SHORT NON-REFEREED PAPER

# EVALUATION OF THE DSSAT-CANEGRO MODEL FOR SIMULATING CLIMATE CHANGE IMPACTS AT SITES IN SEVEN COUNTRIES

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## Abstract

Realistic assessment of future climate change impacts on sugarcane production is essential for strategic planning. Accurate crop simulation models are important tools in this process. This paper reports on the suitability of the DSSAT-Canegro model for simulating sugarcane growth and yield for a wide range of environments across the globe under current and possible future climates. The protocols proposed by the Agricultural Model Intercomparison and Improvement Project (AgMIP) for the assessment of crop models for global climate change applications were followed. Experimental data from 35 treatments, in 10 experiments at sites in Australia, Brazil, Ecuador, Reunion, South Africa, the USA and Zimbabwe were used to calibrate the model in two stages: (1) 'blind' calibration, whereby only management, weather and soil data are provided, and (2) 'phenology' calibration with stage 1 data as well as crop development observations. The model was also subjected to sensitivity analysis, whereby 30 seasons of sugarcane growth were simulated at each site, using historical weather data perturbed by changes to daily air temperatures (-3, 0, +3, +6 and +9°C), rainfall (-25, -10, 0%, +10 and +25%) and atmospheric $CO_2$ concentration (+90, +190, +290 and +390 ppm).

Model performance in predicting stalk dry mass (SDM) was not as good as quoted in previous studies. Using leaf and tiller phenology data for model calibration did not improve model performance, highlighting the need for using leaf area index and biomass data for meaningful calibration. The study also highlighted the need for global model testing in diverse environments and production scenarios, rather than local testing, which may lead to model-fitting by unwarranted parameter adjustments.

The sensitivity analysis suggest that simulated responses in SDM to changes in temperature, rainfall and [$CO_2$] for the diverse production scenarios investigated in this study, are realistic and consistent with current knowledge and accepted theory in this regard.

*Keywords:* climate change, modelling, simulation, assessment, model calibration, sensitivity analysis

## Introduction

Reliable assessment of future climate change impacts on sugarcane production is essential for strategic planning. Accurate crop simulation models are important tools in this process.

This paper reports on the suitability of the DSSAT-Canegro v4.5 model (Singels *et al.*, 2008) for simulating sugarcane growth and yield for a wide range of environments under current and future climates. The objectives were to (1) evaluate the performance of the model to simulate crop growth at seven sites across the globe, and (2) analyse the sensitivity of the model to possible changes in climate at these sites. The study followed the protocols proposed by the Agricultural Model Intercomparison and Improvement Project (AgMIP) for the assessment of crop models for global climate change applications (Rosenzweig *et al.*, 2012).

## Methods

The DSSAT-Canegro v4.5 (Singels *et al.*, 2008) model, adapted with improved capability for simulating high temperature, water deficit and elevated atmospheric $CO_2$ effects on crop development and growth (Singels *et al.*, 2013) was evaluated in this study.

Experimental data (shoot population, leaf number, green leaf number, primary stalk height, green leaf area index (GLAI), aerial dry biomass (ADM), stalk dry mass (SDM) and sucrose mass) from 35 treatments, in ten experiments across the globe (Table 1) were used to evaluate the models in two stages: (1) a ‘blind’ validation, whereby only management, weather and soil data were provided, and (2) a ‘phenology’ validation where crop development (tiller and leaf phenology) data were also available. Simulated values of GLAI, ADM and SDM were compared to observed values.

The model was then subjected to sensitivity analysis, whereby 30 seasons of sugarcane growth were simulated for a selected treatment from each experiment, using historical weather data perturbed by a sets of changes to daily air temperatures (-3, 0, +3, +6 and +9°C), rainfall (-25, -10, 0, +10 and +25%) and atmospheric $CO_2$ concentration ($[CO_2]$ +90, +190, +290 and +390 ppm). SDM responses to these imposed changes were assessed.

## Results and Discussion

Results are summarised in Table 1. The model under-estimated *SDM* for two crops grown in Ayr, one in Ingham, two in Piracicaba, one in Komatipoort, one in Reunion and three at Chiredzi. It over-estimated yields for some of the crops grown in San Carlos. The model seems incapable of producing *SDM* greater than ≈40 t/ha. Overall the root mean square error (RMSE) of *SDM* predictions was 9.02 t/ha with an $R^2$ of 0.79.

Stage 2 calibration resulted in improved simulation of GLAI (RMSE decreased from 2.35 to 1.42 $m^2/m^2$) but not of biomass components (RMSE=9.08 t/ha and $R^2$=0.79). The model over-estimated low values and under-estimated high values of ADM (data not shown), pointing to a systematic weakness. Model performance (predicting SDM) is much poorer than previously reported by O’Leary (2000), Singels and Bezuidenhout (2002), Singels *et al*. (2010), Marin *et al*. (2011) and Jones (2013), presumably because in all these cases the model was calibrated using GLAI and biomass component data. This highlights the potential danger of fitting models, rather than improving simulation capabilities.

