EXECUTIVE SUMMARY

ICROPM2020 CROP MODELLING SYMPOSIUM AND CROP MODEL DEVELOPMENT WORKSHOP MONTPELLIER, FRANCE 3 – 12 FEBRUARY 2020

by

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Matthew Jones travelled to Montpellier, France in February 2020 to attend the ICROPM2020 Crop Modelling Symposium and participate in a crop model development workshop with CIRAD crop scientists. The research visit was conducted as part of the International Consortium for Sugarcane Modelling (ICSM) research project on modelling genotype (G) by environment (E) interaction. The participants in this project are SASRI, CIRAD, Florida SCGC and ZSAES.

The ICROPM2020 symposium was attended by approximately 400 delegates from 50 countries, and was divided into six parallel sessions that included 'Improvement of crop models', 'Linking crop/plant models and genetics', and 'Crop modelling for risk and impact assessment'.

Several authors presented on using models for determining ideal combinations of genetic traits (termed 'ideotypes') for current and future climate-changed environments. The focus on climate change impacts research appears to have moved towards exploring genetic adaptations to climate change. This represents a pertinent application of crop models capable of representing genetic differences in biologically-realistic ways. This overlapped with some of the model improvement papers, where properties of models, approaches to model use, and improved algorithms for representing genetic effects were explored. Integrating models across scales (from molecular, cellular, metabolic through to crop and landscape scales) was explored in several papers and offers some interesting prospects for linking genetics to crop models. Several papers combined proximal/remote sensing with phenotyping, managing risk, and other themes. Risk management was explored through index-based insurance-type interventions (as an alternative to crop management-based approaches) to facilitate beneficial change, such as reducing nitrogen runoff pollution.

Overall, the conference presented comprehensive and detailed coverage of the 'state of art' in crop modelling, and in particular modelling genetic effects. Many of the presentations, related discussions and networking were highly relevant and valuable to the trait modelling research conducted at SASRI and by the ICSM, as well as other current SASRI projects. The author received valuable feedback and useful comments on his poster about the 10CM03 work.

The crop modelling workshop at CIRAD was similarly successful. Genotype-specific germination responses to temperature formed the core of discussions, and a plan has been devised for tackling model improvements in this regard, as part of the ICSM project on simulating and understanding sugarcane GxE interactions. The author also presented a seminar to CIRAD staff, which was well-received and generated insightful questions and discussion.

1. INTRODUCTION

Matthew Jones travelled to Montpellier, France, in February 2020 in order to attend:

- The ICROPM2020 International Crop M Symposium held from 3 – 5 February 2020 at Le Corum Conference Centre, Montpellier, France.
- A sugarcane crop model development workshop with CIRAD scientists at CIRAD Montpellier, 10 – 12 February 2020.

This document reports on presentations of interest and insights gleaned at the ICROP2020 symposium, and activities and outcomes of the model development workshop.

The research visit was sponsored by the International Consortium for Sugarcane Modelling (ICSM) as part of a collaborative research project on modelling genotype (G) by environment (E) interaction in sugarcane to support breeding.

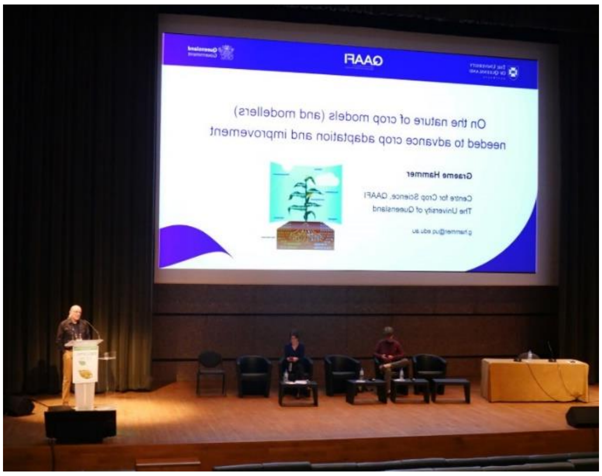

Figure 1
Graeme Hammer presenting his keynote address at the iCropM2020 Symposium

2. ICROPM2020 SYMPOSIUM

2.1 Introduction

The ICROPM2020 symposium was divided into six parallel sessions, of which three were of particular interest and relevance: ‘Improvement of crop models’, ‘Linking crop/plant models and genetics’, and ‘Crop modelling for risk and impact assessment’. See Appendix for the full programme and book of abstracts.

