Modelling biomass, soil water content and mineral nitrogen in dairy pastures: a comparison of DairyMod and APSIM

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Abstract

Realistic simulation of soil nitrogen cycling is important for quantifying nitrogen loss pathways to the environment, as well as the influence of N on pasture productivity. Although several models have been evaluated for their ability to simulate pasture growth, few studies have compared the models APSIM and DairyMod. Here, our objectives were to examine the capability of each model in simulating field measurements of pasture biomass, soil water content, mineral nitrogen and N_2O emissions. For site one, DairyMod generally simulated mineral N, cumulative N_2O and soil water with lower residual error than that from APSIM, but APSIM produced better estimates of pasture biomass. At site two, DairyMod produced more precise estimates of mineral N, but APSIM simulations were more reliable in terms of cumulative N_2O. Overall this study demonstrated that both models produced satisfactory estimates of pasture biomass and soil water dynamics, but further research is necessary to diagnose reasons for the sometimes large discrepancies between simulated and measured mineral N and cumulative N_2O emissions. Part of this discrepancy is likely to be caused by heterogeneity of soil N in the field, spatially and temporally. Although both models produce temporal estimates of mineral N and N_2O, quantification of parameter uncertainty associated with spatial variation in mineral N would help improve model evaluation such as performed in this study.

Keywords

Ammonium; nitrate; mineralisation; mixed species sward; mineral nitrogen; intensive grazing system

Introduction

Reliable simulation of biophysical processes in intensive farming systems is important not only for estimation of environmental losses of N, but also for simulation of livestock profitability aspects related to pasture growth. Two models commonly used to simulate intensive grazing systems in Australia include APSIM (Keating et al., 2003) and DairyMod (Johnson, 2016). APSIM was designed for simulating biophysical processes in farming systems, initially with an emphasis on cropping systems, and more recently also for pasture systems. In contrast, DairyMod was designed predominantly for pasture-based systems. DairyMod operates has been shown to adequately simulate production aspects of pasture-based systems across diverse climates, soil types and pasture species (Johnson, 2016). Although developed for different purposes, both models allow simulation of pasture growth as influenced by dynamics of soil water and nitrogen. APSIM has been validated at several pasture-based sites, but most past studies have been performed in the context of cropping systems; there are few studies of the performance of APSIM in simulating pasture growth in concert with mineral nitrogen, greenhouse gas emissions, and soil water content.

Materials and Method

Each model was calibrated using measurements collected from two field campaigns. Defoliation at both sites was conducted by mechanical cutting. The Camden site was located approximately 50 km SW of Sydney (-34.12S, 150.71E). The pasture at Camden was dominated by annual ryegrass (*Lolium rigidum*) and kikuyu (*Pennisetum clandestinum*). Fertiliser was applied at 46 kg N/ha immediately after every harvest in spring and autumn and every other harvest in summer and winter. Irrigation was applied through a combination of visual inspection of the pasture and soil moisture status. Soil mineral N was measured on a single core in each of three replicated plots. The Noorat site was located at the Glenormiston College Campus (38°10'S; 142°58'E) in Victoria; pastures at this site were dominated by perennial ryegrass. Urea was applied at a rate of 50 kg N/ha after every second defoliation until the end of the growing season each year. In 2012-13, after the low rainfall summer, the site suffered a severe decline in ryegrass density. As a result, oversowing was undertaken to improve ryegrass density of the pasture. At each harvest and seven days after nitrogen fertiliser application, samples of topsoil (0-0.1 m) were collected for NO_3 and NH_4 analyses. Four to six soil cores were collected from the four replicated plots of each treatment. Further details of this experiment are provided in Kelly (2013). APSIM classic v7.10 (Keating et al., 2003) and DairyMod v5.7.6 (Johnson, 2016) were parameterised with data from the two sites. Parameterisation was conducted for cumulative N_2O rather than for daily N_2O fluxes due to the variability of nitrous oxide measurements taken in the field (e.g. Fig. 1d). Several formulae were used for model evaluation following Tedeschi (2006); each metric was used to assess different qualities in the relationship between modelled and measured data. Mean bias (MB) was computed as the normalised difference between the observed and modelled mean; ideal MB values are zero. Root mean square error (RMSE) is the square root of the squared modelled values less the squared observations, divided by the number of observed values. Ideal RMSE values are zero. Mean prediction error (MPE) was calculated as the RMSE divided by the mean of the observed values. MPE values either < 0.10, 0.10-0.20 or >0.20 indicate good, moderate and poor simulation adequacy, respectively. The variance ratio (VR) was defined as the ratio of the variance of the observed data to that of the modelled data. The VR assumes ideal values when equal to unity; values greater than unity indicate that there is more variation in the actual data compared with the simulated data.