The study highlighted shortcomings in the calibration procedure that was followed. Leaf and tiller phenology data are normally collected for primary stalks only. This cannot be used as is to calibrate the simulation of crop canopy cover without using GLAI data, due to the large range in the phenological age of tillers of a developing crop and the lack of leaf dimension data. The start of stalk growth, an important phenological event, could also not be calibrated successfully using primary stalk height data. Stalk mass data are needed for this.

A cooling of 3°C caused reductions in simulated SDM at all sites except Ecuador. Warming of 3°C caused SDM increases for Komatipoort, the Reunion sites, La Mercy and Chiredzi, and reductions for the Australian sites and San Carlos. A 6°C warming caused reductions in SDM at all sites except for Komatipoort and Reunion. A 9°C increase resulted in a SDM reduction at all sites except for Komatipoort, where the harvest age was exceptionally young. Simulated response to rainfall and [$CO_2$] depended on the extent of baseline water-deficit. The largest responses were simulated for La Mercy, followed by Piracicaba. Irrigated crops showed very little response to rainfall and [$CO_2$], as can be expected.

Model behaviour is deemed consistent with current knowledge and accepted theory in this regard.

## Conclusion

Overall model performance in predicting SDM was not as good as quoted in previous studies. Using leaf and tiller phenology data for model calibration did not improve model performance, highlighting the need for using GLAI and biomass data for meaningful calibration of crop canopy development and start of stalk growth. The study also highlighted the need for global model testing in diverse environments and production scenarios, rather than local testing, which may lead to model-fitting by unwarranted parameter adjustments.

The sensitivity analysis suggests that simulated responses in SDM to changes in temperature, rainfall and [$CO_2$] for the diverse production scenarios investigated in this study, are realistic and consistent with current knowledge and accepted theory in this regard. SDM showed a parabolic response to temperature changes, with decreases at most sites at -3°C and +9°C, and increases at +3 and +6°C. SDM increased with increasing rainfall and [CO2].

## Acknowledgements

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**Table 1. Summary of model evaluation: Stalk dry mass values (SDM) at harvest/final sampling, observed (Obs) and simulated for the DSSAT-Canegro v4.5 model in two calibration stages. Treatment factor, variety (Var), crop class and row spacing (RS), available soil water capacity (TAM), seasonal rainfall (RAIN), irrigation applied (IRR), seasonal total incoming shortwave radiation (SRAD), average simulated soil water satisfaction index (SWSI) and average daily air temperatures (TAVG).**