The author presented a poster, ‘Assessment of two sugarcane models for predicting genotype by environment interactions, using an international dataset’ by Jones et al. (Appendix, Section 0). This reported on recent work conducted as part of the ICSM research project, where the abilities of leading sugarcane models for simulating GxE interaction effects on sugarcane growth were evaluated.

Feedback on the author’s poster was fairly limited, but the conference afforded the opportunity to discuss the work in person with his PhD supervisors John Annandale (University of Pretoria) and Graeme Hammer (University of Queensland). Dr Hammer in particular made some very useful comments on investigating periodic radiation use efficiency. Matthew, with the assistance of Abraham Singels, has explored these comments and the findings are likely to be useful in the next project phases.

2.2 Paper highlights from the symposium

2.2.1 Linking crop models to genetics

Casadabeig et al. optimised sunflower cultivar deployment for current Es. Key cultivars were represented in a crop model and used to predict yields. They characterised and clustered Es according to abiotic stress patterns using an “enviro-typing” method from Chenu et al. (2013). G x E combinations were then optimised. They found that a single cultivar choice based on most frequent E type for a given location is robust. Nationally (France), if all farms planted optimally-matched cultivars, the authors found that the yield increase would be equivalent to the mean increase in yields from a year’s worth of genetic gain currently realised through breeding A similar study for sugarcane, if we were to characterise our cultivars and Es sufficiently well, could be of considerable value. This technique (Casadabeig et al., 2016) may have relevance to the final phases of the SASRI project on modelling GxE interaction (10CM03), where the value of a more realistic GxE- sugarcane model is demonstrated. This type of analysis also reveals the value of building up detailed databases of cropping environments.

Chenu et al. reported on a platform for phenotyping transpiration efficiency (TE) in wheat, by weighing pots; TE showed G differences (28% variation) that related to yield differences. A new TE module was developed for APSIM-Wheat, which estimates hourly transpiration rate from vapour pressure deficit (VPD) and soil moisture status, with appropriate G-specific input parameters; this improved predictions of leaf area index, biomass and yield at maturity across five experiments. Reducing transpiration rate at high VPDs (high TE) resulted in yield increases in 70% of the environments tested. Genetic markers were then identified to assist breeding towards ‘more crop per drop’ wheat cultivars.

Chetan et al. reported that heat-tolerant bean cultivars exhibit greater transpirational cooling than others. Their model explained 86% of the variation in leaf temperature using air temperature, relative humidity and genotype as inputs. Yubin et al. used an ensemble of crop models to attempt to predict the ‘days to flowering’ phenotype of 169 rice cultivars. The authors recognised that exploring different algorithms (as embodied in different crop models) reduced the uncertainty arising from the imperfect relationships between plant physiology and genetics.

Parent et al. developed a phenomics-based model of leaf development and expansion, including sensitivity to temperature and soil moisture conditions, for exploring traits underlying the trade-offs between soil moisture conservation and photosynthesis. A total of 254 existing maize hybrids were parameterised for this model using data from a phenotyping platform. Optimal crop cycle durations were calculated for current and future European climates and leaf growth ideotypes were determined for different Es. In general, drought-sensitive cultivars performed best for rainfed production in southern Europe, while less sensitive cultivars were best for irrigated production and northern European Es. The study revealed a boundary of trait possibilities within current genetic diversity, but the best combinations of traits (ideotypes) for each E were not available within the current set of Gs.

2.2.2 Climate change, impacts and genetic adaptations

Dentener reported on the northward migration of climate zones in Europe over the last 40 years; this changes the suitability of crops in different regions. Additionally, extreme events (heatwaves and drought) are becoming more frequent and are expected to become 'the norm' by 2040. This brings both opportunities (including benefits brought about through climate change) and challenges, all of which need to be addressed with climate change adaptation efforts.

Nendel et al. confirmed this, using three models to report that favourable regions for soybean production will move northward in Europe, with some existing rainfed soy production areas in southern regions likely becoming unsuitable. Babacar et al. reported that in the absence of adaptation, winter wheat yields are likely to increase in the mid-century climate change scenario, while summer crop yields were likely to decrease. Cammarano et al. reported likely increases in spring barley grown in Scotland in the 2050s, but along with it, increases in the spatial and temporal variability of yields. Webber et al., using crop model ensembles, also found likely increases in winter wheat yields, and reductions in summer maize yields; the reduction in maize yields, particularly in the lowest-yield decile of seasons simulated, was attributed to drought rather than heat stress. Tommasso et al. used the same data to characterise future wheat and maize production risks, to support long-term planning of risk management, such as irrigation, insurance and breeding.

