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Development and implementation of a generic pasture growth model (CLASS PGM)

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ABSTRACT

This paper describes the development, testing and implementation of a generic pasture growth model (CLASS PGM) which can be used to simulate growth of composite pasture types of multiple species that may be summer or winter active, perennial or annual. The model includes carbon assimilation through photosynthesis and respiration followed by tissue growth, turnover and senescence. Environmental conditions as well as soil water, nutrient and salinity status influences pasture growth and tissue dynamics. The model allows the user to simulate a range of grazing management strategies. Concepts and theoretical basis of the pasture growth model is based upon the detailed technical report on pasture and crop growth modules (Johnson, 2003). For water balance computations, PGM is internally linked to the Richards' equation - based hydrology tool, Unsaturated Moisture Movement Model U3M-1D (Vaze et al., 2004b) PGM is supported by a windows based user friendly graphical users interface (GUI). The model can be downloaded free from the Catchment Modelling Toolkit website supported by the eWater Cooperative Research Centre (http://www.toolkit.net.au/class). This paper gives an overview of the model structure, model inputs and outputs and the soils related inbuilt database. Results from model validation using long term observed data for soil moisture, pasture herbage mass and grazing for a grazing experiment at Wagga Wagga, New South Wales, Australia are discussed. When compared with herbage mass and soil moisture data from the experiment, PGM was found to adequately simulate the patterns and amplitudes of pasture growth and soil moisture recorded in the experiment.

1. Introduction

The Murray–Darling Basin (MDB) in southeastern Australia is bounded in the east by the elevated peaks and plateaus (rising to 2228 m at Mt. Kosciusko) of the Great Dividing Range. Steep to moderate slopes and ranges extend westward about 300 km, to low-relief landscapes dominated by riverine sediments. Rainfall, which is highest along the eastern boundary (>800 mm/year), falls rapidly with distance as we move towards the west to average values of <400 mm/year.

Since the MDB was settled by Europeans in the early 1800s, a range of landuses have evolved across this low-relief but variable landscape, including forestry, grazing, cropping and intensive agriculture associated with irrigation. For both dry-land and irrigated agriculture, water resources are both finite and fully committed, and are influenced to a large extent by interactions between soils, topography and land use. For planning, forecasting and research purposes, there is a need for a modelling framework with generic modelling tools that can be used to evaluate the combined impacts of these factors on small to medium-sized catchments (up to 3000 km^2) within the basin.

Although simulation modelling has been used at large catchment scale within the Basin, most recently in the context of managing dryland salinity (Tuteja et al., 2003; Vaze et al., 2004a), no models realistically and adequately simulate and spatially integrate the various landuses that occur across the catchment. It is not unusual, for instance, for modellers to represent the water balance impact of trees using models/frameworks developed for pastures (Weeks et al., 2005) or crops by changing parameters relating to rooting depth and Leaf Area Index (LAI).

At locations within catchments, landuse is constrained by issues related to topography (slope, drainage networks, soils, etc) and resources (rainfall, enterprise risk and benefit:cost, etc). Thus, there is some confounding between factors restraining landuse and landuse itself. For instance, in the southern sector of the MDB, plantation forestry is generally carried out in high rainfall areas

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(>700 mm/year) in the east; grazing with minor cropping occurs across the steeper near-slopes where rainfall is moderate (600–700 mm/year); cropping increases on lower slope landscapes (rainfall 400–600 mm/year); while broad-scale irrigation is restricted to lands in close proximity to regulated rivers and low to zero slopes.

In order to evaluate the spatial impact of this complex mix of landuse, topography, soils and rainfall on the water balance, a range of models are needed that independently and specifically caters for each of the main landuses. These need to be compatible, and spatially integrated in a catchment-based context.

CLASS (Catchment Scale Multiple Landuse Atmosphere Soil Water and Solute Transport Model) (Tuteja et al., 2004) is one such framework. It consists of a suite of six integrated models that can be used to investigate the effects of landuse and climate variability at both the paddock or enterprise level, as well as at the scale of small to medium-sized (up to 3000 km^2) catchments. These six models can be used independently or as part of the whole framework, where each of them interacts with others to simulate the whole of catchment behaviour.

