SIMULATION OF CEREAL-LEGUME ROTATIONS USING APSIM

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Summary. Use of models to evaluate alternative strategies for supplying nitrogen to cereal crops requires a capability to simulate crop production and nitrogen dynamics in farming systems that include legume leys. While the APSIM model is capable of simulating production of cereal crops as well as soil water and nitrogen dynamics, its capability to 'grow' legume crops is still under development. In this paper, experiments conducted at Tamworth are used to demonstrate that APSIM is capable of simulating changes in soil nitrogen and effects on subsequent cereal crops after the soil organic matter content has been enhanced under a legume ley.

INTRODUCTION

The north-eastern cereal growing areas of Australia have become nitrogen limited through long-term cultivation. Fertiliser use has increased, as has interest in use of legume leys in rotations with cereals. Models of the crop/pasture/soil system provide a tool to integrate existing knowledge of crop, pasture and soil responses to nitrogen inputs and to evaluate profitability and risk associated with alternative nitrogen management strategies. Ultimately the models must be able to simulate the legumes, predict their effect on soil nitrogen and the use of the nitrogen by following cereal crops. Legume modules for APSIM (Agricultural Production Systems Simulator) (7) are currently incomplete, however modules are available to simulate a range of cereal crops and soil water and organic matter balances. Here we test whether APSIM in its current form is capable of reproducing the effects of legume leys on following wheat or sorghum crops, using experimental data for a black earth at Tamworth (1, 2, 3, 4, 5). We have parameterised the APSIM model to simulate parts of the data set to test its capability to simulate the response of cereal crops to nitrogen additions via lucerne pastures and nitrogen fertiliser.

MATERIALS AND METHODS

The first phase in the field experiments (1, 2, 5) examined the effects on crop production and soil nitrogen of four rotations: continuous wheat, wheat following short, mid- and long lucerne leys, wheat following long fallow, and wheat in rotation with grain legumes. Phase two (3, 4) extended the study using sorghum as a substitute for wheat in the same rotations. In this modelling study we have focussed on comparing the continuous cereal system with cereals after the long lucerne ley. These are considered to be the most contrasting treatments in terms of nitrogen supply.

APSIM modules used in simulating these experiments were SOILWAT (soil water balance), SOILN (soil nitrogen), CW (wheat) and CS_SAT(sorghum). From a modelling perspective, the soil data from the experiments was sparse. This caused difficulties both for initialisation of model runs and for testing the predictive performance of the model. Soil water and nitrate-N profiles (to 1 m) before and after the growing seasons were only available for the final years of phase 1 (1975 through 1977). Prior to this, soil water profiles were available but soil nitrate only for the surface soil (0-15 cm), and following this period no water measurements were available until 1983. Soil organic carbon and total nitrogen (0-15 cm) were measured regularly throughout phases 1 and 2.

Simulation of the continuous wheat plots without fertiliser-N, from the start of the trial in 1966 to end of phase 1 in 1977 (without resetting of any system parameters after initialisation), requires input of the starting conditions (soil water, nitrate-N, organic carbon and its partitioning between the soil OM pools considered by the model). Comparison of outputs with the observed yields, soil nitrate contents etc., enabled some "tuning" of these initial conditions. To model the wheat crops that followed the lucerne ley required some assumptions about root residues and how the ley had influenced soil organic carbon (measured in the 0-15 cm layer only) and its partitioning between the soil OM pools. Probert (8) defines the composition of the three soil organic matter pools in the SOILN (soil nitrogen) module In the runs shown, 60% of the extra carbon found following lucerne was initialised as biomass carbon, with the remainder as humic carbon

Sorghum growth was simulated from 1984 through 1987, for both post-lucerne and continuous cereal treatments. Similar assumptions were needed to initialise the model to reflect the previous cropping history.

RESULTS AND DISCUSSION

Fig 1. shows model predictions for change in soil properties during phase 1. Under continuous wheat, organic carbon is predicted to decline with time, the more labile soil organic pool (BIOM) approaches a steady-state, and there is a gradual decline in the nitrate-N that accumulates in the profile during the fallows. The pattern of behaviour in 1972-73 is different because the 1972 crop was drought affected and ploughed out, therefore there was less nitrogen uptake and no removal in grain. Simulated organic carbon following the lucerne ley remains greater than in the continuous wheat treatment, but the post-lucerne BIOM pool declines over 4 years to become similar to continuous wheat. Mineral-N in the profile is increased greatly in the early years following the ley; although the contribution from the ley declines, effects are still evident after eight years. Comparison of predictions and observed mineral-N is only possible for the 0-15 cm layer and shows that the pattern of response agrees closely.

