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Comparison of two pasture growth models of differing complexity

R. Howard Skinner [a,*], Michael S. Corson [b], C. Alan Rotz [a]

[a] USDA-ARS, Pasture Systems and Watershed Management Research Unit, Building 3702 Curtin Road, University Park, PA 16802, United States
[b] INRA, Agrocampus Rennes, UMR 1069, Sol, Agro- et hydro-système, Spatialisation, F-35000 Rennes, France

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ABSTRACT

Two pasture growth models that shared many common features but differed in model complexity were refined for incorporation into the Integrated Farm System Model (IFSM), a whole-farm model that predicts effects of weather and management on hydrology, soil nutrient dynamics, forage and crop yields, milk or beef production, and farm economics. Major differences between models included the explicit representation of roots in the more complex model and their effects on carbon partitioning and growth. The simple model only simulated aboveground processes. The overall goal was to develop a model capable of representing forage growth and ecosystem carbon fluxes among multiple plant species in pastures while maintaining a relatively simple model structure that minimized the number of required user inputs. Models were compared to observed yield data for 12 site-years from three experiments in central Pennsylvania, USA. Both models underestimated observed yield by 6% when averaged across site-years. However, the simple model provided a better fit to the one-to-one line between observed and simulated yield than did the complex model. The models also showed similar relationships between yield and gross primary productivity (GPP), despite the fact that the complex model was specifically developed to optimize simulation of GPP. The simple model predicted much greater shoot respiration and carbon partitioning to above ground plant tissues, but less shoot senescence than the complex model. Published data on the proportion of GPP consumed in aboveground or total plant respiration exhibit a wide range of values, making it impossible to determine which model provided the best representation of respiration rates and, thus, of the entire carbon budget.

1. Introduction

The Integrated Farm System Model (IFSM; Rotz et al., 2007) is a deterministic, process-based model that predicts effects of weather and management on hydrology, soil nutrient dynamics, forage and crop yields, milk or beef production, and farm economics in temperate regions at a whole-farm scale. Future enhancements will incorporate whole-farm gaseous emissions, including ammonia and greenhouse gases, into the model framework. Whole-farm models, such as IFSM, provide a means to evaluate the ability of different production systems to optimize plant and animal productivity and economic returns while at the same time delivering ecological goods and services such as increased soil carbon storage and reduced emissions of other greenhouse gasses. To predict whole-farm carbon dynamics, a plant growth model must be able to accurately predict photosynthetic inputs and respiratory losses.

The Integrated Farm System Model (IFSM) was recently enhanced to represent the growth and competition of multiple plant species in pastures and their effects on pasture productivity and botanical composition in temperate climates (Corson et al., 2006). This enhanced model incorporated plant, water, and soil components of the Simulation of Production and Utilization of Rangelands model (SPUR 2.4; Foy et al., 1999). The enhanced model predicted soil water content and biomass yield reasonably well, but did not adequately predict the relative contribution of individual species to total yield (Corson et al., 2006). The model was next modified to improve simulation of carbon inputs (Skinner et al., 2008). Following those revisions, annual GPP could be predicted with a high degree of accuracy, as could overall seasonal patterns in carbon uptake. All these modifications, however, have greatly increased the number of species- and site-specific parameters required to simulate multiple-species pastures.

The level of complexity needed for a specific model depends on the questions being asked and the amount of information available for model building and testing (Boote et al., 1996). Boote et al. (1996) suggested that models should be simplified as much as possible, in part because complex models often require inputs from

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* Corresponding author. Tel.: +1 814 863 8758; fax: +1 814 863 0935.
E-mail address: howard.skinner@ars.usda.gov (R.H. Skinner).

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field experiments that are not practical to obtain. On the other hand, complex mechanistic models are essential if the goal is to understand plant processes or formulate hypotheses for experimental testing (Vico and Porporato, 2008). The increase in complexity of the enhanced IFSM made its application to a wide variety of farms unwieldy because of the number of parameters needed to describe each farm. Thus, Corson et al. (2007) developed a simpler, yet reasonably accurate, model of multiple-species pastures for inclusion in IFSM. The revised model required fewer than half the number of physiological parameters to characterize each species, and a greatly reduced number of site-specific parameters compared to the more complex version. Corson et al. (2007) concluded that, given the generality and realism required of IFSM, the degree of precision in the simplified model was acceptable for comparing the effects of different management scenarios on forage productivity.

Other studies have compared the mechanistic representation of physical and biological processes, and predictive ability of plant or soil models of differing complexity. Gao et al. (2004) compared the performance of four photosynthesis models, two of which were highly mechanistic biochemical models and two of which were simplified leaf-level models. They concluded that the more mechanistic biochemical photosynthesis models did not offer significant advantages over the simpler leaf photosynthesis models for describing field data. Likewise, Deen et al. (2003) evaluated four crop-weed competition models (ALMANAC, APSIM, CROPSIM, and INTERCOM) against a common dataset, finding that increased model complexity did not greatly improve model predictions. In contrast, Aber et al. (1996) found that a multiple linear regression model was not able to predict gross carbon exchange by a forest canopy as well as a model based on physiological measurements at the leaf level, suggesting that a certain level of complexity was necessary for modeling carbon assimilation and yield. Similarly, in an exercise that modeled 31 temperate and tropical grasslands, the CENTURY model also performed slightly better than empirical regression equations for predicting plant production and peak live biomass (Hall et al., 1995).

