SUGARCANE SIMULATION:
STATE OF THE ART, APPLICATIONS AND IMPLICATIONS

By

N.G. INMAN-BAMBER1,5, S.N. LISSON1,5, M. McGLINCHEY2, A. SINGELS3 and
K.L. BRISTOW4,5

1CSIRO Sustainable Ecosystems, Davies Laboratory, Townsville, Australia
2Swaziland Sugar Association, Simunye, Swaziland
3South African Sugar Association Experiment Station, Mount Edgecombe (SASEX)
4CSIRO Land and Water, Townsville
5CRC for Sustainable Sugar Production, Townsville, Australia

Abstract

Theoretical or mathematical simulation models have improved the understanding of complex biophysical systems that feed and clothe the world's population. Sugarcane growth models have been developed in Australia (APSIM-Sugarcane) and South Africa (CANEGRO) over the past decade. CANEGRO has been used to estimate potential and attainable yields and for benchmarking in commercial production systems. Both models have been used extensively in strategic and tactical decisions about irrigation. APSIM-Sugarcane has been linked with models that simulate catchment runoff, and configured to capture the hydrology of on-farm water storages to provide biophysical data for economic models that evaluate investments in irrigation. This paper reviews the usefulness, strengths and weaknesses of these industry models. The models account for the most important factors affecting crop growth in most production systems. We argue that imperfect and incomplete simulation models complement conventional field plot 'models' which, by definition, are incomplete and seldom perfect. We use the past decade of experience to show that appropriately validated models have contributed considerably to understanding and improving sugarcane production systems in three countries.

Introduction

Initially, the aim of model development was to provide a means of synthesizing detailed knowledge of crop physiological processes in order to explain the response of crops to environmental and management factors (Bouman et al., 1996). In recent years, however, funding for agronomic research has required that models also provide practical benefits to growers and that model development be driven to some extent by the needs of industry and agribusiness. APSIM-Sugarcane (Keating et al., 1999) and CANEGRO (O'Leary, 2000) are examples of process level models for sugarcane which are now making an impact internationally. Contributions to this paper come from South Africa, Swaziland and Australia to illustrate the state of the art in sugarcane simulation and how APSIM-Sugarcane and CANEGRO have benefited the industries in each of these production centres. Through this, we aim to present a case that crop simulation is an essential tool in research and the decision-making processes.

State of the art

CANEGRO accounted for a large number of observations in a limited number of detailed experiments (Inman-Bamber, 1991), and it accounted well for cane dry matter yields in a large number of experiments (16 and 28 respectively) at two rainfed sites where only final yield was measured (Inman-Bamber et al., 1993). Root mean square errors (RMSE) for these sites were 3.2 and 4.0 t/ha respectively and the range of yields was 7 to 40 t/ha at both sites.

APSIM-Sugarcane has been subjected to extensive validation using data from a number of climatic regions in Australia and southern Africa (Keating et al., 1999). RMSE for over 100 observations was 28.7 t/ha in a range of 0 to 270 t/ha for fresh cane yield and was 4.9 t/ha in a range of 0 to 45 t/ha for sucrose yield (O'Leary, 2000). APSIM-Sugarcane has recently been tested in Mauritius under a wide range of wet and dry conditions (117 cane yield observations). RMSE for cane dry matter and sucrose yields were 6.0 and 3.3 t/ha respectively in a data range of 2 to 52 and 0 to 27 t/ha respectively (Cheeroo-Nayamuth et al., 2000).

Difficulties in simulating root water uptake and hence crop response to water stress in CANEGRO have been noted by van Antwerpen et al., (1996). O'Leary (2000) pointed to deficiencies in the concepts of dry matter (DM) partitioning in both models, particularly in CANEGRO. By and large, these difficulties are due to a lack of knowledge rather than deficiencies in the models per se. The models embody the current state of knowledge of the processes of canopy development, photosynthesis and DM partitioning in relation to energy and water balances and in relation to N and carbon balances in the case of APSIM.

They do not account for processes which are important in some regions such as flowering and
Applications—Swaziland

The rapid adoption of CANEGRO by the Swaziland sugar industry is attributed to the large size of individual farms (>6000 ha) which are under the control of technologically advanced managers.

Irrigation

Irrigation issues have driven model development considerably. CANEGRO was used initially to derive reference evaporation for a full canopy, 3 m high. The mean monthly ratio between sugarcane reference evaporation and Class-A pan evaporation was derived for three meteorological sites in Swaziland over a 25-year period. Simple correction factor tables were developed and successfully incorporated into existing scheduling systems based on Class-A pan evaporation. Since this exercise, many estates have progressed, moving away from the Class-A pan completely, in favour of the Penman-Monteith (PM) approach used in CANEGRO (McGlinchey and Inman-Bamber, 1996).

Yield forecasting

CANEGRO was used to improve pre-season yield estimates starting in November each year. Yield estimates have proved accurate and valuable to the industry to the extent that this form of analysis is now routine. Simulations are conducted using actual daily weather records available at the time. Historic weather records are then selected to match the mid-to-long-range climate forecast in order to complete simulations of crops to be harvested next season.