Simulated yields of wheat are shown in Fig. 2. Observed and predicted yields lie reasonably close to the 1:1 line (correlation coefficient 0.72; root mean squared deviation 584 kg/ha), with little indication of any bias in the predictions. However the predicted yield of wheat following lucerne relative to that in the continuous wheat system does not agree well with the observed pattern. Without fertiliser-N, the predicted relative yields decline though time, the only exception being in the first season following lucerne (1970) when greater water deficit after lucerne limited the response to the higher N supply. The large observed responses in unfertilised wheat to lucerne in 1975-77 seem inexplicable. However, Holford (1) showed that while yield response to the lucerne ley increased in 1975-76, levels of response in anthesis biomass and anthesis N-uptake continued declining. Thus much of the response in grain yield (1975-77) is occurring after anthesis, probably due to uptake of nitrate-N below 1 m (2). Where fertiliser was applied, the outcome is much as expected with any response to the preceding lucerne ley being masked at least in the early years; the predicted relative yields >1 in 1975-77 suggests that rates of applied N were not high enough to fully meet the crop’s need.

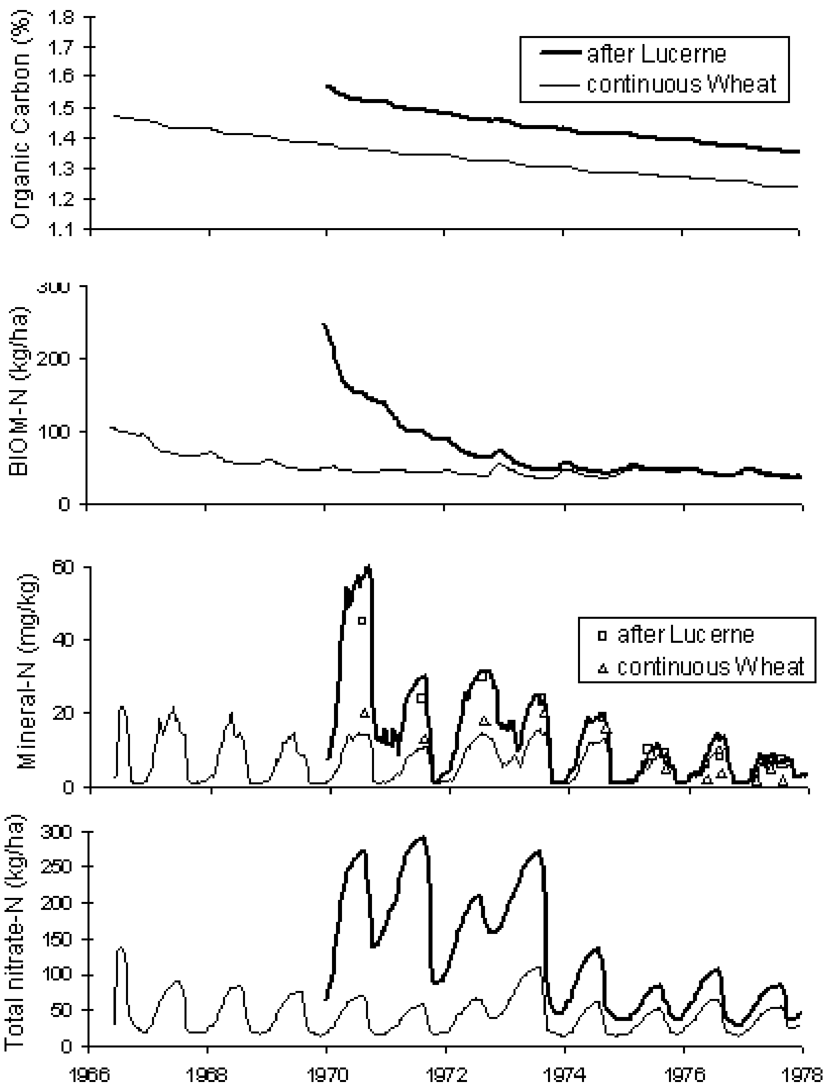

Figure 1. Simulation of organic carbon, the BIOM-N pool and mineral-N in the 0-15 cm soil layer and total nitrate-N in the 1 m profile for the continuous wheat system and following the lucerne ley without fertiliser-N. Observed data for mineral-N in the surface soil are shown as symbols.

