Integration of a pasture model into APSIM

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Abstract

A pasture model (AgPasture) was developed and integrated into APSIM (Agricultural Production System Simulator) to provide a flexible platform for simulating pasture production, the environmental impacts of pasture management and the likely consequences of land use changes. The model structure and its connection with other modules within APSIM are described as well as pasture-specific ‘managers’ for setting up animal grazing management. The mechanisms for quantifying plant growth in response to water and nitrogen limitations are also described. The model performance was assessed against long-term experimental pastures under dry and irrigated conditions. Model-predicted seasonal pattern and inter-annual variation of soil moisture contents and net herbage accumulation (NHA) matched well with field measurements. High correlations were obtained between the simulated and measured NHA (r^2 = 0.60, $p < 0.0001$ for dryland; r^2 = 0.45, $p < 0.0001$ for irrigated) and soil moisture content (r^2 = 0.76, $p < 0.0001$ for dryland; r^2 = 0.47, $p < 0.0001$ for irrigated) at actual measurement dates. Simulated water and nitrogen processes balanced well at system level, and their fluxes among system components agreed with the reported values for similar pasture in the literature. Integration of the pasture model into APSIM provided the capability to simulate the long-term effects of land use changes, such as pasture/crop/woodland conversions, in the dynamic landscape of farming systems.

Key Words

Herbage production, water balance, nitrogen cycle, grazing management, long-term experiments, simulation

Introduction

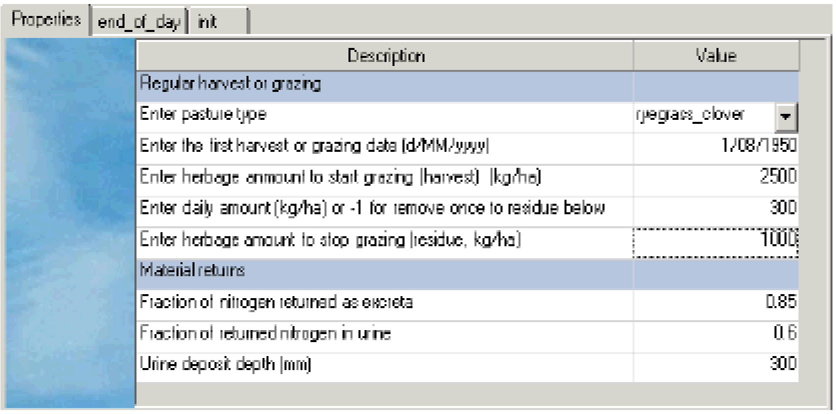
In the current fast-changing agricultural landscape, there is increasing demand for agricultural system models to have the capability to explore the effects of different sequences of land uses and the consequences of land use changes. For a model to be useful here it must encompass a range of pastures, arable crops and woodlands. Most of the process-based pasture growth models were developed without the ability to simulate changes in paddock vegetation during the simulation, e.g. Johnson et al. (2008), or have limited ability to graze mixed pasture species, e.g., the AusFarm Stock module (Freer et al. 1997) within APSIM. Here a mixed-species pasture growth model was developed and integrated into APSIM (Agricultural Production Systems Simulator; Keating et al. 2003) based primarily on the plant physiological model of Thornley and Johnson (2000) and as implemented in EcoMod (Johnson et al. 2008). This paper briefly describes the pasture growth model integrated in APSIM, assesses its performance in predicting pasture growth and soil moisture dynamics, and evaluates its integrity in terms of water balance and nitrogen cycling.

Methods

The pasture model development and integration

The pasture model (*AgPasture*) incorporates the same principles as used in EcoMod (Johnson et al. 2008), but some changes were made to allow integration with APSIM’s soil and management modules and to improve predictions of pasture growth. Plant growth was modelled at the species level. Each species competes for light, water and nutrients in the environment and species properties are aggregated as that of pastures. Linkages, through the APSIM infrastructure, with other existing modules include senescent roots transfer into the soil fresh organic matter (*FOM*) and plant litter returns to soil surface organic matter (*SurfaceOM*). Also, the module interacts with modules for weather (*Met*) and soil processes (*SoilN, SoilWat* and *SWIM)*. Plant water demand is calculated using the Penman-Monteith approach (*Micromet*). Soil moisture (GLF_{water}) and nitrogen (N; GLF_n) stresses for plant growth were defined as the ratio of plant demand to soil supply, and the stress effects on plant growth were incorporated by multiplying the potential plant growth by the stress factors. Symbiotic N fixation by the legume species was calculated before partitioning N between pasture species in proportion to their demands. The GLF_n for each species was applied to plant growth by reducing plant green leaf area expansion and diluting N concentration in plant tissues, which in turn reduced the plant radiation use efficiency.

