INTERNATIONAL CONSORTIUM FOR SUGARCANE MODELLING

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A. Singels and M.R. Jones

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1. INTRODUCTION

The International Consortium for Sugarcane Modelling (ICSM) was established in 2006 and is an international partnership of research and other organizations that have an interest in sugarcane simulation modelling. Current members are Centre de Cooperation Internationale en Recherche Agronomique pour le Dévelopement (CIRAD), Chiang Mai University (Thailand), Commonwealth Scientific and Industrial Research Organisation (CSIRO), South African Sugarcane Research Institute (SASRI), Sugar Cane Growers Cooperative from Florida (SCGC), Sugar Research Australia Limited (SRA), Sugar Research Institute of Fiji (SRIF), and Zimbabwe Sugar Association Experiment Station (ZSAES). The current memorandum of understanding (MoU) is in place until November 2022.

The goal of the ICSM is to promote the development and application of sugarcane simulation models. Key objectives are to coordinate efforts and generate resources for sugarcane modelling projects, and to promote and enable the sharing of knowledge, information and data in the field of sugarcane modelling.

2. ICSM PROJECT ON "MODELLING WORLD-WIDE GXE INTERACTION"

2.1. Introduction

A group of ICSM members (CIRAD, Florida SCGC, SASRI, ZSAES) is conducting research to gain a better understanding of the physiological mechanisms underlying the genetic variation in sugarcane crop response to environmental factors. Crop canopy development, radiation interception, biomass accumulation and partitioning of genetically diverse cultivars grown in diverse environments are monitored using a standardized trial and measurement protocol. The ultimate goal is to develop improved concepts for simulating genetic control of crop response to environmental factors, and to implement these in sugarcane models, with a view to use them to support crop improvement programs, worldwide. The hypothesis is that realistic models with accurate trait parameter values can be used to identify important traits and their ideal values for given environments (including future climates).

2.2. Evaluation of modelling concepts against experimental data

Growth analysis experiments were conducted from 2013 to 2016 (plant and ratoon crops) in Pongola, South Africa; Chiredzi, Zimbabwe; La Mare, Reunion Island; and Belle Glade, Florida, USA using different cultivars (N41, R570 and CP88-1762 at all sites, and HoCP96-540, Q183, ZN7 and NCo376 at some sites). Data collected include soil chemical and physical data, weather data, crop management data, shoot emergence, tiller population and height, leaf dimensions and appearance, fractional radiation interception, dry aboveground biomass component weights and stalk composition at harvest.

The first step was to evaluate existing concepts of genotype (G) and environmental (E) control of plant processes for explaining crop development, growth and yield, using the data collected in the experiments. Main findings included:

- Final yields showed significant E and GxE variation; dry above-ground biomass and stalk yields were highest in La Mare and lowest in Pongola. Cultivar rankings in stalk dry mass for the common cultivars (N41, R570, CP88-1762) varied significantly between Es.
- Significant E variation in phenotypic parameters describing germination, tillering and timing of the onset of stalk growth revealed shortcomings in the underlying simulation concepts.
- Significant G variation was found for germination rate, leaf appearance rate and canopy development rate, and maximum radiation use efficiency, indicating strong G control of the associated underlying processes.
- Solar radiation was found to influence tillering rate and duration of the tillering period, challenging the current theory of thermal time as the sole driver of these processes.

This work was reported in a scientific paper that appeared in Field Crops Research (Jones et al., 2019).

2.3. Assessment of existing sugarcane crop models

In the second phase of the project the aim was to calibrate, assess, and identify weaknesses and recommend improvements to three sugarcane models, DSSAT-Canegro, Mosicas and APSIM-Sugar. It was found that cultivar CP88-1762 developed canopy cover faster, intercepted more radiation and out-yielded, R570 and N41 in Es with cool early-season conditions (Belle Glade and Pongola), while R570 outperformed the other Gs in the warm early season E (La Mare). This dynamic was not adequately captured by any of the models. Models captured G and E effects on seasonal radiation interception and radiation use efficiency reasonably well, although the range of variation was underestimated. Models failed to capture GxE interaction effects on seasonal radiation interception, seasonal radiation use efficiency and biomass yield. Results suggest that sugarcane models must accommodate G-specific base temperature model inputs for germination and canopy development processes, and that biomass accumulation and canopy development processes must be linked to allow source-sink control of crop development. These model interventions are anticipated to result in improved simulation of GxE interaction effects on growth and yield, and hence improve capability to identify desirable traits for target environments.

