Simulating competition between cereal and lucerne grown in mixture

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Abstract

Data collected from a field experiment in NE Victoria was compared with simulated wheat and lucerne grown in mixture (companion crop) and wheat in monoculture, using the Agricultural Production Systems Simulator (APSIM). Detailed field soil measurements along with specific management inputs were used to parameterise the model, while observed cereal and lucerne production data were used to assess model performance. Root mean squared error (RMSE) and time-series plots quantified agreement between simulated and observed data. APSIM satisfactorily estimated cereal production in monoculture and in the presence of lucerne when autumn soil mineral N was reset in the companion crop simulation. RMSE of 28% and 23% of the observed mean was found in the cereal monoculture and 39% and 20% of the observed mean found in the companion crop simulations, for cereal biomass and cereal grain yield respectively. Without resetting autumn soil mineral N in the companion crop simulation, lucerne growth was over-estimated and cereal growth under-estimated in the final crop of the simulation. This may have been caused by the model over-estimating lucerne soil N uptake during the summer/autumn period. Simulated estimates of lucerne production in the companion crop stubble may have been improved with detailed temporal field observations of lucerne N fixation. Satisfactory model performance indicates APSIM can be used to simulate longer term effects of rainfall distribution and management intervention on companion crop performance, thus identifying the circumstances under which the practice might be feasible.

Key Words

wheat, companion crop, APSIM, model.

Introduction

Farming systems with mixed plant communities might be more resilient than monocultures, from the threat of climate change, due to an improved capacity to maximise production from variable rainfall. Cereal crops sown into established lucerne stands could potentially capture and utilise greater quantities of rainfall, and provide dual income streams to mixed farming systems through grain production and out of season feed supply. While previous field based studies have reported reductions in cereal crop grain yields from associated competition with lucerne, little attention has been given to the potential out of season feed supply that companion cropping may deliver. For example, Harris *et al*. (2008) measured up to 3.9 t/ha of lucerne DM from companion crop stubble over one summer period, highlighting the potential for significant rainfall use and forage production between crops.

Some Australian studies have reported the use of the Agricultural Production System Simulator (APSIM, Keating *et al.* 2003) for extrapolation of findings beyond minimal season and site specific field observations. APSIM is the most advanced cropping system computer model used in Australia to study interactions between climate, soil and plant growth, while providing flexibility to stipulate specific management interventions. However, whilst simulation modelling can potentially provide greater insight into the longer-term effects of seasonal variation on companion cropping performance, undertaking such an analysis requires initial testing of model accuracy to simulate competition between cereal and lucerne grown in mixture and subsequent summer lucerne production. In this paper we report on the degree of agreement between simulated and observed data over time from a field experiment, for cereal and lucerne production grown in mixture and cereal grown in monoculture.

Methods

Field experimental data

Field observations presented in this paper were collected from a field experiment detailed by Harris *et al*. (2008). The field experiment was conducted from 2003 to 2006 at North Boorhaman (146?23'E, 36?10'S) in north east Victoria. Temporal observed data for aboveground cereal and lucerne biomass, cereal grain yield, and soil mineral N from the dryland cereal monoculture and companion crop treatments are presented. The current study also use observed soil water content, soil mineral N, crop and lucerne stem population data for model parameterisation. Harris *et al*. (2008) describe the collection, processing and analysis used to generate most of this data, except for soil mineral N (NH_4^+ and NO_3^-). Soil N was measured at the beginning of the growing season in all years and at the end of the growing season in all years, except in 2005. On all occasions three soil cores (diameter 42 mm) were collected from randomly selected positions within each sub-plot. Cores were extracted to a depth of 1.2 m, divided into 0.1 m increments to 0.2 m depth and 0.2 m depth increments thereafter, and bulked for each depth in each sub-plot. Samples were oven dried at 40?C for 48 hours, and passed through a 2 mm sieve prior to measuring soil mineral N.

Simulations

APSIM was configured to perform three simulations wheat grown in monoculture; and wheat and lucerne grown together (companion crop), with and without resetting autumn soil N to field observed quantities in each year. The modules inserted into APSIM 5.3 for all simulations included: *manager* module to describe specific agronomic intervention and inputs; the environmental modules *surface organic matter*, modified *soil* module and *met* file to describe soil and climatic conditions under which the field experiment was conducted; the plant modules *wheat* for the cereal monoculture and companion crop simulations and *lucerne* for the companion crop simulations. An additional *weed* module was included in the cereal monoculture simulation to mimic soil water and nitrogen use by summer weeds over the fallow period between crops. The *canopy* module was included in the companion crop simulations to simulate competition for light by taking into account the differential height and leaf areas of the different species (Carberry *et al*. 1996). Soil water and nutrients were preferentially allocated to each species on alternate days (Robertson *et al*. 2004). Harris *et al*. (2009, in prep) will provide further details regarding model parameterisation and logic codes. The magnitude of error between simulated and observed data was quantified using root mean squared error (RMSE) described by Wallach and Goffinet (1989). As the proportion of RMSE to the observed mean increases, the accuracy of model estimation compared against observed data declines.

