Regrowth simulation of the perennial grass timothy

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ABSTRACT

Several process-based models for simulating the growth of perennial grasses have been developed but few include the simulation of regrowth. The model CATIMO simulates the primary growth of timothy (*Phleum pratense* L.), an important perennial forage grass species in northern regions of Europe and North America. Our objective was to further develop the model CATIMO to simulate timothy regrowth using the concept of reserve-dependent growth. The performance of this modified CATIMO model in simulating leaf area index (LAI), biomass dry matter (DM) yield, and N uptake of regrowth was assessed with data from four independent field experiments in Norway, Finland, and western and eastern Canada using an approach that combines graphical comparison and statistical analysis. Biomass DM yield and N uptake of regrowth were predicted at the same accuracy as primary growth with linear regression coefficients of determination between measured and simulated values greater than 0.79, model simulation efficiencies greater than 0.78, and normalized root mean square errors (14–30% for biomass and 24–34% for N uptake) comparable with the coefficients of variation of measured data (1–21% for biomass and 1–25% for N uptake). The model satisfactorily simulated the regrowth LAI but only up to a value of about 4.0. The modified CATIMO model with its capacity to simulate regrowth provides a framework to simulate perennial grasses with multiple harvests, and to explore management options for sustainable grass production under different environmental conditions.

1. Introduction

Timothy (*Phleum pratense* L.) is widely grown in the northern regions of Europe and North America where it may be defoliated up to three times annually depending on the length of the growing season (Casler and Kallenbach, 2007). Inadequate defoliation frequencies can delay grass regrowth (Hannaway et al., 2000) and reduce yield (Smith, 1975; Trócsányi et al., 2009). In an effort to develop new management practices to improve overall production of perennial grasses, models are used to quantify the complex interactions between the underlying biochemical growth processes and the environment. The mechanisms of perennial grass regrowth are relatively well understood, including the production of daughter tillers from basal axillary buds (Richards and Caldwell, 1985; Richards, 1993). Of note, carbohydrate and nitrogen (N) reserves and their remobilization to active growth sites provide substrates for regrowth until sufficient leaf area provides enough

photosynthates to sustain both plant growth and maintenance. These processes have not been fully quantified and integrated into grass models.

Bonesmo and Skjelvåg (1999) attempted to simulate timothy regrowth with the expo-linear growth equation introduced by Goudriaan and Monteith (1990). This approach, however, does not offer a process-based description of the positive relationship between the relative regrowth rate and non-structural carbohydrates within the stubble. The model LINGRA was also modified to simulate regrowth processes with new leaf appearance related to the concentration of carbohydrate reserves (Höglind et al., 2001). Positive relationships between carbohydrate reserve concentrations and the regrowth rates, however, were not always significant (Volenec et al., 1996; Skinner et al., 1999). The model LINGRA was then improved for timothy regrowth with a function of tillering dependent on carbohydrate reserve concentrations (Van Oijen et al., 2005). The model LINGRA, however, does not take into account N remobilization which is important for regrowth (Volenec et al., 1996; Bakken et al., 1998; Skinner et al., 1999). The model CATIMO (**Ca**nadian **Ti**mothy **Mo**del) was specifically developed to simulate the growth and nutritive value of the primary growth of timothy (Bonesmo and Bélanger, 2002a,b; Bonesmo et al., 2005), but it did not simulate regrowth.

Our overall objective was to further develop the grass model CATIMO to simulate regrowth, particularly for timothy. More specifically, we wanted to: (1) develop a module for regrowth based on the accumulation and remobilization of carbohydrate and N reserves; (2) integrate the regrowth module into the CATIMO model; and (3) evaluate its capability for simulating timothy regrowth using independent field experimental data from different environments.

2. Materials and methods

2.1. CATIMO model

The CATIMO model was developed to simulate the growth and nutritive value of the primary growth of timothy. Based on eco-physiological processes, the model computes the accumulation of harvestable biomass (Bonesmo and Bélanger, 2002a) along with its nutritive value, expressed as fibre concentrations, and cell wall and dry matter (DM) digestibility (Bonesmo and Bélanger, 2002b). The harvestable biomass is estimated from daily radiation use efficiency (RUE) and intercepted photosynthetically active radiation (PAR), and the resultant biomass is partitioned between leaves and stems. Water stress is calculated from values of actual and potential evapo-transpiration using a method developed by Ritchie (1972). The RUE levels off above a critical PAR and has a maximum value within an optimal temperature range. The intercepted PAR is calculated using the incoming PAR and the green leaf area index, which is obtained from the specific leaf area and leaf biomass. Nitrogen stress is estimated from an index of N nutrition that is calculated as the ratio of N concentration to the critical N concentration for a given biomass (Bélanger and Gastal, 2000). Plant N uptake is determined by crop demand and soil N supply. The soil N supply is estimated from the soil mineral N content and N mineralization. The CATIMO model was validated with independent data from several sites in eastern Canada (Bonesmo et al., 2005). Recently, CATIMO was improved by adding the capacity to simulate the stubble biomass DM yield and the above-ground biomass DM yield using functions of shoot apex height and harvest index (Jing et al., 2011).

