Testing the sirius wheat calculator

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Abstract

The Sirius Wheat Calculator is a decision support system that can help farmers make cultivar choice, irrigation and nitrogen (N) fertiliser management decisions. It is designed to run on a standard PC, and predicts both the yield and financial outcomes of irrigation and N scheduling decisions. During the 2001/2002 wheat growing season, the calculator was implemented on five farms where it was used to guide N scheduling decisions. Trials consisted of three replicates of three N treatments; no N, calculator guided management and farmer guided management of the crop. Irrigation management was the same for each treatment. Soil depth and mineral N were measured either to the stones or to 90 cm, and total and mineralisable N were measured in the upper 30 cm when the experiments were set up. The crop and soil N were monitored on occasions through the season, and yield, ear numbers and kernel mass measured at maturity. In most cases, the calculator closely predicted both absolute yield and response to N. Exceptions were where there was a substantial effect of disease (Take-all) in one crop, and in one case where mineral N measurements were restricted in a stony soil.

Additional key words: Decision Support System, DSS, nitrogen, crop model

Introduction

The Sirius Wheat Calculator is a new decision support system (DSS) based on the wheat simulation model Sirius, (Jamieson *et al.*, 1998b). Sirius was developed by Crop & Food Research in conjunction with the Biotechnology and Biological Sciences Research Council in the UK, and closely simulates the effects of restrictions in water supply (Jamieson *et al.*, 1998a) and nitrogen (Jamieson and Semenov, 2000). Although Sirius was initially developed as a scientific tool for testing hypotheses about plant growth processes, it is robust and simple enough to be tailored as a DSS. Most of its development has been in a modern computer language so that software modifications to produce the DSS have been straightforward.

Although the performance of Sirius has been tested against experimental data in a wide range of environments, it had never been assessed as an operational management tool. The purpose of the Sirius Wheat Calculator Project was to provide such assessments by comparing model-directed management against the practices of wheat growers. Such assessments also provide an avenue of feedback from the DSS users to the developers, so that the DSS can be tailored towards the needs of the growers.

Materials and Methods

A draft version of the Sirius Wheat Calculator, developed in the six months prior to commencement of the project, was installed on the computers of nine farmers in mid-Canterbury in August 2001. Five of the farmers had an experiment set up in their wheat fields. These consisted of three treatments replicated three times in a randomised block design. The treatments were:

- Farm Treatment: N fertiliser applied according to farmer preference as decided by the participating farmer.
- Model Treatment: N fertiliser application applied according to decisions made in conjunction with the Wheat Calculator.
- Nil Treatment: No N fertiliser. This treatment was aimed to test the ability of the soil system to supply N to the crop.

Table 1. Trial location, weather station with soil and cultivar information.

Site	Location	Weather Station	Soil Type	Cultivar
1	Dorie	Chertsey	Templeton shallow silt loam	Claire
2	Dorie	Chertsey	Templeton silt loam on sandy loam	Claire
3	Leeston	Chertsey	Paparua sandy loam	Savannah
4	Wheatstone	Chertsey	Waimakariri stony sandy loam	Claire

5	Sheffield	Lincoln	Lyndhurst silt loam	Centaur

Plots 2 m x 10 m, were marked out between tramlines within the crop and isolated with herbicide (glyphosate) strips applied with a weed wiper. The nearest weather station, soil type and cultivar (Table 1) were identified for the Wheat Calculator management file. Nitrogen applications along with soil and plant sampling were carried out as follows:

Soil sampling

Throughout the season the soil under the crop was sampled according to the initial measurement depth and soil mineral N measured. At the time of set-up, samples were taken down to 90 cm or to the stones, whichever was shallowest. Mineral N was measured in each layer in 0-15 cm, 15-30 cm, 30-50 cm, 50-70 cm, 70-90 cm increments. For each plot eight cores were taken for each depth increment down to 50 cm, then four from each corner of each plot for the remaining depths. Total N and other nutrients were measured in the upper two layers for the first sampling. Further sampling was done before the N treatments were applied in late September, early November, late November and mid February. Mineral N content was determined using KCL (2M) extractions.