Results and Discussion

Evaluation metrics for the simulations conducted for the Camden and Noorat sites are shown in Tables 1 and 2, respectively.

Table 1. Assessment of DairyMod and APSIM simulations of biomass, soil NO_3 and NH_4, cumulative N_2O and soil water content in the surface layer (SWL_1) at Camden. Evaluation metrics compared data on a daily time-step.

Model/variable	RMSE	R^2	MB	MPE	VR
DairyMod/biomass	1234	0.05	-70	0.61	0.51
DairyMod/NO_3	26	0.11	11	0.79	2.02
DairyMod/NH_4	11	0.01	7	0.84	0.54
DairyMod/N_2O	540	0.94	-187	0.25	0.70
DairyMod/SWL_1	0.08	0.08	-0.01	0.21	0.90
APSIM/biomass	516	0.13	-171	0.26	1.98
APSIM/NO_3	41	0.07	31	1.22	5.97
APSIM/NH_4	14	0.03	13	1.04	22.60
APSIM/N_2O	719	0.80	401	0.33	0.77
APSIM/SWL_1	0.10	0.10	-0.03	0.27	0.66

Simulated biomass from APSIM at Camden was generally better than that from DairyMod, with RMSE values for individual harvests of 516 and 1234 kg DM/ha, respectively, though R^2 values for both models were poor. This was caused by the transition between the annual ryegrass and kikuyu in autumn and late spring. For example, both models overestimated pasture biomass in late June of 2013 (Fig. 1), indicating that either both models are poorly designed with respect to simulation of mixed swards, both models were poorly parameterised, or that other factors limited pasture growth during this period, such as soil borne diseases, spatial nutrient variability etc. Changes in biomass from harvest to harvest from DairyMod tended to be more variable than that from APSIM; DairyMod overestimated ryegrass and kikuyu production at the start and end of the simulation at Camden (Fig. 1A). Simulated soil NO_3 and NH_4 by both models at each site was generally poor, particularly at Camden (Fig. 1). Simulated NO_3 from DairyMod was generally better than that from APSIM for both sites, as the daily NO_3 flux from the former model tended to be lower than that from APSIM (Fig. 1E). Simulated NH_4 from both models exhibited much greater variability than that in measured data (Fig. 1F). Although both models had NH_4-sensitive parameters (e.g. max denitrification/nitrification rate, NH_4 concentration for half maximum denitrification/nitrification rate in DairyMod), modification of such parameters typically only altered the magnitude of the NH_4 peak, rather than the rate of change of NH_4 in the soil solution (e.g. Fig. 1F). Consequently, the model assessment metrics in Tables 1 and 2 suggest that DairyMod was more reliable than APSIM in simulating trends in both NO_3 and NH_4, though this outcome was primarily caused by the lower temporal variability of mineral N from DairyMod cf. mineral N simulated by APSIM.

