Evaluation of APSIM to simulate nitrogen fixation and uptake in diverse legume species across Australia

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Abstract
Quantification of the nitrogen (N) that legume crops contribute to subsequent crops in a rotation is critical in developing sustainable cropping systems. Process-based simulation models, such as APSIM (the Agricultural Production Systems Simulator) are potential tools to investigate interactions between season, soil chemistry, legume species, and the N cycle. However, even though there is a capacity to simulate N fixation, the performance of APSIM to predict N fixation has not been well validated. Here, the parameterised model was tested for the simulation of N uptake and N fixation in four crop legumes (lupin, chickpea, field pea, and peanut) in tropical, subtropical, semiarid and Mediterranean environments across Australia. The simulations varied in location, cultivar, sowing date, climate, soil type, irrigation and applied fertiliser N. In general, N uptake and fixation in aboveground biomass were reasonably well simulated for all legumes, with 93% of the variation in observed N accumulation and 85% in N fixation being explained by the model. There was a close relationship between simulated aboveground biomass and N fixation, indicating that an adequate simulation of aboveground biomass is a prerequisite to well simulate N fixation.

Key Words
APSIM, legume crops, N uptake, biological N fixation

Introduction
Supply and availability of Nitrogen (N) are important components in the productivity of cropping systems. Legumes can contribute substantial N to farming systems (Peoples et al., 1995), through the process of biological N fixation. However, the processes of biological nitrogen fixation are complicated. The complex interplay between seasons, soil chemistry, legume species and N cycles have been experimentally studied from plant to field crops (Masson-Boivin et al., 2009). However, long-term studies of N uptake and fixation by legumes are needed to understand the contribution of biological N fixation to sustainable agricultural systems.

Process-based simulation models, such as APSIM (Holzworth et al., 2014), are valuable tools to investigate the interactions of plant and soil processes in response to climate and management changes. Simulation models can also potentially extend the timescale of the outcomes of field experiments. The APSIM model simulates growth and development of diverse legume species, with a capacity for simulating N demand, N uptake and fixation (Robertson et al., 2002). However, it is still unclear whether the model is able to simulate N uptake, fixation and their responses to legume types, climate, and soil water and nitrogen levels, which are essential to successfully simulate the N cycle within the legume-based cropping system.

Legume crops, such as arrow-leafed lupin (*Lupinus angustifolius* L.), chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.) and peanut (*Arachis hypogaea* L.) have played an important role in Australian farming systems over the past decades, because of attractive cash returns from their yield, inputs of biologically fixed N to soil and beneficial effects on controls of diseases and weeds when they are rotated with cereals (Jensen et al., 2006). We tested the performance of APSIM v.7.6 in simulating N uptake and symbiotic N fixation for lupin, chick pea, field pea and peanut using experimental results across Australia.

Method
The APSIM legume model
The APSIM-legume model has the functionality to simulate the development, growth, crop N uptake, N fixation and N partitioning for a wide range of legume species, such as lupin, chickpea, field pea and peanut, using a generic crop model template (Robertson et al., 2002). However, it is worthwhile to note that N fixation is modelled simplistically. N fixation (N_fixation, Eqn. 1) is only affected by crop biomass

(biomass), crop N fixation capacity (N_fix_rate) and water stress (swdef (fixation)), the latter of which is a distinctive feature of arid and semiarid regions.

N_fixation = N_fix_rate * biomass * swdef (fixation) (1)

Model evaluation

Available field experimental data from published and unpublished studies were used for model evaluation of legume growth, N uptake and fixation, including lupin during 1994-1996 at Moora in Western Australia (Anderson et al., 1998a, 1998b), chickpea with three N fertiliser treatments (0, 50 and 100 kg N ha-1 were applied before sowing) during 1999 in Queensland (Turpin et al., 2002), field pea obtained from Wongan Hills site in 1988, Beverley and Mt Barker sites in 1989 in South Western Australia (Armstrong et al., 1994a, 1994b) and peanut during 1996-1997 and 1998-1999 at Goodger and during 1998-1999 at Kingaroy in Queensland (unpublished data). These data were selected because they all had measurements of aboveground biomass, yield, N uptake and N fixation (by 15N analysis).