The relative complexity or simplicity of different models is a highly subjective concept. Photosynthesis models can range from simple computations of uptake based on intercepted photosynthetically active radiation (PAR) and canopy radiation use efficiency (Nouvellon et al., 2001), to complex biochemical representations of carbon assimilation processes (Farquhar et al., 1980), which can be further enhanced to included biophysical relationships such as mesophyll conductance and leaf water potential effects on metabolic processes (Vico and Porporato, 2008). Even the simple radiation interception models can become increasing complex as leaf area index, canopy structure, soil albedo, and leaf optical properties are included in simulating intercepted PAR (Nouvellon et al., 2001). Thus, a model considered to be simple in one application could be relatively complex under other circumstances.

The purpose of the current research was to compare the two forage production models developed for IFSM that differed in the complexity of their representations of environmental and management effects on carbon uptake, partitioning among plant compartments, respiratory loss, and forage yield. Most notable among the differences was the lack of explicit representation of roots in the simple model. Designation of these models as "simple" or "complex" was strictly relative to each other, without any attempt to place them within the overall continuum of model complexity. The null hypothesis was that no difference existed between the two models in their ability to simulate key components of the plant carbon cycle. Accurate simulation of plant carbon dynamics is a necessary step in providing the simulations of pasture and whole-farm carbon fluxes that are needed by producers and policy makers to guide greenhouse gas reduction efforts.

2. Methods

2.1. Model development

Development of the two pasture models has been described in detail elsewhere (Corson et al., 2006, 2007; Skinner et al., 2008). Briefly, the IFSM has been modified to simulate multiple functional groups with the pasture system. In these simulations, functional groups are based on morphological characteristics and include grasses, legumes, and non-leguminous forbs. The complex model was based on the rangeland model, SPUR, which was modified to represent temperate pasture conditions. In the complex model, root and shoot nitrogen and carbon structural and substrate contents, of both live and dead tissue, were represented explicitly, as were the nitrogen and carbon contents of plant residue, soil-applied manure, and soil organic matter. Plants recycled a portion of structural carbon from dying shoot and root tissue to substrate-carbon pools. Transpiration from each soil layer was a function of plant rooting depth and was taken first from the upper layer, with unmet demand cascading to the next lower layer.

The complex model was originally calibrated with data from the three-species mixtures from the 2002 Dairy Graze experiment (Table 1) (Corson et al., 2006), then the photosynthesis component was refined based on data from the Haller Grass 2003 experiment that contained a single functional group (Skinner et al., 2008). To refine the photosynthesis model, daytime fluxes were measured by eddy covariance then partitioned into their photosynthetic and respiration components as described in Gilmanov et al. (2003). Continuous micrometeorological measurements of photosynthetic uptake at the Haller Grass site allowed seasonal and even daily comparisons between observed and simulated plant carbon assimilation.

In contrast, the simplified pasture growth model, based on the Grazing Simulation Model (GRASIM) (Mohtar et al., 1997), lacked an explicit representation of roots. A portion of daily assimilated carbon was partitioned belowground by the model but its fate was not tracked beyond that point. Soil organic matter was represented only as biomass, from which ammonium was mineralized. Dying plant tissue did not recycle structural carbon to substrate-carbon pools. Soil was divided into four layers. Transpiration from each of the first three soil layers was fixed, and all unmet transpiration demand came from the lowest layer. Compared to the complex model, the simple model required considerably fewer species- and site-specific parameters and variables (Table 2). This model was calibrated with data from three-species mixtures from the 2002 Dairy Graze experiment.

Table 1
Brief description of study sites used for comparison of pasture growth models

Site	Year	Functional groups (no.)	Harvests (no.)	Precipitation (mm)	Forage Yield ($g\ m^{-2}$)
Haller Grass	2003	1	4	1108	403
Haller Grass	2004	1	4	1190	358
Haller Grass	2005	1	4	715	205
Haller Alfalfa	2003	2	3	1108	478
Haller Alfalfa	2004	2	3	1190	319
Haller Alfalfa	2005	1	3	715	209
GRACEnet simple	2005	2	5	715	374
GRACEnet complex	2005	3	5	715	432
Dairy Graze 2 species	2002	2	5	942	432
Dairy Graze-2 species	2003	2	7	1148	804
Dairy Graze-3 species	2002	3	5	942	538
Dairy Graze-3 species	2003	3	7	1148	819

Pastures contained either 1 (grass), 2 (grass–legume), or 3 (grass–legume–forb) functional groups based on plant morphological traits.