This work was reported in a scientific paper that appeared in Field Crop Research (Jones et al., 2021)

2.4. Development of an improved model for simulating G and E effects

The third phase of the project entailed the development and evaluation of an improved model for simulating G and E effects on crop growth by combining strong features from existing models with new concepts to address the weaknesses identified in the study. The main features of the new model (named CaneGEM) include:

- Genotype-specific temperature control of shoot emergence and canopy development.
- Canopy level (as opposed to leaf and shoot level) simulation of leaf area expansion co-regulated by source and sink strength. The latter is determined by temperature, and light conditions within the canopy. Leaf density (specific leaf area) varies depending on the balance between assimilate availability and sink demand for leaf expansion. Leaf expansion and senescence therefore now dynamically respond to

source availability, sink demand and light conditions, as opposed to being prescribed by empirical inputs. It is also connected to the carbon balance, addressing the problem of a disconnected canopy development used in some existing models.

- A gradual transition (as opposed to an abrupt step change) from the tillering phase to the stalk growth phase is simulated, which is governed by the light environment within the stool (as opposed to user specified thermal time or above-ground dry biomass threshold). The timing of the onset of stalk growth is influenced by genetic (temperature sensitivity) and environmental (temperature, water status, light) factors, allowing crop development to respond more dynamically to these factors.
- Structural stalk growth is also co-regulated by source and sink strength. When assimilate availability cannot fulfil sink demand, stalk growth rate is reduced accordingly. When assimilate supply exceeds the demand, the excess is stored as sugars in the stalk, provided adequate capacity exists.

Validation outcomes for the CaneGEM model indicated similar performance to that of DSSAT-Canegro, but with simpler underlying concepts and a greater degree of inter-process coupling, and with a smaller number of genetic control parameters. The CaneGEM model outperformed DSSAT-Canegro for predicting GxE interaction effects in seasonal radiation interception and biomass yields, provided germination phase duration was predetermined.

An important finding from the project is that germination phase duration has a strong influence on subsequent canopy development, radiation capture and yield formation. Existing models that employ the conventional thermal time approach based on air temperature was unsuccessful in predicting the duration of the germination phase observed in the ICSM experiments, which resulted in poor prediction of GxE interaction effects in canopy development and yield formation. Attempts to modify the germination algorithm to use simulated soil temperatures were inconclusive.

2.5. Application of the CaneGEM model

The CaneGEM was then used to assess the impact of genotype-specific cardinal temperatures for canopy development for the environments where field experiment were conducted namely: Belle Glade, Florida, USA; Chiredzi, Zimbabwe; La Mare, Reunion island, France; and Pongola, South Africa). Simulation results suggest that for the four sites investigated, adaptation to cooler temperatures will result in faster canopy development with increased radiation interception and hence higher biomass accumulation. The magnitude of the response depended on the temperature regime. For example, warm La Mare showed a 5% increase in seasonal average stalk yield for the 2°C reduction in cardinal temperatures, compared to 8% for cool Pongola. impacts also depended on time of harvest, with crops harvested early and mid-season showing a bigger response to cardinal temperature changes than crops harvested late in the season. For example, a 2°C reduction in cardinal temperatures caused average stalk yield increases in mid-season crops of 10% at Pongola, Bell Glade and Chiredzi, and 6% at La Mare, compared to 5% for late season crops at Pongola and Belle Glade, and 3% at Chiredzi and La Mare.

It was concluded that the CaneGEM model meets some of the requirements of process models for supporting plant breeding: complex traits (such as canopy development and yield) are predicted as the emergent consequences of processes regulated by simple traits (such as cardinal temperatures); the model has the potential to predict GxE interaction effects; and the model is parsimonious, being relatively simple and computationally undemanding. More work is required to improve the prediction of date of primary shoot emergence, a key driver of subsequent canopy development and yield formation.

A more detailed description of model development, evaluation and application can be found in the full project report (Jones, 2022). A draft article was also submitted to the ISSCT editor for possible presentation at the 31st ISSCT Congress to be held in Hyderabad, India in February 2023.

All data and code generated in the project will be made available to project participants via a Dropbox account. The use of data for further research requires the permission of all participants and acknowledgement of contributors.

3. ICSM ADMINISTRATION

The financial status of the Consortium as of 30 August 2022 is shown in Table 1. Expenses in the last two years comprised of an allowance to a post-doctoral research assistant to the principal investigator Matthew Jones, a full-time employee of SASRI during this time.

Table 1. ICSM finances in ZAR (US$ 1 ≈ ZAR 17)

Year	2020/21	2021/22
Income	0	0
Expenses	166 400	83 200
Balance of funds	132 974	49 774

The term of the current memorandum of understanding governing the Consortium ends in November 2022. Members will be polled to determine the interest for the Consortium to continue to exist, and to determine the fate of the remaining funds. A business meeting is planned to be held during the XXXI ISSCT congress in India in February 2023, to review achievements and plan for the future.

4. REFERENCES

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