The primary objective of this study is to evaluate the performance of APSIM in simulating nitrogen fixation and uptake in legumes, not in simulating crop phenological development. Therefore the default cultivar parameters for lupin (cv. Merrit and cv. Gungurru), peanut (cv. Streeton) were primarily adopted from APSIM v7.6. The parameters (thermal time target from to flowering to start of grain filling, thermal time target from start grain filling to end grain filling and radiation use efficiency) of chickpea were modified to improve the biomass simulations. For field pea crop, cultivar parameters (cv. Wirrega and Dinkum) were not available and we used the parameters for similar cultivars in APSIM.

Results

Generally, APSIM was able to simulate the observed N accumulated in aboveground biomass for the four legume crops lupin, chickpea, field pea, and peanut (Fig. 1a-d), although peanut biomass N was moderately overestimated in the low N treatment in the dry season (Fig. 1d). For all crops, the model explained about 93% (90-95% for individuals) of the variation in biomass N, with a RMSE of 24.5 kg N ha-1 DM (14.5-34.1 kg N ha-1 DM for individuals; Table 1; Fig. 1).

The model simulated the fixed N in aboveground biomass reasonably well for each crop (Fig. 2a-d). The discrepancies of fixed N for field pea (Fig. 2c) indicated that the model tended to underestimate N fixation under water-limited conditions (267 mm of precipitation at Avondale in 1989) and overestimate it under wet conditions (421 mm at Mt Barker in 1989). The model could explain at least 79% of the variations in observed N fixation in above-ground biomass for each crop, with lower RMSE values. Overall, APSIM could explain 85% of the variation in observed N fixed in aboveground biomass for all crops (Table 1). These results indicate that the APSIM model is able to simulate N uptake and N fixation of legumes and its response to water and N supply.

Table 1. Evaluation results for APSIM predictions of N uptake and fixed N in biomass of four crops.

Model attribute	r^2 [1]	a[2]	b[3]	RMSE (kg N ha^{-1})[4]
Biomass N	0.93	1.10	-3.5	24.5
Fixed N	0.85	0.97	-2.8	22.7

[1] Coefficient of determination (r2); 2Slope of linear regression; 3Intercept of the linear regression; 4Root mean squared error

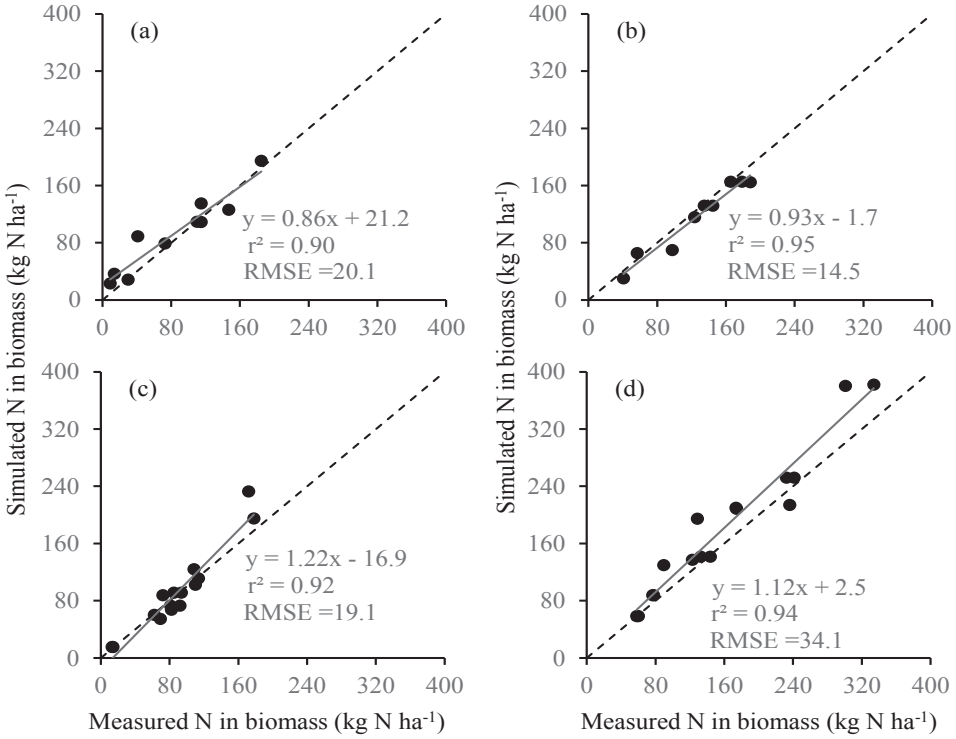


Figure 1. Comparison of observed and simulated N in aboveground biomass for lupin (a), chickpea (b), field pea (c) and peanut (d).