Results

In the cereal monoculture, APSIM simulated cereal biomass with a RMSE of 1619 kg DM/ha (28% of the three year observed mean of 5884 kg DM/ha, Figure 1a). Resetting autumn soil N in each year of the companion crop simulation reduced the RMSE for estimations of cereal biomass from 2347 kg DM/ha (52% of the three year observed mean of 4496 kg DM/ha) to 1761 kg DM/ha (39% of the three year observed mean). The time series plots showed that without resetting soil N in the companion crop simulation, APSIM under-estimated cereal biomass in the final crop at cereal maturity by 4889 kg DM/ha compared with the observed mean of 6830 kg DM/ha (Figure 1b).

Resetting autumn soil N in the companion crop simulation resulted in a substantial improvement in simulated lucerne biomass production. The time series plots showed that without autumn soil N resets in the companion crop simulation, APSIM over-estimated lucerne biomass production in the last crop at cereal maturity by 3524 kg DM/ha compared with the observed mean of 2240 kg DM/ha (Figure 1c). However, even with resets of soil N, APSIM over-estimated lucerne biomass production in the companion crop stubble. In the second and fourth summer/autumn periods lucerne production was over-estimated by 424 and 577 kg DM/ha respectively (Figure 1c).

Acceptable agreement between simulated and observed soil mineral N was achieved in the cereal monoculture simulation, with a RMSE of 15 kg N/ha (37% of the three year observed mean of 39 kg N/ha); also supported by the time series plots showing acceptable agreement on most sampling dates (Figure 1d). In contrast without resetting autumn soil N the estimated soil mineral N in the companion crop simulation was less reliable, with a RMSE of 36 kg N/ha (74% of the three year observed mean of 49 kg N/ha). Resetting soil N in each year reduced the RMSE to 5 kg N/ha (26% of the three year observed mean of 18 kg N/ha excluding autumn soil N data). The time series plots also showed that without resetting soil N, APSIM tended to under-estimate soil mineral N levels in the autumn of the second and final crops of the companion crop simulation (Figure 1e).

APSIM estimations of cereal grain yield in the cereal monoculture simulation were again satisfactory, giving a RMSE of 780 kg/ha (23% of the three year observed mean of 3372 kg/ha). Once more, without resetting autumn soil N in each year of the companion crop simulation, APSIM under-estimated grain yield by 1789 kg/ha in the final crop (Table 1). The improvement in estimation was further supported by a reduction in the RMSE from 1171 kg/ha (49% of the three year observed mean of 2405 kg/ha) to 475 kg/ha (20% of the three year observed mean) when resets of autumn soil N were included in the companion crop simulation.