Taru et al. presented on a stakeholder-centric study of farming system adaptations in the North Savo region (Finland), using APSIM. Some analyses that were deemed important by growers, such as exploring optimal forage seed mixes, were beyond the abilities of the crop model. This paper underlines the value in stakeholder consultation and knowledge exchange in strategic research, a principle adopted and encouraged at SASRI.

Robock asked about the capacity of crop models to simulate the impacts of a sudden and large increase in stratospheric aerosols (caused by, e.g. volcanic eruption, sulfate geo-engineering efforts, or nuclear war) on agriculture. He concluded that crop models lacked the necessary sensitivity to relatively increased diffuse radiation, UV radiation and atmospheric ozone concentration; and questioned crop model responses to reduced temperatures and direct radiation. While this research may seem largely unnecessary, improving these model aspects will improve models more generally; and, recent experiences with COVID-19 and even the response to the Health Promotion Levy in the SA sugar remind us that unexpected system shocks happen, and developing contingency plans can be enormously beneficial. Slightly closer to home, Koo et al. explored the biophysical and economic impacts of El Nino Southern Oscillation (ENSO) on agriculture in Ethiopia; this is as much a current-climate risk as a future-climate consideration. This analysis revealed spatial variation in impacts across various agricultural sectors, and permitted evaluation of several possible ENSO impact-mitigation policies on different household income categories.

Sultan et al. analysed the impacts of historical global warming on West African millet and sorghum yields, using the SARRA-H and CYGMA models and simulated historical climate data (with and without greenhouse gas emissions). An apparent warming of 1°C, along with increased frequency of drought and heat events, has resulted in regional average yield reductions of 10-20% for millet and 5-15% for sorghum.

An interesting shift in climate change impact research was noted, where the focus has changed from assessing climate change impacts towards exploring genetic adaptations to climate change. This represents a pertinent application of crop models capable of representing genetic differences in biologically-realistic ways. This valuable and exciting nexus of climate change and genetic trait modelling has direct relevance to 10CM03. In addition to the previously-mentioned papers by Parent et al. and Taru et al., Senapati and Semanov used the Sirius model to develop wheat ideotypes for Europe for the 2050s. Genetic adaptation to climate change in this case was predicted to increase future yields by 66-89% compared to today's cultivars grown in the 2050s.

2.2.3 Credibility of models and modellers

Graeme Hammer outlined requirements for credible models and modellers for crop improvement work. Model features include parsimony (Hammer et al., 2019b), the ability to predict phenotypic outcomes for high-quality experiments (i.e. model validation), and generate known responses to key factors (N, maturity, etc). Qualitative testing is required – do model outcomes make sense?

The final key requirement is that models can predict emergent phenotypes and interactions associated with key traits. An example is the so-called 'stay-green' trait (the ability for certain cultivars to retain green leaves during water stress, considered favourable for certain Es) in sorghum. Through modelling, it was possible to emulate the stay-green phenotype through realistic modelling of tillering and transpiration response to VPD – i.e. 'stay green' was shown to be a consequence of simpler tillering and transpiration traits (Hammer et al., 2019a). As a result of this modelling study, sorghum breeders can select for this stay-green behaviour in new sorghum Gs by focussing on specific tillering and transpiration traits that are stable across Es.

Hammer presented an example where a crop model was able to explore risk management strategies for sorghum grown in a rainfed environment with high seasonal rainfall variability. A low-input strategy, consisting of reduced 'skip-row' planting and a medium-maturing cultivar, ensured that 95% of seasons achieved yields above the economic 'break-even' level. In the high-input scenario (standard planting density and late-maturing cultivar), profits were higher on average, but a far greater fraction of seasons resulted in economic losses. Such analyses hold potential for the SA sugar industry, where large- and small-scale growers face different risk and risk-mitigation characteristics in different socio-economic contexts.