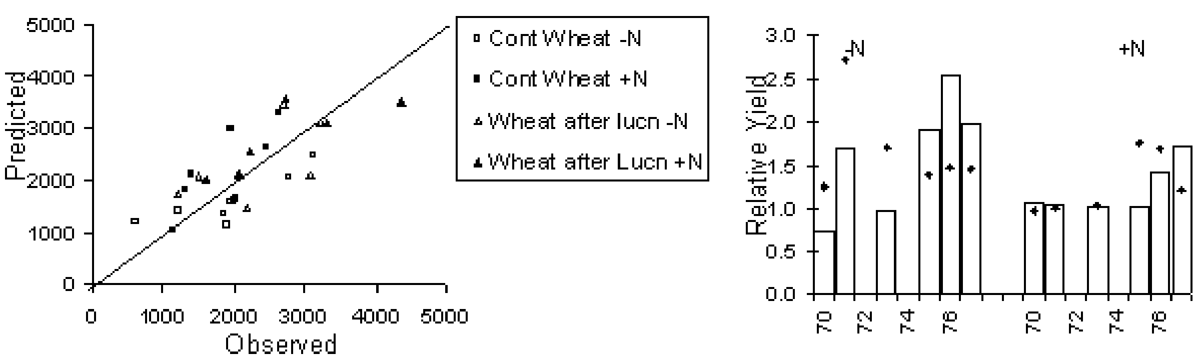

Figure 2. Observed and predicted yields of wheat. The right hand plot shows the relative yields (i.e. yield after lucerne / yield after wheat) for the treatments without and with fertiliser N, the bars representing the observed data and the points the simulations (The 1972 crop was ploughed out and the 1974 crop was hail damaged).

Predictions of the sorghum yields (1984-87) agreed well with the observed (Fig. 3) (correlation coefficient 0.95; root mean squared deviation 961 kg/ha), and the pattern of relative yields is much better aligned with observations. Both observed and predicted relative yield decline with time after the lucerne ley as the nitrogen derived from the ley declines. Some of the reason for better simulation of responses during the sorghum phase could be that rates of mineralisation for the continuous cereal treatments had declined through time enabling clearer expression of responses to added nitrogen in the later (sorghum) seasons.

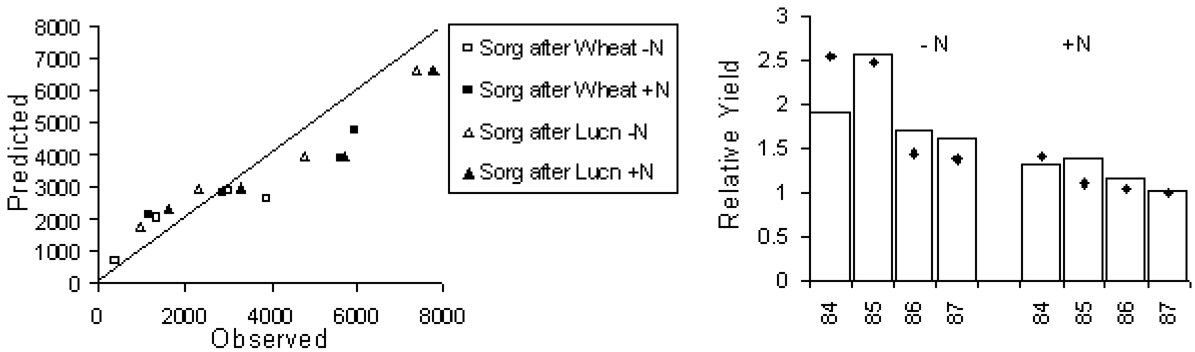

Figure 3. Observed and predicted yields of sorghum. The right hand plot shows the relative yields (i.e. yield after lucerne / yield after sorghum) for the treatments without and with fertiliser N, the bars representing the observed data and the points the simulations.

CONCLUSIONS

These simulations and similar studies on legume ley systems in the tropics (6) show that models are capable of producing sensible output for how soil organic matter and nitrogen behave after soil fertility has been raised by a ley and the contribution this makes to subsequent crops. We had success in simulating the sorghum response to the ley, but only limited success in describing the unusual nature of the response under wheat in phase 1. Despite our capability to simulate responses in the soil and crop to lucence leys, development of legume models is still necessary for quantifying and comparing cropping systems in terms of profitability and sustainability.

ACKNOWLEDGMENTS

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