| Site latitude, longitude and altitude | Treatment factor | Var | Crop class | RS (m) | Start & harvest dates | Harv age (days) | TAM (mm) | IRR (mm) | RAIN (mm) | SRAD (MJ/$m^2$) | TAVG (°C) | SWSI stage 2 | Obs SDM (t/ha) | Stage 1 SDM (t/ha) | Stage 2 SDM (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Australia, Ayr<br>(19.57 S, 146.41 E;<br>150 m a.s.l) | N-app. amount | Q117 | P | 1.50 | Apr-92 - Aug-93 | 478 | 197 | 5725 | 521 | 9613 | 23.1 | 0.98 | 68.7 | 42.0 | 42.0 |
| | | | R | 1.50 | Sep-93 - Oct-94 | 397 | 197 | 4333 | 356 | 8560 | 23.7 | 0.91 | 54.6 | 41.4 | 41.4 |
| Australia, Ingham<br>(18.70 S, 146.20 E;<br>16 m a.s.l) | N-app. amount | Q117 | P | 1.47 | Jul-92 - Aug-93 | 391 | 216 | 698 | 980 | 7209 | 23.3 | 0.99 | 52.3 | 36.6 | 36.6 |
| | | | R | 1.47 | Aug-93 - Aug-94 | 369 | 216 | 1716 | 2008 | 6843 | 23.5 | 0.99 | 43.0 | 36.3 | 36.3 |
| Brazil, Piracicaba<br>(22.80 S, 47.50 E;<br>560 m a.s.l) | Irrigation vs rainfed | RB 72454 | P | 1.40 | Oct-04 - Sep-05 | 331 | 168 | 705 | 929 | 5292 | 22.4 | 1.00 | 39.6 | 32.7 | 32.7 |
| | | | | | | 331 | 168 | 0 | 929 | 5292 | 22.4 | 0.78 | 38.1 | 20.6 | 20.6 |
| Ecuador, San Carlos<br>(2.21 S, 79.43 E;<br>44 m a.s.l) | Row-spacing | CR-74250 | P | 1.50 | Oct-09 - Nov-10 | 408 | 193 | 600 | 1485 | 3613 | 25.5 | 0.94 | 10.3* | 19.0 | 14.0 |
| | | | P | 1.65 | | 408 | 193 | 600 | 1485 | 3613 | 25.5 | 0.94 | 9.2* | 18.9 | 14.1 |
| | | | P | 1.80 | | 408 | 193 | 600 | 1485 | 3613 | 25.5 | 0.94 | 9.5* | 18.8 | 14.1 |
| | | | | .40x1 .40 | | 408 | 193 | 600 | 1485 | 3613 | 25.5 | 0.94 | 13.9* | 19.1 | 13.8 |
| RSA, La Mercy<br>(29.58 S, 31.15 E;<br>72 m a.s.l) | Crop start date | NCo376 | R | 1.20 | Jun-89 - Oct-90 | 488 | 140 | 0 | 1295 | 7934 | 19.6 | 0.80 | 34.7 | 22.7 | 22.7 |
| | | | | | Aug-89 - Dec-90 | 491 | 140 | 0 | 1506 | 8425 | 20.1 | 0.85 | 26.7 | 29.8 | 29.8 |
| | | | | | Oct-89 - Feb-91 | 492 | 140 | 0 | 1684 | 8680 | 20.8 | 0.85 | 33.4 | 34.4 | 34.4 |
| | | | | | Dec-89 - Apr-91 | 488 | 140 | 0 | 1616 | 8627 | 21.2 | 0.87 | 34.7 | 36.7 | 36.7 |
| | | | | | Feb-90 - Jun-91 | 488 | 140 | 0 | 1520 | 8217 | 20.6 | 0.87 | 42.5 | 36.6 | 36.6 |
| | | | | | Apr-90 - Jul-91 | 486 | 140 | 0 | 1218 | 7827 | 19.6 | 0.79 | 38.3 | 26.9 | 26.9 |
| | | | | | Jun-90 - Oct-91 | 487 | 140 | 0 | 1236 | 7874 | 19.4 | 0.84 | 30.5 | 25.3 | 25.3 |
| | | | | | Aug-90 - Dec-91 | 489 | 140 | 0 | 1444 | 8236 | 20.0 | 0.83 | 27.9 | 30.0 | 30.0 |

| **Site latitude, longitude and altitude** | **Treatment factor** | **Var** | **Crop class** | **RS (m)** | **Start & harvest dates** | **Harv age (days)** | **TAM (mm)** | **IRR (mm)** | **RAIN (mm)** | **SRAD (MJ/m$^2$)** | **TAVG (°C)** | **SWSI stage 2** | **Obs SDM (t/ha)** | **Stage 1 SDM (t/ha)** | **Stage 2 SDM (t/ha)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RSA, Komatipoort (25.55 S, 31.83 E; 170 m a.s.l) | Irrigation deficit level | N25 | R | .40x1 .40 | Apr-02 - Feb-03 | 306 | 79 | 1307 | 400 | 5572 | 22.4 | 0.94 | 43.0 | 31.9 | 33.1 |
| | | | | | | 306 | 79 | 671 | 400 | 5572 | 22.4 | 0.76 | 27.4 | 27.1 | 27.6 |
| | | | | | | 306 | 79 | 535 | 400 | 5572 | 22.4 | 0.64 | 22.8 | 20.5 | 21.9 |
| Reunion, Ligne Paradis (21.31 S, 55.49 E; 150 m a.s.l) | - | R570 | R | 1.50 | Aug-94 - Aug-95 | 369 | 90 | 954 | 910 | 7116 | 22.9 | 0.93 | 45.6 | 35.0 | 33.1 |
| Reunion, Colimaçons (21.12 S, 55.31 E; 800 m a.s.l) | - | R570 | R | 1.50 | Aug-94 - May-96 | 646 | 159 | 716 | 1533 | 8734 | 19.2 | 0.90 | 22.9 | 18.0 | 22.1 |
| | | | | | Aug-98 - Jun-00 | 692 | 159 | 0 | 1570 | 9349 | 18.9 | 0.71 | 22.1 | 13.3 | 14.0 |
| 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 | 1.00 | 21.2 | 17.0 | 17.0 |
| Zimbabwe, Chiredzi (21.04 S, 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 | 0.99 | 77.3 | 34.4 | 36.6 |
| | | ZN7 | | | | 383 | 110 | 1351 | 539 | 6907 | 24.0 | 0.99 | 58.7 | 34.4 | 36.6 |
| | | ZN6 | R | 1.50 | Jun-10 - May-11 | 357 | 110 | 1124 | 600 | 6980 | 24.0 | 0.96 | 53.3 | 35.4 | 37.3 |
| | | ZN7 | | | | 357 | 110 | 1124 | 600 | 6980 | 24.0 | 0.96 | 39.3 | 35.4 | 37.2 |

[*] Estimated from fresh cane yield using simulated dry matter content.