It is imperative that model users understand how the models work in terms of representing the biology of the plant, in order that models are used appropriately and model outputs are interpreted correctly. The 'model user effect' is exemplified in a discussion where Kimball et al.'s poster comparing evapotranspiration predictions in 29 maize crop models (run by 29 different model users) was challenged by another scientist: she stated that the comparison was invalid as every user (potentially) followed different methodologies within the broad methodological parameters of the study. A similar criticism could be levelled at many model intercomparison studies.

This presents an interesting dilemma to the author: very few modellers have the deep knowledge (required for modeller credibility) of more than one or two models; but ideally, one (or each) modeller ought to run model intercomparison studies with all models to ensure consistency in model inputs and other assumptions. Our own research in SASRI project 10CM03 reveals that different sugarcane models are fundamentally similar, particularly under irrigated conditions, and when appropriate measures are taken to ensure that each model is run with equivalent inputs, modelling outcomes are very similar.

2.2.4 Integration across scales

'Integration across scales' describes efforts to bridge modelling between metabolism- and crop-level scales.

Amy Marshall-Colon presented the 'crop in silico' (http://cropsinsilico.org) team's aim to develop 'virtual plant models', made up of an interlinked cascade of mechanistic models of plant processes such as gene expression, photosynthetic metabolism, and leaf physiology. A modelling framework has been developed that permits inter-model communication. The system permits development of ideotypes (ideal genotypes for specific environments) from a genetic rather than phenotypic basis. Challenges include the large number of parameters required and the difficulty of collecting input/verification data. They have demonstrated success with soybean photosynthesis, finding that the overexpression of GmGATA2 was predicted to increase photosynthetic rates under elevated atmospheric CO_2 content. A new journal, '*in silico* Plants' has been launched to publish results of this project and related projects, including more traditional phenotypically-based exploration of G and E effects and ideotype design.

Francois Tardieu presented a philosophical paper discussing modelling across scales, with a particular focus on predicting consequences of genetic variability. He argued that although there is enormous complexity in plants, with processes happening at very short time scales, evolution has favoured combinations of very low-level (hormonal and gene expression) mechanisms that allow these to be effectively described in simpler terms as higher-level phenotypes and behaviours at daily, weekly and seasonal time scales. There is a fractal-like complexity, where for e.g. the behaviour of one stomate requires a model of equivalent complexity to a model of canopy-level transpiration. While Tardieu did not advise against linking models across scales, he suggested that doing so may not be necessary; and cautioned that a single model capable of transcending all scales might be an unrealistic aspiration.

Wu reported on a cross-scale modelling framework that connected biochemical models of photosynthesis with crop models. In this case, C3 and C4 models of photosynthesis were linked to APSIM models of wheat and sorghum respectively, and then yield impacts of combinations of metabolic-scale trait values (Rubisco carboxylation rate, electron transport rate and mesophyll conductance) were assessed. The models were demonstrated to give generally realistic results, and also highlighted the need for further understanding of the link between photosynthesis and stomatal conductance (which may be relevant to the outcomes of SASRI project 11CM02).

Coussement developed a model of maize leaf growth that responds to water stress in different cell expansion zones in the leaf. This model appears relatively simple and can be integrated easily into full crop models. This may be valuable for our DSSAT-Canegro sugarcane model.

2.2.5 Managing risk through financial instruments

An enlightening theme in this conference was that of using financial instruments (i.e. insurance) to manage risk and effect change. Several papers showed crop modelling was used in insurance-related tools to build sustainability, both in terms of grower welfare and the biophysical environment more generally.

Thorburn et al. explored the idea of using crop loss insurance to reduce risk associated with reduced N applications, as a means to reduce over-application of N and consequent nitrate pollution for 176 000 ha of sugarcane grown in north-eastern Australia. They developed a 'Climate Index Derivative', based on the APSIM-simulated difference between conventional and insured-reduced N applications. With the proviso that calculations are done with site-specific soil types, climate data and management factors, the authors showed that this approach is likely to be effective for reducing N pollution and can be structured to be financially profitable for both the grower and insurer for most regions. This compares with a completely different crop management-based approach, whereby Everingham et al. developed a system that links the Canegro algorithms (embedded in the IrrigWeb model) directly to an irrigation system, allowing the model to control irrigation across a sugarcane farm. By improving irrigation scheduling, N runoff was reduced.

