SHORT NON-REFEREED PAPER

EVALUATION OF THE APSIM-SUGAR MODEL FOR SIMULATING SUGARCANE YIELD AT SITES IN SEVEN COUNTRIES: INITIAL RESULTS

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Abstract

Accurate crop simulation models are important tools for evaluating different crop management strategies and understanding potential impacts of climate change. This paper reports initial results from an international collaborative effort to improve sugarcane models, particularly for predicting impacts of projected climate change. Data from 35 experiments conducted in seven countries were simulated with the APSIM-Sugar model, firstly ‘blind’, using only climate, soil and management data, then again with the addition of available phenology data from the experiments. Surprisingly, the addition of the phenology data resulted in only small improvements in overall predictions of stalk dry mass, although the improvement was substantial (12-30 t/ha) at several sites. The generally small improvement suggests that either there is not a lot of vital information in phenology data for prediction of final stalk dry mass of a sugarcane crop, or the APSIM-Sugar model is not overly sensitive to these parameters. Further work is required to resolve these issues.

Keywords: AgMIP, climate change, impact assessment, model calibration, simulation

Introduction

Accurate crop simulation models are important tools for a variety of applications, such as the evaluation of different crop management strategies and understanding potential impacts of climate change. In agriculture, research groups and/or organisations have historically developed and/or applied a single model. The uncertainty of predictions from that model are generally characterised by the error statistics determined from prediction of experimental data. Such a procedure may be adequate when subsequent applications of the model take place within the bounds of the development and testing ‘space’. However, increasingly models are being applied beyond the conditions within which they were developed and tested. In these situations, it is difficult to characterise the uncertainty associated with a prediction. There are several approaches to characterising and reducing uncertainty, two of which are testing models across a wider range of conditions and applying ensembles of crop models.

The Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweig *et al*., 2013) is an international collaboration to characterise and reduce uncertainty in agricultural modelling for climate change applications, using the above approaches. As well as regionally-based activities, AgMIP includes workgroups focusing on better testing and development of models for specific crops, including sugarcane. This paper reports the initial evaluation of the APSIM-Sugar model (Keating *et al*., 1999) within the AgMIP-Sugarcane Pilot, comparing the model's performance against data from seven countries prior to and following calibration. APSIM-Sugar is one of six models participating in the Pilot.

Methods

The model was evaluated against experimental data from 35 treatments, in 10 experiments conducted in seven countries (Table 1). The APSIM-Sugar model was evaluated in two stages: Stage 1, a 'blind' simulation, whereby only management, weather and soil data were provided; and Stage 2, simulation following calibration of selected parameters to available phenology data, but **not** stalk biomass or sugar yield. The parameters calibrated were primarily those defining the number and size of leaves, partitioning of biomass to sucrose in the stalk and early growth of the crop. While a wide range of predicted crop growth and soil parameters were output during the simulations, this paper focuses only on stalk dry matter (SDM).

Results

Across all the experiments, measured SDM ranged from 2.7 t/ha (in one treatment at Chiredzi, Zimbabwe) to 76.1 t/ha (in one treatment at Colimaçons, Reunion). Predicted SDM in the Stage 1 simulations ranged from 0.4 to 85.5 t/ha. The range was reduced to 7.5 to 76.1 t/ha after calibration to phenological data in Stage 2. The root mean square error (RMSE) of predicted SDM was 20.8 t/ha for the Stage 1 simulations, and reduced to 18.9 t/ha after calibration.

At individual sites, differences between measured and predicted SDM were up to 53 t/ha (Figure 1). Two sites at Chiredzi, Zimbabwe (marked as ZIM_CHI_5 and ZIM_CHI_6 in Figure 1) had very low measured SDM, which was substantially over-predicted by the model both before (Figure 1a) and after (Figure 1b) calibration. Likewise, SDM at Colimaçons, Reunion (RI_CO1_1 and RI_CO2_1) was over-predicted before and after calibration. Conversely, there was one site (ZIM_CHI_1) where SDM was under-predicted before and after calibration. For these five sites, the process of calibration to phonological data had little impact on the prediction of SDM, indicating that yield results in these experiments were being controlled by factors/processes outside those addressed in this study, or factors not included in the model.

At other sites however, calibration improved predictions. The improvement was greatest in absolute terms at the two sites in Brazil (BR_PIR_1 and BR_PIR_2) and two in Australia (AU_AYR_3 and AU_ING_3) where predictions of SDM improved by 12.5 to 30 t/ha (Figure 1). For all other sites, the absolute improvement was less than 5 t/ha.