In addition to using existing management modules common to other plants/crops in APSIM, pasture-specific management (e.g., grazing, mowing and renewal, return of animal-ingested plant material into soil through excreta) was added using a set of predefined but user-editable *Manager* components (Figure 1).



Description	Value
Regular harvest or grazing	
Enter pasture type	ryegrass_clover
Enter the first harvest or grazing data (d/MM/yyyy)	1/08/1950
Enter herbage anmount to start grazing (harvest) (kg/ha)	2500
Enter daily amount (kg/ha) or -1 for remove once to residue below	300
Enter herbage amount to stop grazing (residue, kg/ha)	1000
Material returns	
Fraction of nitrogen returned as excreta	0.85
Fraction of returned nitrogen in urine	0.6
Urine deposit depth (mm)	300

Figure 1 An example of a pasture manager specifying a grazing management rule to start grazing when pasture cover reaches 2500 kg/ha and remove 300 kg/ha/day until a residue of 1000 kg/ha remains. 85% of nitrogen in the ingested herbage is returned to the soil through excreta, of which 60% is in urine and returned into the soil profile to a depth of 30 cm.

Model evaluation against experimental data

Measurements of herbage accumulation and soil moisture content of a long-term irrigation experiment which began in 1952 at Winchmore, New Zealand (Richard and McBride 1986) were used to assess the model performance. The pasture was perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) based, grown on a Lismore silt loam soil and under a dry and cool climate. It received superphosphate fertiliser annually and lime. No N fertiliser was applied. The control (dryland, 4 replicates) and full irrigation (applying 100 mm water through a border-dyke irrigation system when soil volumetric moisture content was depleted to 20% of field capacity, 5 replicates) treatments for 1966 to 2004 were used in this comparison. The paddocks of the irrigated and dryland pasture were grazed by separate flocks of sheep. The fully irrigated paddocks received, on average, seven irrigations each year (ranging from 2 to 11). Six to nine herbage accumulations were measured per year using the exclusion cages. The measurement dates varied from year to year depending on pasture growth.

Simulations were run for the dryland and irrigated pastures over the period 1966 – 2004. The first eight years of the experiment were not simulated as sufficient weather data were not recorded. Observed weather data, measured on site, were used. For simulation of the irrigated treatment, the dates of actual irrigation applications were used and irrigation efficiency was assumed to be 0.75. The pasture harvests were also simulated at the measurement dates. The post-grazing residual was assumed to be 1000 kg DM/ha. The harvested herbage was compared to the simulated amount of herbage ingested by grazing sheep and the animal excreta were specified as in Figure 1. Soil parameters were set up according to measurements during the experimental period (Srinivasan and McDowell 2009). Soil organic carbon contents were set to 4.0% and 3.5% for the top 10 cm soil for the dryland and irrigated pastures.

Measured and simulated net herbage accumulation (NHA) and soil moisture content at actual measurement dates were compared. The pasture growth rate and inter-annual variability of NHA were summarised. Coefficients of variation (CV) of simulated and measured NHA were calculated to assess their variability. The correlation coefficient and root mean squared deviation (RMSD) between the simulated and measured values were used to gauge the accuracy of model prediction. The water balance and nitrogen cycle in the model system were presented and assessed.

Results and discussion

Net herbage accumulation

Pasture NHA was measured 281 times during the 37 years. Simulated NHA agreed well with that measured, as shown in Figure 2 for period 1999-2000. The simulated and measured NHA were well correlated under both dryland and irrigated conditions, but had relatively large RMSD (dryland: $r^2 = 0.60$, $p < 0.0001$, RMSD = 505 kg DM/ha; (irrigated: $r^2 = 0.47$, $p = 0.001$, RMSD = 530 kg DM/ha).