Pramod et al. reported on the development of a 'Crop-loss Assessment Monitor', aimed at monitoring yields for crop insurance purposes. This tool integrates crop modelling, statistical methods, remote sensing and weather indices to predict crop loss indices. Using this tool, insurance providers can calculate accurate premiums and compensation; and also permits analysis of risk associated with different insurance scheme designs.

2.2.6 Remote and proximal sensing

Chapman et al. used drone-based proximal sensing with crop models to characterise radiation use efficiency (RUE) of sorghum. The objective was to understand how sorghum Gs differ in terms of leaf area development and radiation interception. Two approaches were taken to estimate radiation interception: the first (in Australia) predicted fractional radiation interception (Fi) and above-ground dry biomass (ADM) from drone imagery-based vegetation indices, from which RUE was calculated. The alternative technique (USA) used drone-derived plant population measurements with hand-measured leaf counts, angle and final canopy leaf-size profile as inputs into the APSIM model, from which LAI, Fi and RUE (from biomass samples) were calculated. This demonstrates that glasshouse measurements of leaf parameters can be extrapolated to field scale, a similar approach to what was conducted for sugarcane in SASRI project 11CM02.

Van Oort et al. reported on using Sentinel satellite data to develop field-specific calibrations for potato growth in the Netherlands, using the Tipstar model. De Swaef et al. screened soybean Gs for drought tolerance using UAV imagery combined with modelling, to address the expectation of increased frequency and severity of NW European summer droughts in future.

Basso et al. reported on a system combining crop models and Planet Labs satellite imagery to produce high-resolution (spatial and temporal) maps showing yield stability classes, facilitating strategic analysis into N loss reductions, land use change decisions, and identification of growth-limiting factors. Similar analyses in the South African sugar industry would be of great value, given current industry pressures on profits.

2.2.7 Other points emerging from interactions with delegates

Henrique Borolo Dias is a PhD student at the University of Sao Paulo, supervised by Geoff Inman-Bamber and Paulo Sentelhas. Henrique has published two excellent sugarcane modelling papers during his PhD work, which is due for completion in May 2020. He expressed an interest in joining SASRI as a post-doctoral student if an opportunity to do so arose. This would be enormously beneficial to SASRI, giving us much-needed additional modelling capacity.

Mr Dias is the in process of writing a collaborative paper on the effect of temperature on sugarcane photosynthesis (RUE). This was discussed informally on several occasions during the conference.

Gerrit Hoogenboom and Cheryle Porter from the University of Florida (and the DSSAT Foundation) introduced me to Max De Antoni Migliorati (max.deantoni@qut.edu.au); he is a post-doc in Peter Grace's group at the Queensland University of Technology (Australia), and he apparently has data that could be used for testing/calibrating the nitrogen model in DSSAT-Canegro. Dr Hoogenboom reiterated his request for us to incorporate the N model into a public release version of DSSAT-Canegro and offered to host me at a future DSSAT development sprint to do so.

Dr Marshall-Colon and Dr Chenu invited participants to submit papers to the new journal, 'in silico Plants'. The title and outline of a follow-up paper to the 10CM03 work presented at iCropM has since been accepted in principle for fee-waived open access publication in this journal (subject to editor and reviewer acceptance).

3. RESEARCH VISIT TO CIRAD

3.1 Introduction

In the course of the work conducted in the ICSM research project, weaknesses in the simulation of timing of germination by leading sugarcane models have been revealed: the models were unable to simulate GxE interaction in germination rate and shoot emergence observed in field experiments. This affected the quality of canopy development and yield predictions.

Dr Christophe Poser at CIRAD Montpellier is a sugarcane physiologist with a particular interest and expertise in sugarcane germination. His colleague Dr Mathias Christina, a sugarcane modeller who is based in Reunion Island, was also present in Montpellier for the ICROPM2020 symposium. Both Poser and Christina are involved in the ICSM research project. A three-day mini 'workshop' was arranged, with the theme of genotypic control and seasonal/temperature effects on germination of sugarcane. Specifically, the aims were to update on project progress, glean novel insights into the underlying physiological processes relating to germination, develop new germination algorithms, perhaps also identify additional datasets for testing hypotheses, and to plan next steps.

3.2 Discussions

Key topics for discussion were as follows:

3.2.1 The author provided a **summary of progress with the ICSM project**, in particular regarding model evaluation for predicting G and E effects on sugarcane growth (Appendix), and a summary of modelling approaches to simulating germination and canopy development.

