is above base temperature; 1D = 1 day above base temperature (start defined by model user).
[k] Regrowth dynamics: RDG = reserve dependent growth, SSDG = source (LAI, reserves) and sink (tillers) dependent regrowth.
[l] Soil C/N model: CN = soil CN model, N = soil N model with only mineral N; P(x) = number of organic matter pools; B = microbial biomass pool.