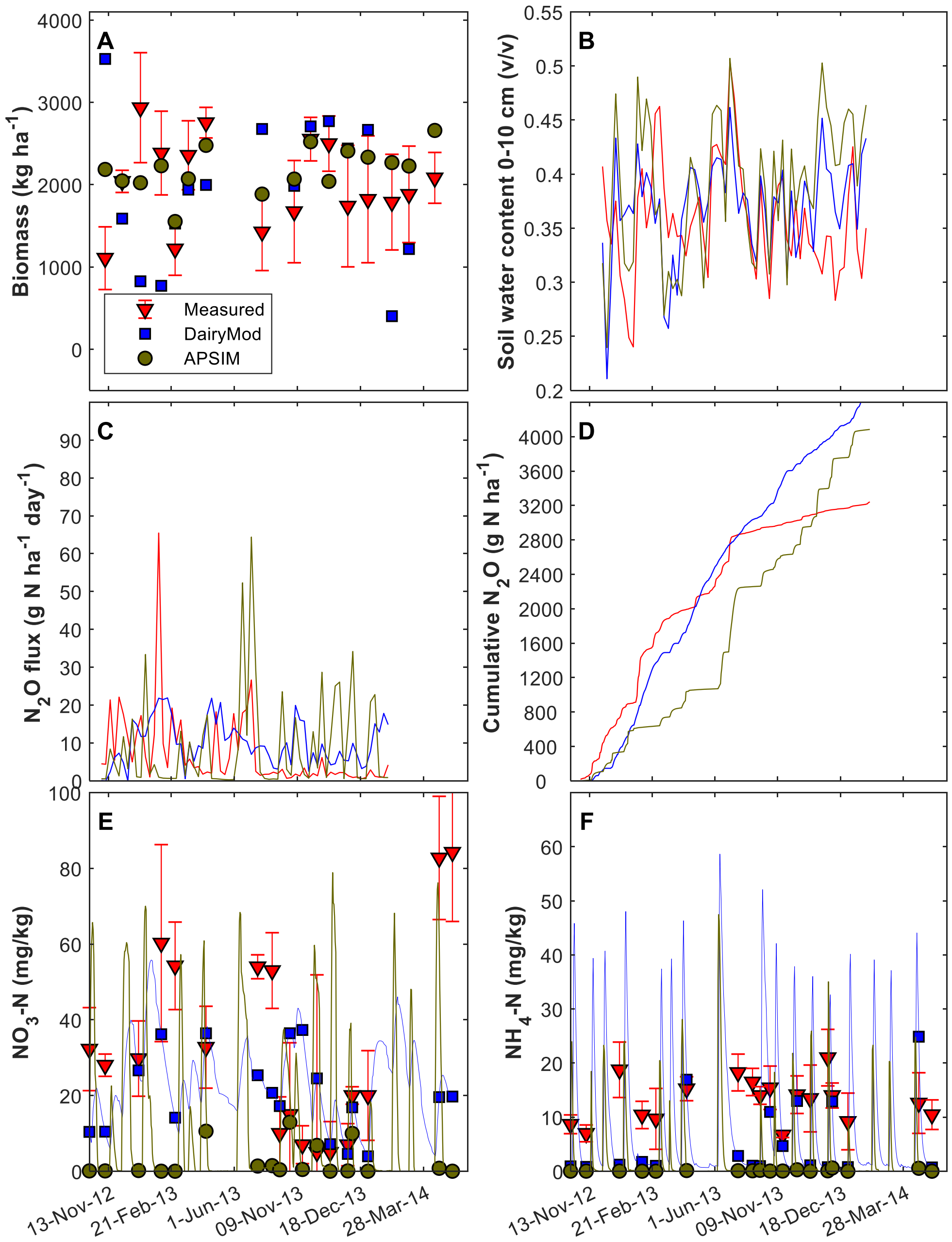

Fig. 1. Simulated and measured (A) pasture biomass, (B) weekly average soil water content, (C) cumulative weekly N_2O flux rate, (D) cumulative daily N_2O emissions, (E) soil NO_3 and (F) soil NH_4 from 14 October 2012 to 13 May 2014 at Camden, NSW, Australia.