3.2.2 **Ideas for a new approach to modelling germination** – different base/optimal temperatures (Tbase, Topt, °C) for calculated thermal time accumulation, perhaps from simulated soil temperature rather than measured air temperature. A different approach, elaborated by Parent et al., 2010 and Parent and Tardieu, 2012, was extensively discussed and may be explored: temperature responses for many processes can be expressed using a single equation normalised with respect to process rates at 20°C, based on enzyme thermodynamics. An attractive feature from this model is that G differences can be represented with single parameter values. Parent and Tardieu (2012) have published model parameter values for sugarcane, which are reflected as cultivar G2 in **Error! Reference source not found.**.

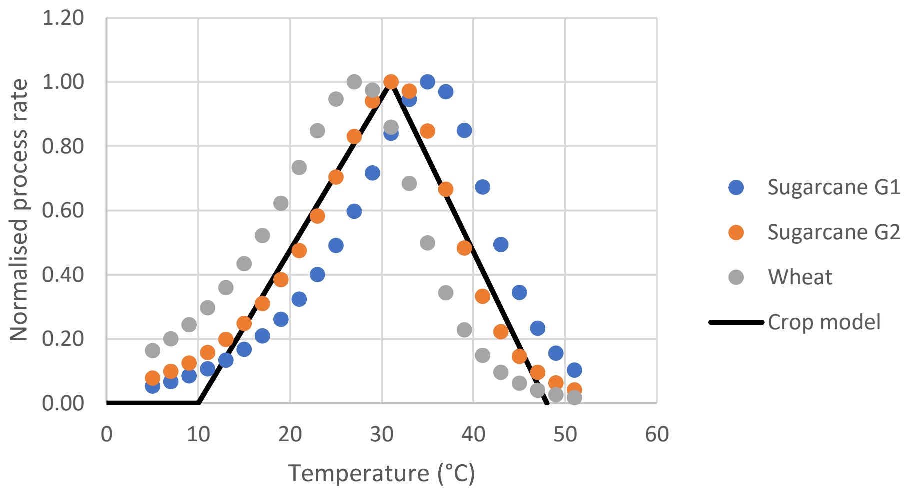

Figure 2
Johnson equation for sugarcane, reproduced from Parent & Tardieu (2012), normalized such that the maximum value = 1, for two hypothetical sugarcane

genotypes (G2 = published parameters, G1 = hypothetical G adapted to warmer conditions), wheat (using published parameter values), and with the standard crop model temperature response model superimposed.

These concepts appear very interesting and warrant further exploration. There is potential for simplification of crop model concepts and improvements to the biological realism of models.

3.2.3 **Observed temperature effects on germination from Poser's PhD**. Germination for several Gs grown in trays was monitored in chambers set to different temperatures. Key points: (1) different Gs do appear to have different base temperatures, and highlands-adapted cultivars have lower Tbase values (indicating that this is an important trait for breeding for cooler conditions); (2) germination rate and bud viability (i.e. whether or not a bud ever germinates) depends on temperature – at temperatures nearing the base temperature, germination was slower in TT terms AND the final germination fraction was lower. Tbase values were found for (mostly) Reunion varieties; of interest: R570 = 13.3°C, NCo376 = 12.5°C.

3.2.4 **Hot water treatment (HWT) of setts and effects on germination**. This was not specified in the ICSM trial protocols and it appears that none of the seedcane was HWT. There is evidence in the literature that HWT methods vary, and it has an impact on germination rates (possibly G-specific). This is an important consideration for model verification on historical trial data where HWT might have been performed.

3.2.5 **Presentation and carbon sink limitations discussion**: The author was asked to give a presentation to 12 CIRAD scientists, on his recent ICSM research work, of evaluating sugarcane models' abilities to predict GxE interaction effects in biomass yields (Appendix, Section 0). One challenging and thought-provoking question asked if carbon sink limitation had been considered when analysing the ICSM data.

