Extension of the Model-System Expert-N by a Pasture Ecosystem Simulator

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Abstract
Dynamic ecosystem simulations are used more and more frequently as research and education tools and to assist in making management decisions. In order to simulate nitrogen and carbon fluxes in the pasture ecosystems Expert-N has been extended by a grass and grass/clover growth component. This paper gives an overview of the development process.

1 Introduction

The response of ecosystems to elevated CO_2 concentrations due to global environment change is a widely discussed topic. Additionally it is increasingly evident that agricultural research and policy have transferred their goals from means to provide the plant with sufficient nitrogen to maximize output towards means to prevent pollution from nitrogen inputs while maintaining adequate output (WU and MCGECHAN, 1998).
Grasslands make up a substantial part of the worldwide used agricultural land. Their importance as sinks and sources in the world carbon and nitrogen cycling has received much attention recently (THORNLEY and CANNELL, 1997), but its elaboration by experimentation has some inherent difficulties to overcome. Ecosystem modelling provides a feasible alternative to experimentation. It can be beneficial in understanding interactions among the processes involved in the cycling of nitrogen and carbon in the soil-grass-atmosphere system, and to assist in making decisions on optimal nitrogen inputs and grass management.
In order to represent nitrogen and carbon fluxes in pasture ecosystems, the Hurley Pasture Model (THORNLEY, 1998) has been adapted and extended to become the pasture crop growth component of the soil nitrogen and carbon dynamics model Expert-N. The Hurley Pasture Model has been chosen since it is distinctive in its comprehensive treatment of plant growth processes, coupling of C, N and water fluxes, explicit representation of assimilate transport and utilization, modulation of all biochemical processes by temperature and water status, including the grazing of animals. This paper is intended to give an overview of the development process.

2 The Simulation Software

Expert-N offers a modular architecture which allows simple incorporation of new modules in form of dynamic link libraries (dll's). The pasture module was developed and tested using Microsoft Visual C++ on a Pentium-III-866 MHz with 256 MB RAM.

3 The Plant Model

A full description, including all formulas, of the Hurley Pasture is given by THORNLEY (1998). The plant growth component is a dynamic, deterministic, mechanistic mathematical model. Dynamic refers to the model describing the time-course of various variables, such as plant water potential. Deterministic means that the model makes predictions of variables without any associated probability distribution; there are no random number generators in the model.

Mechanistic implies that the model is based on assumptions about the mechanisms of processes represented in the model which are thought to be important in the system.

In the original Hurley Pasture Model the crop is assumed to be composed entirely of a vegetative C_3 grass such as *Lolium perenne*. To account for grass/legume pasture systems as well, the approaches of TOPP and DOYLE (1996) for modelling photosynthesis in mixtures and of WU and MCGECHAN (1999) for nitrogen fixation were used. Since simulatons run over one year the composition of grass:clover within in the pasture is assumed to be constant. The model is driven by C input from photosynthesis and N input from soil mineral N pools (ammonium and nitrate). Expert-N influences plant growth only by altering the supply of mineral N and water.

Dependence of gross photosynthesis on light is described by a non-rectengular hyperbola (for illustration see HARLEY and TENHUNEN (1991)), with three parameters: the sharpness of the knee of the hyperbola is constant at 0.95. The initial slope is set to a value equivalent to 19 quanta per molecule of CO_2 (JONES, 1992), with modifiers for CO_2 concentration (representing photorespiration suppression), temperature and shoot water status. The asymptote (P_{max}) has a notional maximum at 350 μmol mol^{-1} CO_2 of 1×10^{-6} kg CO_2 m^{-2} s^{-1} equivalent to 23 μmol CO_2 m^{-2} s^{-1}, typical of C3 grasses, with cubic modifers for temperature and water status, and modifiers for leaf N level (with minimum and maximum set at 1 and 2 g N m^{-2}, HIROSE and WERGER, 1987), CO_2 and stomatal conductance. The optimum temperature for P_{max} is dependent on CO_2 concentration (LONG, 1991) although this is unimportant in a temperate climate (THORNLEY and CANNELL, 1997).

Canopy photosynthesis in grass monoculture is calculated using a single analytical expression where the contributions of all leaves are added by using an algebraic expression for the integral through the canopy. This method gave similar results to two alternative methods evaluated by THORNLEY (1998) who showed that canopy photosynthesis was not appreciably affected by decreasing foliage N concentration from the youngest to oldest age category. Therefore uniform canopy N concentrations were assumed. In order to calculate canopy photosynthesis of mixed canopies, the knowledge of the relative position of each leaf-area component within the sward is required. The method of estimating vertical distribution was adapted from TOPP and DOYLE (1996). Photosynthesis rate was calculated for individual components (e.g. crops), which were then summed.

Stomata are open only during the day. Their conductance varies linearly, between fully open and closed depending on relative water content of the shoot. The allocation of assimilates depends on the growth rates of the plant parts (see below) and the conductances to C and N substrate transport along opposing root-shoot concentration gradients within the plant. Transport conductances increase with temperature and water status and are scaled with plant mass. This mechanism simulates widely observed behaviour of shoot/root allocation related to plant C/N status, including responses of *L. perenne* to CO_2 (CANNELL and DEWAR, 1994; SHENCK *et a*l., 1995). Shoot and root growth are proportional to their structural mass times the product of local C and N substrate concentrations, modulated by temperature and water status.

Constant fractions of C substrate are used for growth respiration, using established conversion factors (PENNING DE VRIES *et al.*, 1974). Maintenance respiration rates are proportional to structural mass, weighted by age category, and modifed by temperature and water status.

The quantities of of available soil ammonium and nitrate simulated by Expert-N are import variables to the plant growth submodel. In turn the nitrogen uptake and decomposition of clover litter estimated by the submodel are considered as components in the soil nitrogen balance by the main routines of Expert-N. Nitrogen uptake rate from nitrate and ammonium soil pools follows Michaelis-Menten kinetics depending on the mineral pool sizes, weighted towards ammonium at low temperatures, and modified by temperature, root water status, and soil relative water content.

N_2-fixation by clover plants was included according to the approach of WU and MCGECHAN (1999). It is assumed that clover has a potential capacity to fix nitrogen under optimal conditions. Several factors affect that potential of which temperature is thought to be of major importance.

4 Future Work

To test the pasture submodel time-series data of the FAM (Forschungsverbund Agraröko-systeme München) pasture will be used. Biomass production, nitrogen and carbon fluxes of grasslands will be compared to grass/clover mixtures to see whether it is sufficient to account only for the nitrogen fixing ability of clover leaving out differences in photosynthetical properties.

However, future improvements will be necessary for light interception of mixed swards to account for different plant heights of grass and clover. Furthermore it is intended to decouple the plant model for clover and grass accounting for differences in carbon and nitrogen allocation, shoot and root growth, and photosynthesis in both crops.

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