Can the *APSIM* model simulate wheat yield and grain protein in south-western Queensland?

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ABSTRACT

Two models of wheat production (Nwheat and Iwheat) are tested by comparing simulated and observed grain yield and protein content for an experiment where responses to N fertilisers were being investigated. Coefficients of determination (R^2) between the observed and simulated yields (kg/ha) were 0 for both Nwheat and Iwheat. For grain protein (%), the R^2 values were 0 and 0.13 for Nwheat and Iwheat, respectively. The models gave more accurate results when data for 1998, where the crop was affected by disease or waterlogging, were excluded. The R^2 for yields and proteins increased to 0.68 and 0.07 for Nwheat and 0.37 and 0.74 for Iwheat, respectively. In general, the models were poor at simulating the observed leaf area and dry matter at anthesis. The low average yield in this environment emphasised the errors in the simulated results. In other environments the same quantum of error may be less important. A fourfold reduction in error is necessary before simulations could substitute for experimental results.

Key words

Wheat, model, fertiliser, testing, validation.

INTRODUCTION

This study explores the use of crop models as alternative sources of information concerning crop agronomy. Accurate and reliable crop models would be valuable for replacing or enhancing information derived from expensive and arduous field experiments. APSIM (Agricultural Production Systems Simulator) (2) has been used under a wide range of conditions in numerous studies to simulate crop production from soil, crop and weather and management data. It contains two alternate models of wheat production (Nwheat (6) and Iwheat (5)), as well as software to simulate soil moisture and fertility, pasture, crops other than wheat, runoff, drainage and soil erosion. APSIM and Nwheat were used by Robinson *et al.* (7) to simulate long-term average responses to N fertiliser in south-western Queensland, but the model was tested using only 1 year of data. Four years of data (1996 to 1999) and 2 models are now available for testing, and this study reports the results of this wider testing.

The wheat production issue

Many areas in south-western Queensland that were cleared of native vegetation for cultivation in the 1950s and 1960s now have low soil fertility due to depletion of soil organic matter, and consequent reductions in mineralisable nutrients. In particular, wheat yield and protein percentage are often reduced due to low levels of available soil nitrogen (1). Consequently, there is increasing demand for N fertilisers, and this is likely to further increase as the average age of cultivation increases. To date, information about crop responses to N fertilisers has come mainly from field experimentation, which has been limited to a few sites and seasons.

This study tests the accuracy and reliability of the Nwheat and Iwheat models for estimating wheat yield and protein content under the conditions in south-western Queensland.

METHODS

Nwheat and Iwheat were used to simulate wheat yields and proteins in an experiment at Nindigully, near St George. Simulated and observed yield and protein results (1996 to 1999) were compared graphically and by linear regression. To determine whether the models were sensitive to factors affecting the growth and development of the crop, simulated and observed leaf area indices (LAI) and above-ground biomass (DM, kg/ha) at anthesis were also compared.

The experiment site has a deep grey clay (Coolibah) soil, and has been cropped for approximately 50 years. A range of seasonal conditions occurred in the period 1996 to 1999, resulting in a wide range of yield and protein outcomes. Treatments in the experiment included 4 fertiliser rates each year. Also, in 1997, 1998 and 1999, 2 additional fertiliser rates were applied in combination with 2 tillage treatments (zero and conventional tillage), giving a total of 28 treatments ? years of observations.

The APSIM model (2), Nwheat (6) and Iwheat (5) were used to simulate crop growth and grain yield and protein for each treatment. Each simulation used measured pre-plant soil moisture and nitrate concentrations for that treatment, as well as the relevant fertiliser rate. Other factors were based on either measured values (plant density, variety, soil organic carbon, runoff curve number) or values that have proved reliable in other studies.