A relevant iCropM paper by Luquet et al. asserted that physiological and morphological adaptability of source-sink relationships is 'pivotal' in generating ideotypes for crops in general (their study focussed on rice and sorghum) grown in climate-changed future Es. The DSSAT-Canegro model uses source-sink concepts to simulate sucrose partitioning (Singels and Bezuidenhout, 2002). The effects of excessive source strength have also been explored using the Canegro model (Van Heerden et al., 2010); while the study provided support for the hypotheses that sugar mediated feedback inhibition of photosynthesis is a likely cause of reduced growth in some crops, it also showed that the existing Canegro model and existing experimental data were not ideally suited to thoroughly validate the hypotheses. Carefully-designed field and glasshouse trials are needed to measure structural growth, photosynthesis and sugar accumulation of contrasting genotypes more precisely and at higher resolution.

3.3 Next steps

The following steps for building and testing an improved germination sub-model are proposed:

3.3.1 Daily estimated soil temperature outputs from existing model runs and measured air temperature for the ICSM experiments should be used as input.

3.3.2 A simple standalone R model of germination will be used to search for G specific base temperature that would minimize the thermal time required for completion of the germination phase at the different Es. It will be run with different base temperatures for germination (5-18°C).

3.3.3 The improved germination model will be implemented in a full sugarcane model and the improvements in simulating on biomass yield will be assessed.

Thereafter, a Parent/Tardieu temperature response model approach can be compared to the current approach of linear splines, as is currently used in DSSAT-Canegro (Jones and Singels, 2018) and APSIM-Sugar (Keating et al., 1999). An additional feature, to predict bud viability in response to temperature (based on the mortality observed by Poser), could also be incorporated.

For model evaluation, two possible datasets have been identified: Dr Poser's Reunion data, and data from the SASRI A/Temp experiment (from the mid-2000s); in both cases a set of Gs was grown in warm coastal and cooler high-altitude conditions and provides insights into temperature impacts. Additionally, the standard DSSAT-Canegro validation set (NCo376 only) includes two experiments started at different times of year (Pongola 1969-71 and La Mercy 1989-1991), which should reveal if incorporating simulated soil temperature improves simulation outcomes.

4. CONCLUSION AND IMPLICATIONS

The rich selection of papers presented at ICROPM2020 exploring linkages between crop models and genetics was extremely interesting and valuable. The author was exposed to new areas of work, which will strengthen the sugarcane trait modelling research, particularly in refining the objectives and methods for the final phase of the ICSM research project, whereby an improved model of sugarcane growth will be applied to demonstrate its value to assist breeding. Many other papers presented ideas – such as risk reduction through physical interventions and financial instruments, evaluating radiation use efficiency with proximal sensing, and genetic adaptations to climate change – that have potential for valuable application in South African and other sugar industry. Valuable feedback on ICSM research was received.

The research visit to CIRAD Montpellier was similarly valuable. Current knowledge and understanding of genotypic and temperature determinants of germination were considered, and a plan for model improvement and testing has been devised for the ICSM project on simulating and understanding of sugarcane GxE interactions.

5. ACKNOWLEDGEMENT

The author would like to extend his grateful thanks to the ICSM and its constituent member organisations for funding this trip and the research project; to SASRI for its support and for permitting the author to attend; and to CIRAD for hosting his visit there. The author would also like to thank Abraham Singels, Christophe Poser, Mathias Christina, John Annandale and Graeme Hammer for their extremely valuable assistance, scientific guidance and support, and Les Betts and Belinda Naidoo at SASRI for their administrative assistance in making logistical arrangements.

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7. APPENDIX

7.1 iCropM programme and book of abstracts

The full programme and book of abstracts is available here:

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7.2 iCropM poster

Jones, M.R., Singels, A., Chinorumba, S., Patton, A., Poser, C., Singh, M., Martine, J-F., Christina, M., Annandale, J., Hammer, G., 2020. Assessment of two sugarcane models for predicting genotype by environment interactions, using an international dataset. Proceedings of the International Crop Modelling Conference iCropM, 2020.

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7.3 Presentation to CIRAD

Jones, M.R., Singels, A., Chinorumba, S., Patton, A., Poser, C., Singh, M., Martine, J-F., Christina, M., Annandale, J., Hammer, G., 2020. Evaluating sugarcane growth simulation models for predicting genotypic effects on biomass yields. Presentation to CIRAD Montpellier, France, February 2020.

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Abstract of iCropM poster

Assessment of two sugarcane models for predicting genotype by environment interactions, using an international dataset

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Keywords: crop model, genetic trait, GxE, breeding, biomass.