Simulated cumulative N_2O from DairyMod was more accurate than that from APSIM at Camden (Table 1 and Fig. 1D), though the converse was true at Noorat. Differences in N_2O emissions between models was a partially caused by differences in denitrification and consequently N_2O/N_2 ratios. In both models, N_2O/N_2 ratios are calculated as a function of water-filled pore space (WFPS; the volumetric water content relative to saturation), and peaks of N_2O are sensitive to the WFPS value at which denitrification begins (between drained upper limit and saturation), as well as NO_3 concentration. Parameters specifying heterotrophic CO_2 respiration and gas diffusivity in the soil also affect the N_2O/N_2 ratio in APSIM. For Camden, the observed data had the greatest N_2O peaks around 21 February 2013 and 1 June 2013; these peaks generally coincided with peaks in observed soil water content (cf. Figs 1E and 1B). Compared with the observed data, simulated N_2O from APSIM had a lower baseline but with more peaks (Fig. 1C), somewhat reflecting the greater frequency of soil water peaks in the surface layer (Fig 1B). In contrast, simulated N_2O from DairyMod had fewer peaks than that from APSIM, and for Camden DairyMod simulated cumulative N_2O more reliably until the start of November 2013 (Fig. 1B).

Table 2. Assessment of DairyMod and APSIM simulations of biomass, soil NO_3 and NH_4, N_2O and soil water content (v/v) in layers 0-10 cm (SW_1), 10-20 cm (SW_2), 20-30 cm (SW_3) and 30-50 cm (SW_4) at Noorat. Data were compared on a daily time-step. Evaluation metrics are described in the methods.

Model/variable	RMSE	R^2	MB	MPE	VR
DairyMod/biomass	695	0.42	-313	0.56	0.61
DairyMod/NO_3	11	0.53	4.7	0.49	0.93
DairyMod/NH_4	23	0.25	3.8	0.98	1.59
DairyMod/N_2O	39	0.88	7.6	0.27	0.60
DairyMod/SW_1	0.06	0.71	0.00	0.22	0.91
DairyMod/SW_2	0.04	0.84	0.01	0.16	0.87
DairyMod/SW_3	0.03	0.93	-0.03	0.12	0.83
DairyMod/SW_4	0.03	0.85	0.01	0.07	1.55
APSIM/biomass	660	0.19	-405	0.54	1.02
APSIM/NO_3	25	0.02	-6.4	1.08	0.72
APSIM/NH_4	31	0.02	-0.6	1.30	1.29
APSIM/N_2O	14	0.97	5.0	0.10	0.82
APSIM/SW_1	0.04	0.87	0.02	0.15	0.93
APSIM/SW_2	0.04	0.89	0.02	0.13	0.95
APSIM/SW_3	0.02	0.88	0.01	0.08	0.94
APSIM/SW_4	0.03	0.85	0.01	0.07	1.55

CONCLUSIONS

This study has demonstrated a need for calibration of models to multiple sites when comparing simulations of mineral N, N_2O emissions and soil water content, as well as increased replication of field data to provide an indication of variability. Our results showed that the “right” answer can be achieved for the “wrong” reasons; coefficients used in N_2O algorithms in both models could be manipulated after having calibrated mineral N, allowing reasonable estimation of cumulative N_2O even though simulated NO_3 and/or NH_4 exhibited a temporal dynamic that was not present in the data. In addition to daily data, future modelling of mineral N should thus consider conducting validation over longer periods (e.g. weekly averages) due to the tendency of NO_3 and particularly NH_4 to fluctuate widely in short time spans. More frequent field measurements of mineral N would also be useful in this regard. The discrepancies between measured and modelled mineral N are likely partially due to both modelled and measured data; existing model equations and model parameterisation may not be sufficient to capture the complexity of biological processes influencing mineral N content such as mineralisation, nitrification and denitrification. On the other hand, the temporal and spatial variability of mineral N in the field may not have been adequately captured in the measured NO_3 and NH_4 data.

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