Simulated and measured annual NHA showed a similar mean and inter-annual variation for both dryland and irrigated conditions (Table 1). The annual NHA was highly correlated under dryland, but not irrigated conditions due to the rather small inter-annual variation under irrigated conditions (Table 1).

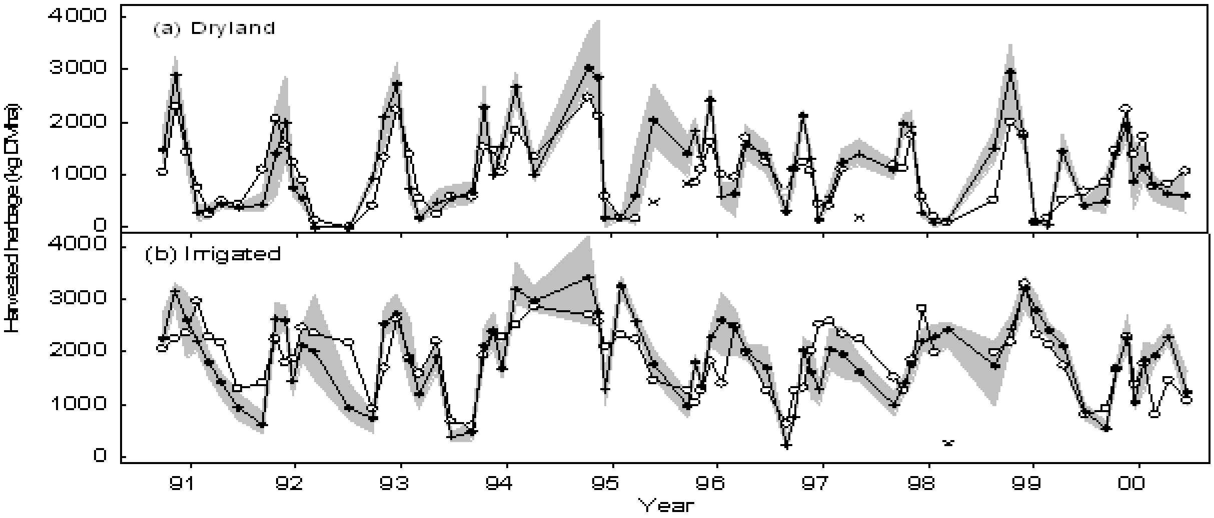


Figure 2 Simulated (circles) versus measured (crosses and shaded areas for mean and range) net herbage accumulation under dryland and irrigated conditions

Table 1 Comparison of measured and simulated annual mean and inter-annual variability (?CV) of net herbage accumulation (kg/ha), and the correlation (r^2) between simulated and measured values.

Pasture	Measured	Simulated	RMSD (%)	r^2
Dryland	7277 (?27%)	6833 (?29%)	16	0.838 ($p<0.0001$)
Irrigated	12844 (?11%)	12475 (?10%)	17	ns ($p=0.314$)

Soil moisture dynamics

Model-predicted soil moisture dynamics in the top 10-cm soil layer matched well with the measurements. The measured (M) and simulated (S) soil moisture contents were highly correlated for the 338 measurements over the 10 year period (1990-2000) (dryland: M = 1.025?S -1.7088, $r^2 = 0.76$, $p < 0.0001$, RMSD = 23%; irrigated: M = 0.808?S +7.75, $r^2 = 0.45$, $p < 0.0001$, RMSD = 23%) (Figure 3).

Water balance and nitrogen cycle

Prediction of balanced matter fluxes among system components is vital for system integrity. Although water and N fluxes were not measured, examination of the simulated values can add confidence regarding the model integrity. For the dryland *vs.* irrigated pastures, the long-term annual average water input of rainfall plus effective irrigation (721 mm *vs.* 1209) balanced against the outputs of plant transpiration (301 *vs*. 544), soil water evaporation (224 *vs.* 209), drainage (183 *vs.* 436) and runoff (13 *vs.* 16). The irrigated pasture had higher plant transpiration and drainage but less soil evaporation than the dryland pasture.