RESULTS

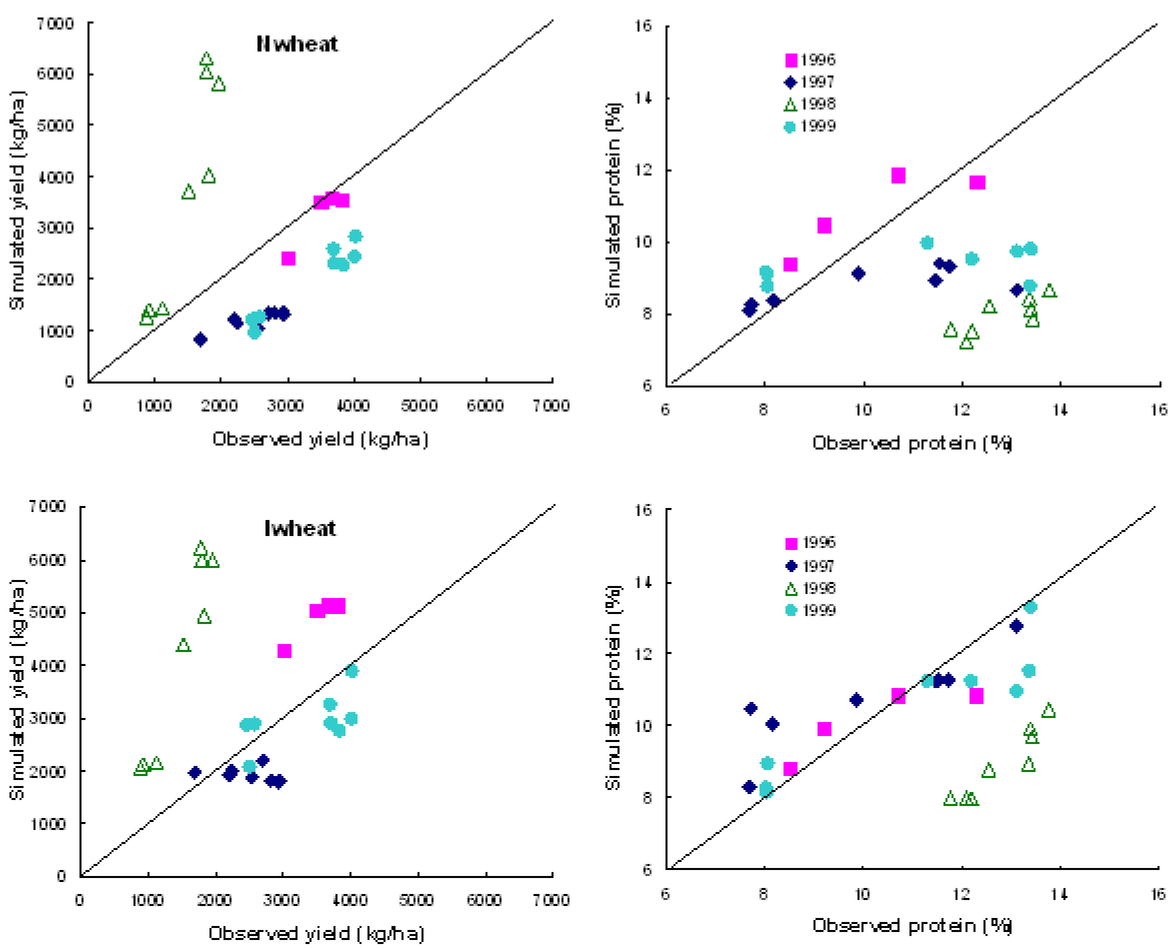

Figure 1. Wheat yields (kg/ha) and grain protein content (%) simulated by Nwheat (top) and Iwheat (bottom) and those observed at Nindigully. The lines indicate equivalence (1:1).

Figure 1 shows the simulated results from the models and the observed yield and protein data at Nindigully. Nwheat simulated yields in 1996 quite well, but underestimated yields in 1997 and 1999, and overestimated 1998. Iwheat simulated yields well in 1997 and 1999, but overestimated yields in 1996 and 1998. The mean absolute errors in the simulated yields (|observed – simulated|) were 1447 kg/ha for Nwheat and 1358 kg/ha for Iwheat. The mean of the observations was 2595 kg/ha. Both models over-predicted yields by large amounts in 1998, probably due to effects of disease (yellow spot) and waterlogging reducing yields in the experiment. Unfortunately, there appears to be no means of knowing or compensating for such errors *a priori.*

Protein contents simulated by Nwheat fell predominantly in a range between 8 to 10 %, which underestimated many observed values by between 3 and 6 %. The mean absolute error was 2.6 %. Iwheat was better at simulating higher protein contents, and had smaller errors (mean = 1.7 %). Protein was severely underestimated by both models in 1998, probably as a consequence of the yield over-prediction mentioned above.

Table 1 shows that the model estimates were not significantly correlated with the observed variation in yield (R^2 = 0.0 for Nwheat, R^2 = 0.0 for Iwheat) and protein (R^2 = 0.0 for Nwheat, R^2 = 0.13 for Iwheat). None of the relationships had a slope near the ideal value of 1, and all of the slopes were much less than 1, indicating that the models were not sensitive to the factors that produced the observed variations in grain yield, protein and N yield.