Discussion

This study is the most extensive independent evaluation of the APSIM-Sugar model undertaken to date. The model was developed on 35 datasets from 19 experiments conducted in four countries (Keating *et al*., 1999); Australia, South Africa, Swaziland and USA (Hawaii). However, subsequent studies have assessed model performance on only one or a small number of sites and/or specific process (e.g. Inman-Bamber and McGlinchey, 2003;

Thorburn et al., 2002; 2011). In those studies, values of the RMSE for SDM have ranged from 1.4 to 8.7 t/ha, less than half the value found in Stage 2 of this study. The higher RMSE values found in this study are not surprising, given that only phenology data were used to determine varietal parameters whereas stalk mass was included in model development and/or calibration in previous studies. Thus, the evaluation statistics in this study are a more realistic validation of the model than equivalent statistics from previous studies.

An interesting aspect of the results of this study is the small overall improvement in SDM predictions that resulted from calibration to the phenology data from the experiments. Publication of 'blind' model applications (i.e. Stage 1 of this study) is not common, and so there are few quantitative examples of the extent to which predictions are improved by the calibration process. In a previous study, the prediction of wheat yields based on climate, management and phenology data was substantially improved when yield data was included in the calibration of the models' crop parameters (Asseng *et al*., 2013). However, that study is not equivalent to ours as the initial simulations undertaken by Asseng *et al*. included phenology data. The small improvement gained in Stage 2 over Stage 1 in this study suggests that either (1) there is not a lot of vital information contained in phenology data to inform the prediction of final SDM of a sugarcane crop (i.e. SDM is more determined by climate, soils and/or management for sugarcane), or (2) the APSIM-Sugar model is not overly sensitive to these parameters (leaving open the possibility that other sugarcane models are). Certainly, in some previous applications of APSIM-Sugar, much more emphasis has been put on site and management factors than sugarcane varieties (e.g. Thorburn *et al*., 2002; 2011), with the resultant RMSE values being better than those obtained in the model's development (Keating *et al*., 1999). There are also parameters in APSIM-Sugar (e.g. radiation use efficiency) that are considered species-specific and are not changed (calibrated) between varieties, possibly making the model less sensitive to varieties, and more sensitive to site and management than other sugarcane models. Combining the results from all models participating in the AgMIP Sugarcane Pilot will provide insights into these questions.

Finally, this paper reports only the initial results of the AgMIP Sugarcane Pilot for APSIM-Sugar. Apart from comparing the results of all participating models, further stages of the work will include calibration to yield and phenology, and determining sensitivity of the models to potential climate change impacts (i.e. changed precipitation, temperature and atmospheric CO_2 concentrations). The ultimate aim of the Sugarcane Pilot is to test and develop the models against experiments of climate change impacts on sugarcane growth and yield to improve the performance of sugarcane models under a wide range of conditions.

Acknowledgement

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Table 1. Details of the experiments used in the model evaluation: Treatment factor, variety, crop class (P-plant, R-ratoon), row spacing (RS), planting and harvesting dates, age at harvest (Age), soil water capacity (AW), irrigation applied (Irr), average seasonal rainfall, seasonal total incoming shortwave radiation (SRad) and average daily air temperatures (TAvg).