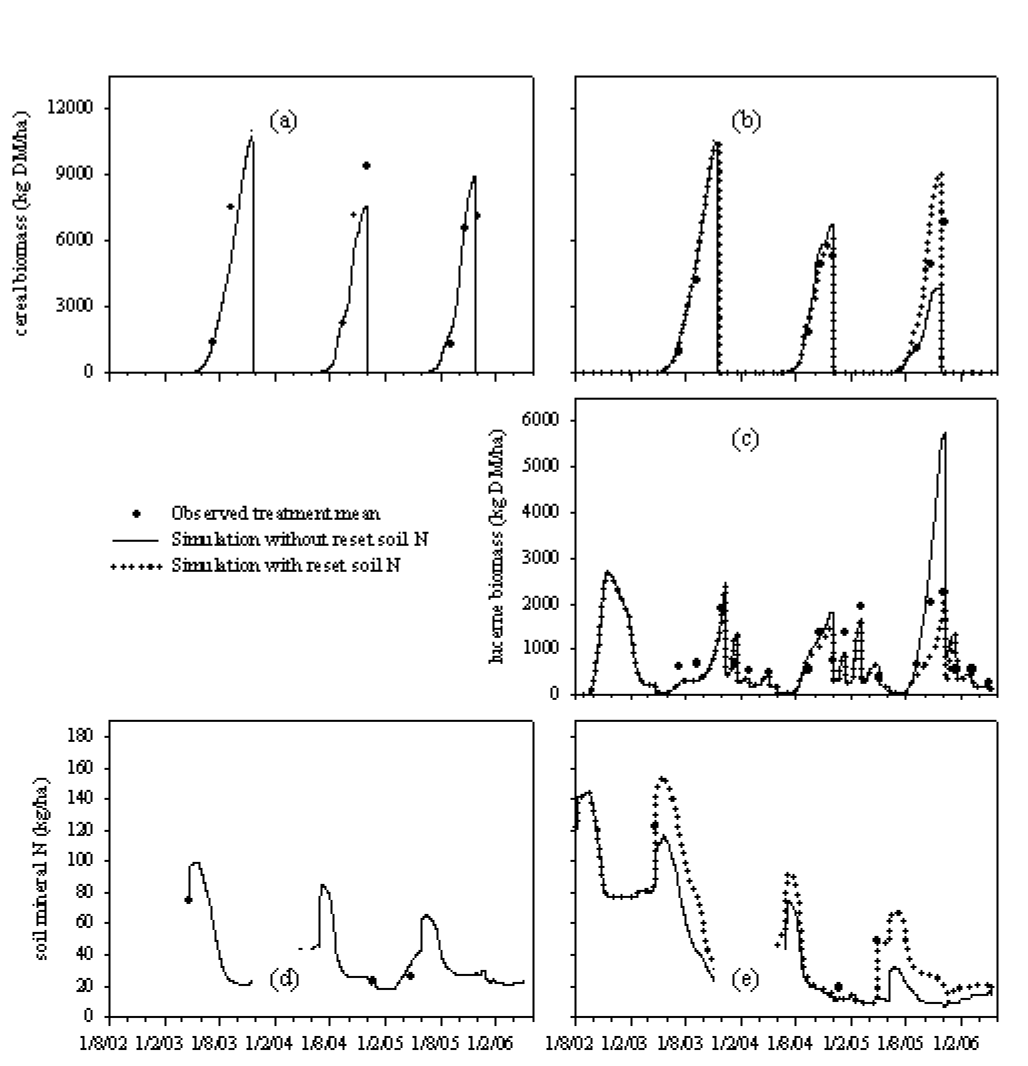

Figure 1. Time series plots of observed mean (scatter plots) and simulated (line) cereal biomass (a and b), lucerne biomass (c) and soil mineral N (d and e) in the cereal monoculture (a and d) and companion crop (b, c and e) treatments.

Table 1. Observed and simulated grain yields (kg/ha) of cereals growing in monoculture and with lucerne.

Year	Cereal monoculture		Companion crop		
	Observed	Simulated	Observed	Simulated without reset soil N	Simulated with reset soil N
2003	3808	3335	3069	3321	3656
2004	3095	2461	2048	1556	1837

2005	3322	2446	2263	474	2071

Discussion

The data presented in this paper suggest that the quantity of soil mineral N early in the growing season affects the degree of competition between the cereal and lucerne components. If the simulated soil mineral N is too low, APSIM will assume plant N uptake exhausts soil mineral N. Thereafter lucerne demand for N is satisfied through N fixation resulting in continued lucerne canopy development and capture of solar radiation, at the expense of the companion cereal which is largely denied access to adequate mineral N. When autumn soil mineral N was reset to more accurately reflect field conditions, the competitive advantage remained with the cereal component in the simulations, consistent with field observations.

The observed soil mineral N in autumn was higher than estimated by APSIM in the companion crop simulation. Field measurements of autumn soil N showed that most (>85%) of the mineral N was contained in the 0-0.1 m soil layer. This discrepancy may have resulted from soil N being 'spared' under the low density lucerne stands in the field experiment. Dear *et al*. (2001) found greater soil mineral N under sparse (5-10 plants/m^2) lucerne stands compared with low density phalaris (5-10 plants/m^2) or dense (40 plants/m^2) lucerne stands over the autumn/winter period; they attributed this effect to the superior ability of phalaris compared with lucerne to compensate for low plant density by increasing individual plant size and consequently exploiting a larger surface soil volume. In a companion cropping situation, presumably the companion cereal with a similar fibrous root system to phalaris and planted at a high density would be more effective at scavenging mineral N from the topsoil than lucerne. Perhaps APSIM may have over-estimated root exploration and therefore lucerne soil N uptake over the summer/autumn period, as lucerne plant densities ranged from 12 to 8 plants/m^2 over the lifespan of the corresponding field experiment.

The over-estimated summer/autumn lucerne biomass production in the companion crop simulation may have arisen from the N fixation parameter being too high for this environment. In the corresponding field experiment, the initial acid (pH 4.3 $CaCl_2$) topsoil conditions may have reduced rhizobia survival and therefore lucerne N fixation. We conducted a simulation where the lucerne N fixation parameter was reduced, resulting in a lower estimation of lucerne biomass over the summer/autumn period (data not shown). Measurements of lucerne N fixation in the corresponding field experiment could have improved model parameterisation and estimations of lucerne production.

Conclusion

APSIM satisfactorily simulated cereal production in the presence of lucerne, providing autumn soil N was reset each year. The model probably over-estimated lucerne soil N uptake over the summer/autumn period, and this seems the most likely reason necessitating the soil N resets. Measurements of lucerne N fixation in the corresponding field experiment could have improved model parameterisation and estimated lucerne biomass production over the summer/autumn period. Satisfactory model performance indicates APSIM can be used to simulate longer term effects of rainfall distribution and management intervention on companion crop performance, thus identifying the circumstances under which the practice might be feasible.

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