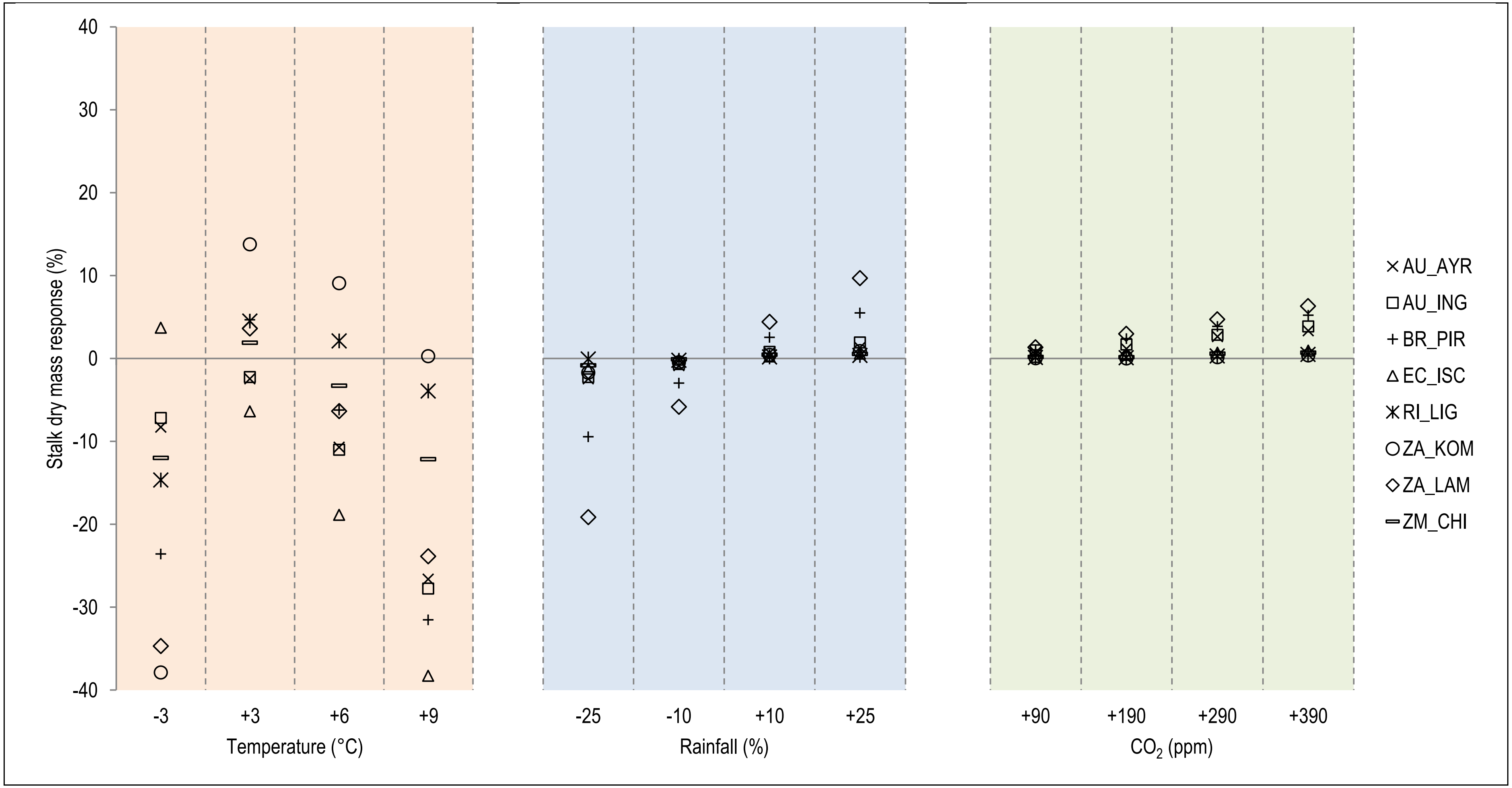

**Figure 1. Response in long term mean simulated stalk dry mass changes in temperature, rainfall and atmospheric CO$_2$ content, expressed as percentage of the baseline (climate unchanged) values for each site (AU_AYR: Ayr, Australia; AU_ING: Ingham, Australia; BR_PIR: Piracicaba, Brazil; EC_ISC: San Carlos, Ecuador; RI_LIG: Ligne Paradis, Reunion Island; ZA_KOM: Komatipoort, South Africa; ZA_LAM: La Mercy, South Africa; and ZM_CHI: Chiredzi, Zimbabwe).**

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