Plant sampling

Plant samples were taken to measure biomass and plant N content. Two 0.1 m^2 samples were taken from each plot before tillering (August), full flag leaf emergence (November), anthesis (December) and just prior to harvest in February. Plants and tillers were counted, roots removed and each sample was dried at 60°C, weighed and retained for grinding and N analysis. The final biomass sample was threshed with a stationary thresher to separate the grain and straw for separate N analysis.

The trials were harvested with a mechanical harvester near the end of February. Yield, thousand grain weight (TGW) and grain moisture were determined for each sample. All results were adjusted to 14 % moisture content.

Nitrogen applications

N fertiliser was applied by hand as urea (46 %N) according to the treatments at each site (Table 2). The model treatments were determined by entering cultivar, sowing date, required protein level, mineral N and soil type values into the management file for each site. The resulting N management output was manipulated to find the most appropriate rates and timings to give the optimum yield. Farmer participation

Nine farmers were selected from a meeting organised by the Foundation for Arable Research (FAR) in conjunction with Crop & Food Research (C&FR) to introduce the model. One to two hours instruction was provided by C&FR staff when installing the model on the farmers' computers. The farmers were required to save daily weather data, which was sent out via email three times a week, and provide feedback on the model's performance and design.

A meeting with FAR staff and the farmers involved in the project was held on 17 April 2002 at Lincoln. The purpose of this meeting was to present them with the results and record their recommendations and suggestions about the model.

Data were analysed using analysis of variance (ANOVA).

Results

Yield predictions and observations

Treatment yields at 14 % moisture varied from 4.5 to 14.3 t/ha (Table 3). On all but one farm, and one treatment on another farm, predictions of yield from the calculator were close to those observed in the plots, and response to applied N fertiliser was accurately predicted (Table 3).

One of the exceptions (Site 4) was associated with a severe Take-all (*Gaeumannomyces graminis* var. *tritici*) infection that reduced yields substantially. Predictions exceeded measured yields by more than 2 t/ha when no N fertiliser was added, and by more than 5 t/ha when N fertiliser was added (Table 3). The other exception (Site 1) was where measured yield without added N exceeded calculated yield by about 5 t/ha. In this case sampling of soil N was severely restricted because the depth to stones was only 30 cm and apparently not all of the soil N was accounted for in the calculations. With these outlying plots excluded, the model accounted for 81 % of the variation in wheat yield over a two-fold range (Fig. 1).

Table 2. Nitrogen (N) fertiliser application dates and amounts (kg/ha) for the farm and model treatments.

	Farm Treatment		Model Treatment	
Site	Date	N (kg/ha)	Date	N (kg/ha)
1	08/10/01	120	26/09/01	90
	31/10/01	120	08/11/01	150
	Total	**240**		**240**
2	08/11/01	92	08/11/01	46*
	Total	**92**		**46**
3	08/11/01	90	12/11/01	170
	Total	**90**		**170**
4	25/09/01	76	08/10/01	90
	08/10/01	92	12/11/01	100
	12/11/01	58		
	Total	**226**		**190**
5	08/10/01	32	23/10/01	60
	23/10/01	69	19/11/01	40
	19/11/01	120		
	Total	**170**		**100**

* The model recommended no N fertiliser, so 46 kg/ha was applied to provide a treatment different from the control

Table 3. Treatment yields (t/ha) according to method of management. Figures in brackets are the wheat calculator predictions of yield.

Site	Farm Treatment	Model Treatment	Nil Treatment	LSD 5 %*
1	12.7 (12.7)	13.1 (13.4)	10.5 (5.4)[2]	0.70
2	13 (13.5)	14.3 (13.5)	12.3 (3.5)	3.31
3	10.0 (10.4)	11.0 (12.2)	9.6 (9.5)	1.35
4	7.8 (13.3)[1]	7.2 (13.2)[1]	4.5 (6.9)[1]	1.23
5	11.9 (10.1)	11.0 (10.1)	8.0 (6.8)	1.68