Site (latitude, longitude, altitude)	Treat-ment factor	Variety	Crop class	RS (m)	Plant & harvest dates	Age (days)	AW (mm)	Irr (mm)	Rain-fall (mm)	SRad (MJ/m^2)	TAvg (°C)
Australia, Ayr (19.57 N, 146.41 E; 150 m a.s.l)	N-app. amount	Q117	P	1.50	Apr-92 - Aug-93	478	197	5725	521	9613	23.1
			R	1.50	Sep-93 - Oct-94	397	197	4333	356	8560	23.7
Australia, Ingham (18.70 N, 146.20 E; 16 m a.s.l)	N-app. amount	Q117	P	1.47	Jul-92 - Aug-93	391	216	698	980	7209	23.3
			R	1.47	Aug-93 - Aug-94	369	216	1716	2008	6843	23.5
Brazil, Piracicaba (22.80 N, 47.50 E; 560 m a.s.l)	Irrigation vs rainfed	RB 72454	P	1.40	Oct-04 - Sep-05	331	168	705	929	5292	22.4
						331	168	0	929	5292	22.4
Ecuador, San Carlos (2.21 N, 79.43 E; 44 m a.s.l)	Row-spacing	CR-74250	P	1.50	Oct-09 - Nov-10	408	193	600	1485	3613	25.5
			P	1.65		408	193	600	1485	3613	25.5
			P	1.80		408	193	600	1485	3613	25.5
				.40x 1.40		408	193	600	1485	3613	25.5
RSA, La Mercy (29.58 N, 31.15 E; 72 m a.s.l)	Crop start date	NCo376	R	1.20	Jun-89 - Oct-90	488	140	0	1295	7934	19.6
					Aug-89 - Dec-90	491	140	0	1506	8425	20.1
					Oct-89 - Feb-91	492	140	0	1684	8680	20.8
					Dec-89 - Apr-91	488	140	0	1616	8627	21.2
					Feb-90 - Jun-91	488	140	0	1520	8217	20.6
					Apr-90 - Jul-91	486	140	0	1218	7827	19.6
					Jun-90 - Oct-91	487	140	0	1236	7874	19.4
					Aug-90 - Dec-91	489	140	0	1444	8236	20.0
RSA, Komatipoort (25.55 N, 31.83 E; 170 m a.s.l)	Irrigation deficit level	N25	R	.40x 1.40	Apr-02 - Feb-03	306	79	1307	400	5572	22.4
						306	79	671	400	5572	22.4
						306	79	535	400	5572	22.4
Reunion, Ligne Paradis (21.31 N, 55.49 E; 150 m a.s.l)	-	R570	R	1.50	Aug-94 - Aug-95	369	90	954	910	7116	22.9
Reunion, Colimaçons (21.12 N, 55.31 E; 800 m a.s.l)	-	R570	R	1.50	Aug-94 - May-96	646	159	716	1533	8734	19.2
					Aug-98 - Jun-00	692	159	0	1570	9349	18.9
USA, Houma (29.64 N, 90.84 E; 2 m a.s.l)	-	HoCP 96-540	P	1.80	Jan-12 - Sep-12	254	182	0	2035	4711	23.0
Zimbabwe, Chiredzi (21.04 N, 31.62 E; 429 m a.s.l)	Variety/ planting date	ZN6	P	1.50	May-09 - Jun-10	383	110	1351	539	6907	24.0
		ZN7				383	110	1351	539	6907	24.0
		ZN6	R	1.50	Jun-10 - May-11	357	110	1124	600	6980	24.0
		ZN7				357	110	1124	600	6980	24.0
		ZN6			May-11 - May-12	370	110	1172	430	7312	23.2
		ZN7				370	110	1172	430	7312	23.2

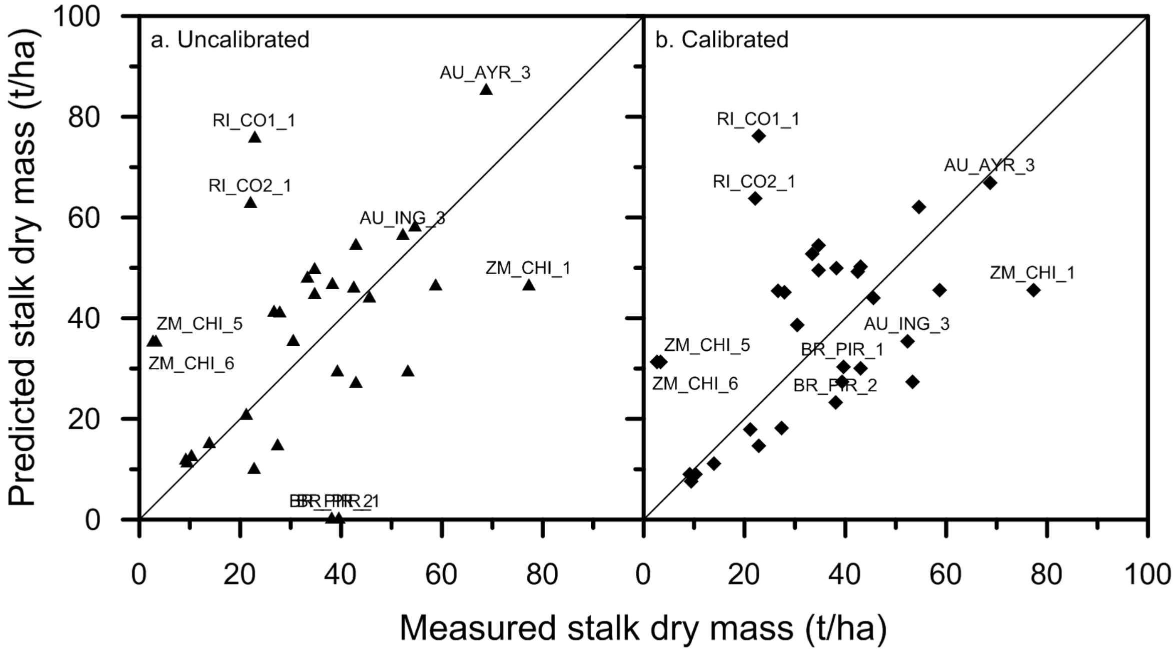

Figure 1. Stalk dry mass measured at and predicted with APSIM-Sugar, (a) prior to and (b) after calibration to available phenology data at the sites, for 10 experiments from seven countries. Specific sites discussed in the paper are identified.

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