Introduction

Traditional sugarcane breeding is costly, and challenged by the presence of genotype (G) by environment (E) interactions. An integrated approach to crop improvement, using realistic process-based crop models, can be useful for breeding (Hammer and Jordan, 2007). Jones et al. (2019) assessed concepts of G and E control used in sugarcane models using an international multi-E, multi-G dataset. These models have not however been systematically evaluated for their abilities to predict GxE interaction effects on yield.

Our goal was to evaluate DSSAT-Canegro ("DC", Jones and Singels, 2018) and Mosicas ("MS", Martiné and Todoroff, 2004) for simulating G and E effects on crop development and growth using an international growth analysis data set.

Materials and Methods

The dataset (described by Jones et al., 2019) consisted of crop development and growth observations from irrigated trials using cultivars N41, R570 and CP88-1762, conducted at Pongola (South Africa), La Mare (Reunion Island, France), Belle Glade (Florida, USA) and Chiredzi (Zimbabwe). G-specific trait parameter values for DC and MS were determined by (1) deriving values directly from observations; or (2) using trial-and-error to minimise simulation prediction error of process-output variables; or (3) using default model values.

Model performance was quantified by comparing simulated and observed values of canopy development (fractional interception of photosynthetically-active radiation, FiPAR, %) and above-ground biomass accumulation (ADM, t ha^{-1}). Prediction of GxE interaction was assessed by analyzing variance across Es and Gs.

Results and Discussion

DC predicted FiPAR most accurately (RMSE = 12.8%, R^2 = 0.84). MS overestimated FiPAR during warm periods and underestimated it during cool periods, suggesting a too-high default base temperature.

Simulated and observed ADM yields are shown in Figure 1. The La Mare first ratoon (“R1”) crop produced highest yields, followed by the Belle Glade plant (“P”) crop. Lowest yields were recorded for the Pongola P crop. Highest-yielding Gs were: CP88-1762 at Belle Glade (P and R1) and Chiredzi R1; R570 for La Mare R1; and N41 for Pongola P.

DC and MS had similar ADM simulation accuracy (RMSE ~ 6.5 t ha^{-1}, R^2 ~ 0.90). DC could not predict the low ADM yields observed for Pongola P, while MS underestimated yields for La Mare R1. All models underestimated variation between Es, suggesting inadequate process-level responses to E drivers.

G variation in ADM yields was underestimated by both models. Neither model could predict the high ADM values for R570 at La Mare R1, and N41 at Pongola P (Figure 1); this is not yet fully understood. G rankings per E were correctly predicted in three of five Es by DC, and only one of five by MS.

Further analysis is required to understand the reasons for the poor model performance; this may lead to recommendations for model improvements.

Conclusions

DSSAT-Canegro and Mosicas underestimated both E and G variation in ADM yields, and were unable reliably to predict observed G rankings, for these irrigated Es. Further analysis is required to understand why the models failed in these ways. We intend to use these findings to improve algorithms and calibration protocols to strengthen model-assisted sugarcane breeding.

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	Observed ADM (t ha^{-1})				DSSAT-Canegro sim. ADM (t ha^{-1})				Mosicas sim. ADM (t ha^{-1})			
Site, crop	N41	R570	CP88-1762	Avg.	N41	R570	CP88-1762	Avg.	N41	R570	CP88-1762	Avg.
Belle Glade, P	41.9	52.3	62.4	52.2	43.7	44.9	47.0	45.2	46.7	46.7	49.7	47.7
Belle Glade, R1	34.7	46.6	48.1	43.1	44.0	45.4	48.7	46.0	49.0	47.9	51.5	49.5
Chiredzi, R1	45.8	45.7	50.0	47.2	55.5	55.1	57.5	56.0	52.2	51.5	54.1	52.6
La Mare, R1	68.3	71.2	56.4	65.3	59.7	61.4	62.9	61.3	53.2	52.9	54.9	53.7
Pongola, P	43.4	35.9	38.4	39.2	45.4	45.7	49.1	46.7	34.2	34.7	37.0	35.3
All experiments	46.8	50.3	51.1	49.4	45.4	45.7	49.1	51.1	34.2	34.7	37.0	47.7

P = Plant crop, R1 = ratoon crop

Figure 1. Heatmap of above-ground dry biomass (ADM) yields, observed and simulated by DSSAT-Canegro and Mosicas. The colour scale indicates ADM yield rank for each experiment, with green the highest and red the lowest.

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