Table 1. Relationships between simulated yield, protein and N yield (X) and the observed values (Y) at the Nindigully experiment, 1996 to 1999.

	Nwheat			Iwheat		
	equation	R^2	SE	equation	R^2	SE
Yield (kg/ha)	2594 - 0.0006 X	0.0	971	2403 + 0.058 X	0.0	967
Protein (%)	12.2 + 0.11 X	0.0	2.15	5.38 + 0.57 X	0.13	1.98
N yield (kg/ha)	39.5 + 0.29 X	0.07	21.6	31.2 + 0.34 X	0.14	20.8

Figure 2 shows the relationships between simulated and observed LAI and DM. Nwheat was better at simulating LAI than Iwheat, which substantially under-predicted LAI in many instances. Iwheat was better than Nwheat at simulating DM (mean error = 1874 kg/ha). DM prediction by Iwheat was within +/- 30 % of the observed values except for the 1996 data and the treatments with high fertiliser rates in 1998. Nwheat rarely estimated DM within 20% of the observations (Figure 2). Table 2 shows the mathematical relationships between the simulated and observed LAI and DM data.

Table 2. Relationships between simulated (X) and observed (Y) leaf area index (LAI) and above-ground biomass (DM, kg/ha) at the Nindigully experiment.

Nwheat	Iwheat

	equation	R^2	SE	equation	R^2	SE
LAI	Y = 1.0 + 0.28 X	0.13	0.57	Y = 1.41 + 0.003 X	0	0.64
DM (kg/ha)	Y= 4301 + 0.24 X	0.09	1417	Y = 3855 + 0.21 X	0.05	1449

Although the models did not simulate the observed yields and proteins overall, some results were better than others. In particular, some of the largest errors concerned treatments with high fertiliser rates in 1998. It may be argued that 1998 was an exceptional year due to the occurrence of excess rainfall and plant diseases, and that the 1998 data are not as representative of the usual run of seasons as the other test data. By assuming that 1998 is not representative of seasons that would usually want to be simulated, these data could be omitted from the analysis. Results that exclude 1998 show that the errors in simulations are smaller, but still far from ideal (Table 3).

Nwheat produced a useful level of correlation with the observed yields in these data (R^2=0.68), but not for protein (R^2=0.07). Iwheat did not reliably simulate these yield data (R^2=0.37), but reproduced the protein data quite well (R^2=0.74). The results for N yield were substantially better than for the all-years data set.