2.2. Regrowth

2.2.1. Mechanism description

Grass regrowth depends on C and N reserves, residual leaf area, and the number and status of active meristems (Richards, 1993). Non-structural carbohydrate (NSC) reserves are the main substrates for regrowth in spring, or after herbage removal when virtually no residual leaves are left (White, 1973). The amount of NSC reserves stored in the lower parts of the stems (i.e., corms and rhizomes) determines the regrowth rate for 2–7 days (Raese and Decker, 1966; Lardner et al., 2003). This initial growth in spring, or after herbage removal, can be defined as reserve-dependent growth. The rate of reserve-dependent growth increases with the amount of NSC in the storage organs (Davies, 1965; Bonesmo, 2000). The NSC reserves are replenished later in the growth cycle. In the spring, NSC reserves are remobilized towards new growth sites to form new shoots and roots when ambient temperatures are above a base temperature. Stored NSC is also used for root respiration over the winter period. Nitrogen remobilization is also closely related to the quantity of stored N at the start of regrowth (Strullu et al., 2011). Remobilization processes for N and NSC pools operate independently but in parallel with respect to reserve-dependent growth (Bakken et al., 1998). The regrowth mechanisms of perennial grasses are graphically described in Fig. 1.
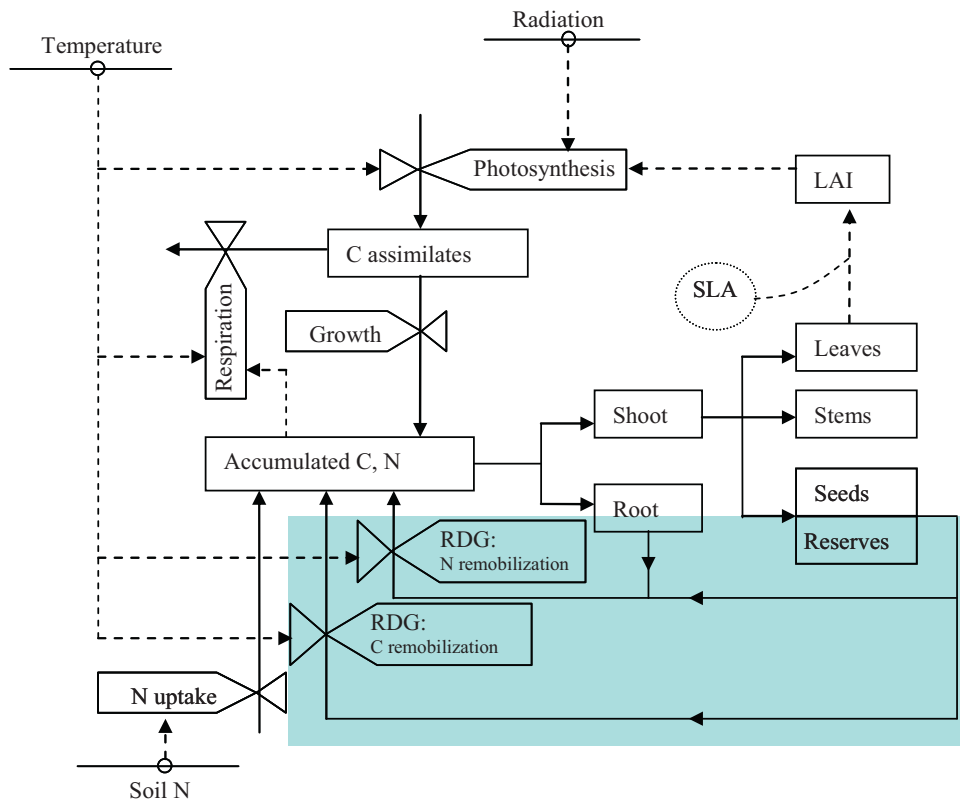
Fig. 1. Relational diagram of the mechanisms of regrowth for perennial grasses. The shaded area highlights the regrowth module. RDG, reserve-dependent growth; LAI, leaf area index; SLA, specific leaf area.