[1] Take-all reduced yield
[2] Wheat Calculator prec
* d.f = 4

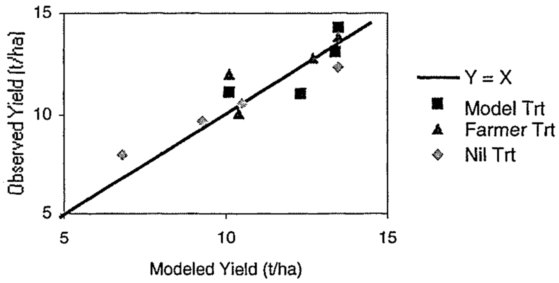

Figure 1. Comparison of yields modelled by the wheat calculator with those measured in plots managed according to farmer best practise (▲), by using the model (■) and with no added N (□). The solid line is Y=X. The R^2 for the regression of observed on modeled yield was 0.81.

Table 4. Thousand grain weights (g) according to method of management.

Site	Farm Treatment	Model Treatment	Nil Treatment	LSD 5 % *
1	42.9	46.4	47.7	2.64
2	46.4	46.0	46.8	3.15
3	51.6	52.0	48.7	1.92
4	40.5	37.9	37.2	4.73
5	42.7	42.0	42.6	0.56

*d.f = 4

Treatment differences

Statistical analysis showed no differences ($p>0.05$) between the yields of the farm or model treatments (Table 3). Variations in TGW were a minor or insignificant contributor to yield variations (Table 4).

Although there was no statistical difference in yield, there were differences between the amount of N applied for the Farm and Model treatments (Table 2). At Site 1 the amount of N applied was the same, but applied at different timings. At Site 2, 4 and 5, the Farm treatments exceeded the Model treatments, whereas the Model treatment was higher than the Farm treatment at Site 3. In all but one case (Site 2, Table 3), there was a substantial increase in yield from added N fertiliser. This site also had the highest soil mineral N content (Table 5).

Weather stations

Site 5 (Table 1) was near Sheffield, at higher altitude than Lincoln, and no weather station was near the site. The simulations were run using weather from Lincoln, and predictions for growth stages, particular GS30 and anthesis, were about two weeks earlier than observed at the site. Hence modelled yields were 1 tonne more than those observed in the trial plots (Table 3). This could be caused by the temperature differences associated with the elevation difference (320 m at Site 5, cf. 11 m at Lincoln). The adiabatic lapse rate is approximately 1°C/100 m (Sturman & Tapper, 1996), and would result in a temperature depression of 3°C if there were no other influences. The Lincoln weather file was modified by reducing the minimum and maximum temperatures by 3°C. This subsequently led to better yield estimates and growth stage predictions (Table 6).

Table 5. Soil depth (cm) and mineral N (kg/ha) at each site. Figures in brackets are the mineral N content of the upper 30 cm.

Site	Sampling Depth	Farm Treatment	Model Treatment	Nil Treatment
1	30	48	40	46
2	90	251 (59)	288 (81)	284 (74)
3	70	123 (33)	127 (36)	118 (35)
4	50	64 (32)	65 (33)	62 (33)
5	50	76 (29)	69 (27)	79 (29)

Table 6. Comparisons of anthesis date predicted by the wheat calculator and yields (t/ha) based on Lincoln weather data, and Lincoln weather data with temperatures cooler by 3°C (Modified) with observations from Site 5.

	Observed	Modeled	
		Lincoln data	Modified data
Anthesis date	16/12/01	01/12/01	21/12/01
Nil Trt Yield	8.0	6.8	7.4
Model Trt Yield	11.1	10.1	11.0
Farm Trt Yield	11.9	10.1	11.7

Discussion

Yield predictions and observations

The model predictions of yield were close to those observed in the plots. There were two exceptions, disease and soil N measurements, which require further explanation.

Disease

The Wheat Calculator predicts yields of wheat grown under optimum conditions, and takes no account of disease. If we accept that the Wheat Calculator estimates of yield are reasonably close in the absence of disease, then the yield loss associated with the Take-all at Site 4 can be quantified in monetary terms. This approach suggests that the plots given normal N management under-performed by between 5.5 and 6.0 t/ha, representing a loss of $1250-$1500/ha. In this sense, the calculator is useful at identifying the costs of yield losses.