The model predicted N fluxes going through the irrigated pasture system were about twice that in the dryland pasture system. In the irrigated pasture, plant N uptake was primarily from soil mineral N (504 kg/ha/yr) with N-fixation supplying about 103 kg/ha/yr. Most of the plant N uptake was returned to the soil through senescent plant materials (129 kg/ha/yr) or animal excreta (406 kg/ha/yr). The annual N removal from the system (animal products and urine volatilisation 72 kg/ha/yr, leaching 25 kg/ha/yr and gaseous N emission 2 kg/ha/yr) was slightly lower than biological N–fixation input, resulting in a slight increase in soil N (3 kg/ha/yr). N cycling rate rather than soil N content was related to pasture production. Detailed N processes were reported and discussed elsewhere (Li and Snow 2010). Model-predicted water and N fluxes had general agreements with the observed or calculated values from this (e.g., Goh and Bruce 2005) and other similar pastures (e.g., Whitehead 1995; Ledgard 2001).

Conclusions

The pasture model predicted the seasonal and inter-annual variation of pasture growth and soil moisture dynamics quite well. The water and nitrogen processes simulated in the model agreed well with reported values for similar pastures in the literature. This evaluation provided the confidence in the model's capability to simulate pasture production under variable management, and demonstrated the capability and flexibility of APSIM with the pasture model with regard to setting up simulations based on the actual pasture management on a day-to-day basis. Validations under a wider range of soil and climate variation are underway and are expected to identify model limitations that will require further improvement.

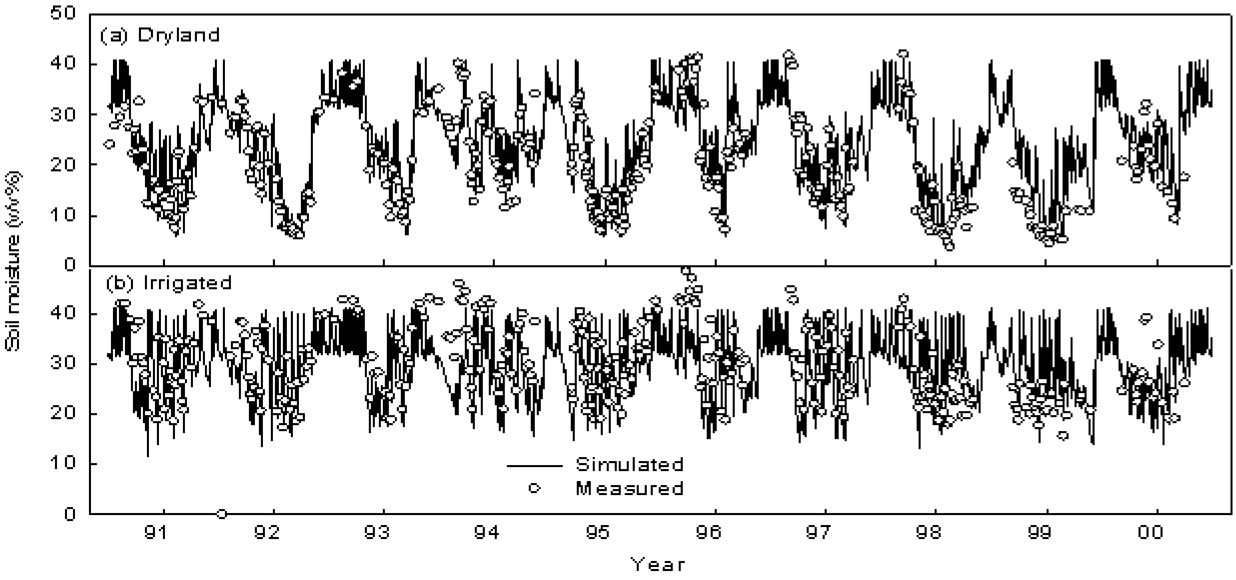


Figure 3 Simulated (lines) and measured (circles) soil moisture content in top 10 cm soil layer under dryland and irrigated conditions

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