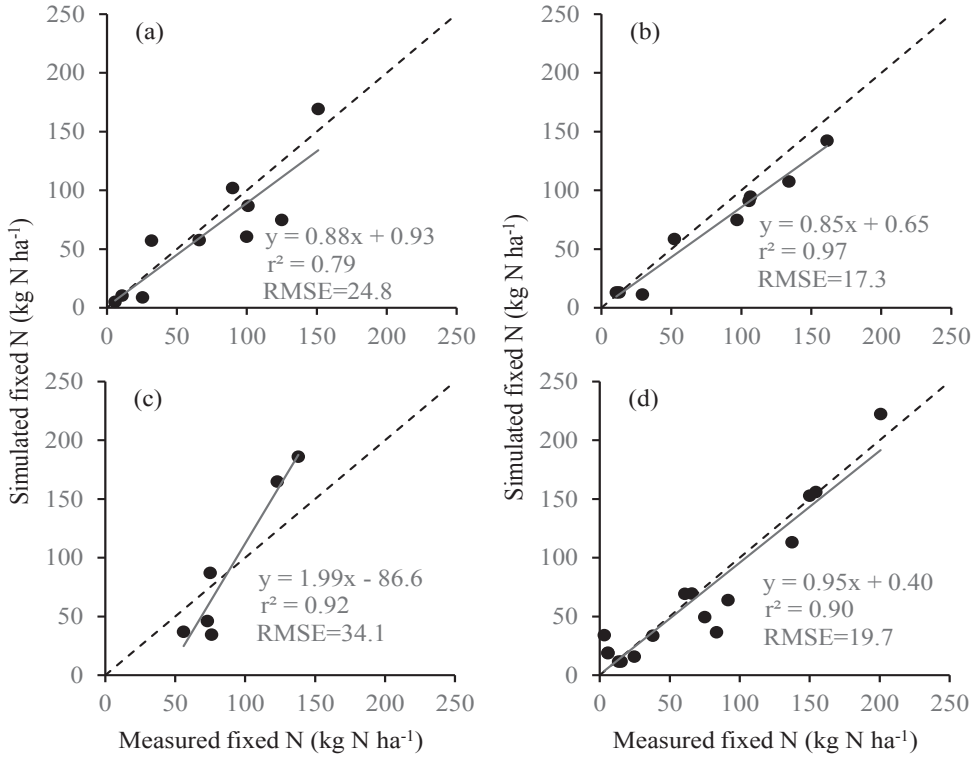
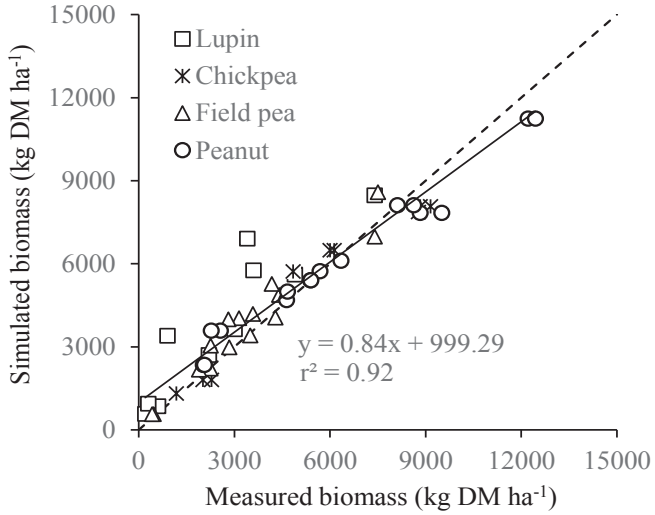


Figure 2. Comparison of observed and simulated fixed N in aboveground biomass for lupin (a), chickpea (b), field pea (c) and peanut (d). Unit of RMSE; kg N ha-1.

Figure 3. Comparison of observed and simulated values of biomass for all crops (lupin, chickpea, field pea and peanut). DM: biomass.



Conclusion

The good agreement between simulated and measured N fixation indicates that APSIM has captured the main environmental factors (leaf area development, radiation use and temperature) to estimate N fixation by legumes. We propose that simulation models such as APSIM are valuable tools to improve the knowledge about the role of legumes in farming systems. We conclude that the aboveground biomass must be simulated well to successfully simulate N accumulation and N fixation.

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