Soil N

The differences in soil depth available for sampling had an influence on the calculation of mineral N that was used in the model simulations (Table 3). These depths varied from 30 cm at Site 1 to more than 90 cm at the Site 2. Sites 3, 4 and 5 had very similar amounts of mineral N in the top 30 cm at the baseline measurement, but this represented from half to a quarter of the mineral in the complete measured profile.

At Site 1 the Nil plots yielded substantially more than the calculator estimate. The mean measured yield for these plots was 10.5 t/ha, but the calculator estimate was only 5.4 t/ha, based on the measured mineral N content of the upper 30 cm of soil (46 kg N/ha, Table 5). To achieve a yield that matched the yield measured from the plots, a further 85 kg/ha of N was needed in the soil.

Given that a 10.5 t/ha crop of wheat contains in excess of 200 kg of N/ha, the initial mineral N measured plus the N that mineralised during the season is not enough to supply that need, the extra 85 kg N/ha had to be in the layers of the stony soil underlying the 30 cm of topsoil. Interestingly, if this change was made for the other plots, then the calculator showed no difference in yield between the farmer and model-managed plots.

As noted, the Site 1 measurement was restricted to 30 cm of topsoil, and the measurement apparently represented only about a third of the mineral N that was there. In cases where the stone layer is shallow, a book-keeping approach using various combinations of crop calculators may be a solution to estimating early season mineral N.

Site 2 had the deepest soil (Table 5), enabling measurement of N content down to 90 cm. The calculator indicated no N was required, so the Nil treatment in Tables 2 and 3 are really the calculator recommendation. The other two treatments were made up by adding 46 and 92 kg N/ha. The yields were sufficiently variable among the plots that the LSD (0.05) was large (Table 3), but the mean yield across all plots was 13.5 t/ha, exactly matching the model prediction.

Treatment differences

Differences between the Model and the Farm treatments were mainly in the amount of fertiliser applied, where model treatments were generally less than farmer, and in one case, the timing of the applications.

At Site 1, the amounts of N applied were the same in the Farm and Model plots at 240 kg N/ha in total (Table 2), but the timing differed. The calculator predicted that the farmer-managed plots would yield less than the calculator-managed plots (Table 3). The measured yields were similar to the calculated yields (Table 3), and although the measured yields were not significantly different, the grains in the farmer managed plots were significantly smaller than those in the calculator plots (Table 4).

Weather stations

The results from Site 5 (Table 6) emphasise the need for local weather information. Modification of weather files by adjusting for altitude may be a useful approach in areas lacking weather stations.

Conclusions

The Sirius Wheat Calculator has proved to be a reliable predictor of crop performance, given accurate weather and soil information, in well managed wheat crops in 2001/2002. Management of N fertiliser using the calculator recommendations proved at least as good as the selected wheat farmers in Canterbury. Even then, the farmers made their recommendations on better information than they usually have as knowledge of the soil mineral N content through a substantial portion of the root-zones meant that their own management was possibly better than normal.

The trial highlighted areas of the Wheat Calculator that need further research, in terms of measuring mineral N in stony soils and the proximity of weather stations to farmers' fields. A system for incorporating disease is being developed at present.

Generally the users were enthusiastic about the Wheat Calculator and had very positive suggestions about changes in layout and additional information they would like to see. Moreover, there were no negative comments about the system and all participants were keen to continue their involvement.

Acknowledgements

The authors gratefully acknowledge the cooperation of the farmers who made their land available for this project. They were John Evans, Stuart Wright, David Lilley, Don Williamson and Tinus Lepoutre. Also, John Chynoweth, Eric & Maxine Watson, David Grant, Craige Mackenzie and Tony Davoren for their comments. Craig Tregurtha, Ross Hanson and Glyn Francis assisted with aspects of the experiments.

Funding for this project was provided by the Foundation for Arable Research, Ballance Agri-nutrients and the Foundation for Research Science and Technology.

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