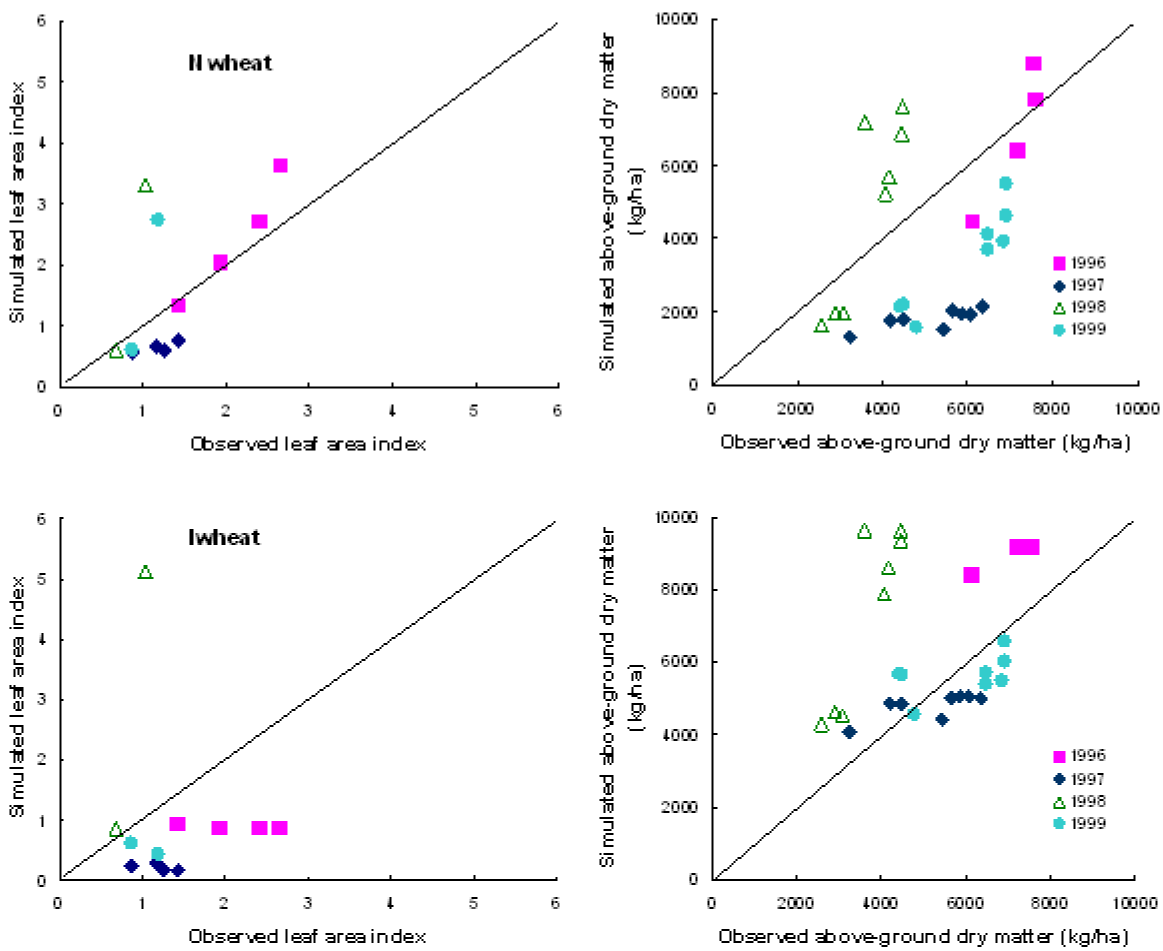

Figure 2. Leaf area indices and above-ground dry matter (kg/ha), measured at anthesis at Nindigully and simulated by Nwheat (top) and Iwheat (bottom).

Table 3. Relationships between simulated yield, protein and N yield (X) and the observed values (Y) at the Nindigully experiment in 1996, 1997 and 1999, excluding 1998.

	Nwheat			Iwheat		
	equation	R^2	SE	equation	R^2	SE
Yield (kg/ha)	1842 + 0.62 X	0.68	387	1952 + 0.37 X	0.37	550
Protein (%)	3.53 + 0.74 X	0.07	2.05	-3.08 + 1.29 X	0.74	1.11
N yield (kg/ha)	33.7 + 0.72 X	0.37	17.5	24.2 + 0.62 X	0.38	17.5

DISCUSSION

These results show that these crop models would not be suitable for replacing or enhancing results from the Nindigully field experiment. The best results were from Nwheat, which simulated yield and protein in 1996, and Iwheat that simulated protein in 1996. However, overall, there are systemic problems in the models, as evidenced by the discrepancies between simulated and observed leaf area and dry matter at anthesis (Figure 2). Excluding data from 1998 improved the fit of the simulated yield and protein data, but not to a high level. These results show that the effects of disease, weeds, *etc.* can be very important, and it would be unwise to assume that the distribution between years of yields or proteins from the model is indicative of the distribution of results from experimental plots or farmers paddocks.

The Nwheat simulations were approximately as accurate (SE = 971 kg/ha) in absolute terms as a previous major study (6), where a SE of 937 kg/ha (R^2 = 0.30) was reported between simulated and observed wheat yields. The results here for Iwheat (SE = 967 kg/ha) are also similar to those (SE = 940 kg/ha) calculated from low-yielding situations (below 4 t/ha) in another study (4). To achieve a SE equal to 20 % or less of the long-term average yield in the region, a wheat model to have a SE of no more than 250 kg/ha. At present, these models produce errors almost 4 times larger than this.

The low accuracy of the wheat models at this site calls into question the conclusions of other studies that have assumed Nwheat or Iwheat and APSIM are accurate (e.g. 7, 3). Depending on the circumstances, it may be hazardous to use APSIM to estimate the consequences of decision-making in this region.

These results contrast with the best results achieved at other locations. For an N fertiliser experiment at Condobolin, Iwheat simulated yield and protein with impressive accuracy (Robinson, unpublished data). The SE of yield and protein in those data were 141 kg/ha and 0.38 %, respectively (R^2 = 0.91 and 0.96). Further work is required to establish the causes of the disparity in accuracy between locations.

CONCLUSIONS

Testing the Nwheat and Iwheat models revealed that neither model was suitable for estimating wheat yields and proteins in southwest Queensland.

It would be useful to estimate the validity of APSIM in other regions and circumstances, and to use the information to continuously improve the software.

ACKNOWLEDGMENTS

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