CLASS PGM is one of the six models developed as part of this framework. There are a range of soil moisture and pasture growth models available that use less pertinent hydrology (e.g. bucket models for water balance accounting with limited treatment of plant growth). At the other end of the spectrum are models that are very comprehensive in their treatment of plant physiology, which make them less suited for practical catchment hydrology applications. CLASS PGM has been developed with the aim to obtain a balance between plant physiology and hydrology by simulating the most important and relevant processes from both areas accurately and in appropriate detail. PGM is developed under the catchment modelling toolkit platform (www.toolkit.net.au) which uses the latest available integrated modelling approach and so it can be used with any other model developed using this platform.

This paper outlines the concepts (agronomy and water balance) and data requirements for the Pasture Growth Model—CLASS PGM (Vaze et al., 2004c, 2005). Data from a long-term field experiment (Johnston et al., 2005; Johnston and Cornish, 2005) is used for validation purposes.

2. Model concepts

PGM is a mechanistic biophysical simulation model, with a daily time step for growth calculations and user-specified sub-daily time steps for the water balance calculations using U3M-1D (Vaze et al., 2004b). The model incorporates modules for carbon assimilation, herbage production and utilisation, water dynamics, nutrient and salinity stresses and animal intake/grazing. It provides a cohesive structure for analysing the behaviour of the pasture system and the complex interactions between the different model components. These interactions are the key to understanding efficient pasture management and utilisation and also the environmental impact of management through its influence on water dynamics.

2.1. Agronomy

Pasture growth and utilisation results from a complex set of interactions between pasture plants, the environment, soil conditions, and grazing animals, and there is a range of possible approaches to modelling these processes. The level of complexity chosen in this model attempts to strike a balance between realism and tractability. The aim is to remain biophysically realistic while keeping the description of each individual process relatively simple. It is possible to use a growth curve approach, whereby a single expression is used to describe the daily net pasture production. However, it is difficult to expand this to allow for the important process of litter production and turnover, which can play a vital role in the water and nutrient dynamics in pastures. Conversely, very detailed models of photosynthesis, plant morphological development, and so on, can be used, but these models require complex parameterisation and can be unwieldy to work with.

The approach here aims to include the key processes of pasture growth and utilisation, as well as the interaction between the pasture and the environment. The model is structured in such a way as to allow future developments to incorporate the influence of soil organic matter and nutrient dynamics.

The pasture growth module is based primarily on the approach described by Johnson and Thornley (1983), Johnson and Parsons (1985) and Parsons et al. (1988), and is similar to that used in the SGS Pasture Model (Johnson et al., 2003).

The key agronomy aspects of PGM can be summarised as follows:

- The model is constructed for generic pasture species so that particular species are defined through the basic model parameters.
- The model includes carbon assimilation through photosynthesis and respiration followed by tissue growth, turnover and senescence.
- Pasture growth and tissue dynamics are influenced by the environmental conditions (light and temperature) as well as the soil water, nutrient and salinity status.
- Multiple species are considered, which may be perennial, annual, legume, C3, C4.
- For annual species, vegetative (emergence to anthesis) and reproductive (anthesis to maturity) growth phases are included.
- A simple treatment of animal intake is implemented to simulate the effects of grazing. However, animal growth and physiology are not included.

The approach used in PGM to calculate pasture growth can be summarised as follows:

- Calculate transpiration in terms of live leaf area, potential transpiration, and soil water content.
- Estimate the water stress in terms of actual and potential transpiration.
- Calculate the potential pasture growth rate.
- Adjust the potential to actual pasture growth rate in response to water stress.
- Incorporate the influence of soil salinity and nutrient status limitation to growth.
- Calculate the tissue dynamics—growth, senescence and transfer to litter.

2.2. Water dynamics

The pasture growth computations are coupled with Richards' equation based water balance modelling using U3M-1D. U3M-1D can be used for partitioning water balance in the unsaturated zone. The water balance computations in U3M-1D are similar to the concepts used in HYDRUS-2D (Šimunek et al., 1999).

U3M-1D uses a variable sub-daily time step that senses the transient nature of the climate conditions and increases or decreases the time step accordingly. A balance is conducted for each soil material; and evaporation, drainage and solute fluxes are simulated over time. Water balance error associated with the numerical approximation is quantified for each soil material.

In U3M-1D, a soil water excess is calculated when the available soil moisture in a soil layer/material is greater than the saturated