Yield benchmarks

CANEGRO has been used extensively to benchmark field and manager performance. The measured performance of each field on three large estates has been compared to simulated yields to identify problem fields and as a means of assessing and monitoring manager performance.

Applications—South Africa

Yield potential and benchmarking

CANEGRO has been used to establish yield potentials for fully irrigated and rainfed conditions in southern Africa (Inman-Bamber, 1995). This type of application has assisted in the planning and development of new sugar production projects such as a syrup production system in the Mazoe valley of Zimbabwe and new sugarcane projects in the Ntondweni and Nkundusi regions of KwaZulu-Natal, near Umfolozi.

Irrigation

In 1990, simulated responses to different water allocations were used by engineers in the Department of Water Affairs to upgrade the canal system of the Pongola Scheme. Yield responses to irrigation on major soil groupings of a large estate in Northern KwaZulu-Natal were compared with field records to aid decision making regarding optimum water and land usage (Inman-Bamber et al., 1993). Production was abandoned on some soils to concentrate water on others.

PM subroutines of CANEGRO have been used extensively in irrigation scheduling in conjunction with automatic weather stations, funded by grower groups in some cases. One study showed commercial yield and water use efficiency benefits from the use of this scheduling system over a period of three years (Culverwell et al., 1999).

Season length

CANEGRO was used to support both growers and millers in debates about the length of the milling season. For example, a milling company wanted to know the implications for cane and sucrose yield if the milling season was increased from 33 to 37 weeks. On the other hand, growers required guidance on the effect of mill closing and opening dates on the yield and quality of cane harvested towards the end of the 1995 and 1996 milling seasons.

CANESIM

Unfortunately, the detailed SASEX version of CANEGRO can only be used by specialists. A user-friendly management tool called CANESIM was developed from CANEGRO for distribution to extension officers to support decisions requiring yield benchmarking, and future yield estimates and estimates of crop water use (Singels et al., 1999a). CANESIM has been used to assess the economics of strategies for supplementary irrigation of sugarcane in South Africa (Singels et al., 1999b). CANESIM is available on the internet (www.sasa.org.za/sasex/irricane/index.htm) where it is linked to a real-time weather database. CANESIM is currently being used to update crop yield estimates for the next milling season.

Applications—Australia

Irrigation

APSIM-Sugarcane (AS) has been accepted as the best means to determine effective rainfall in the Bundaberg region in order to benchmark productivity and water use efficiency. A necessary step in this application was to reassess hydraulic properties of soils in the Bundaberg region using the model in reverse (Inman-Bamber et al., 2000). The model has also been used by advisory staff at Proserpine to determine effective rainfall, irrigation requirement and potential responses to irrigation (Hardie et al., 2000). Brennan et al., (1999) demonstrated a method of finding the most profitable use of limited water on a farm with a range of crop classes and soils using AS and a linear programming approach. AS was used to develop drying-off strategies for three major irrigation schemes in Australia and South Africa (Robertson et al., 1999).
The costs and benefits of on-farm water storages (OFWSs)

The AS model has recently been applied in the Bundaberg region where OFWSs are required to help capture runoff and to store surplus allocated and out of allocation water. A key industry support group within the Bundaberg region provided impetus for the development of DAM EASY, a modelling tool designed for industry consultants to assess the costs and benefits of investing in supplementary irrigation and OFWSs (Lisson et al., 2000). DAM EASY integrates an OFWS-based sugarcane configuration of AS and an economic model within a customised user interface.

Carbon and nitrogen management

APSIM (‘Sugarcane’ and other modules) has been used to simulate the decomposition of sugarcane surface residues and the subsequent impact on N, C, water and crop dynamics under different trash management systems (Thorburn et al., 1999a, 1999b). The model has also been used to investigate issues of N requirement, N loss and opportunities for improved N management (Keating et al., 1997). These applications are leading to new N management guidelines within the industry. Crop yield and selected outputs from APSIM’s carbon and nitrogen balances were integrated with various established algorithms in a calculator called GreenCalc, for estimating annual net emissions of the key greenhouse gases for various sectors of the Australian sugar industry (Lisson et al., 2001). Potential applications of the calculator include the estimation of current greenhouse gas emission levels and investigation of abatement strategies.

Implications (discussion and conclusions)

Modelling and scenario analysis are now well accepted tools of the trade in many fields of endeavour, including business, space exploration, and industrial and aeronautical engineering. We have shown that significant progress has been made in developing and applying crop models within the sugar industry, at the field and farm enterprise scale, and in coupling biophysical and economic models. We believe the sugar industry as a whole needs to take a more aggressive approach to fostering development and application of modelling and scenario analysis as a means of helping to address the many production and environmental issues currently facing the industry. While field and laboratory experimentation remain tools of our trade, these tools allow consideration of only a subset of the wide range of possibilities, and they are universally limited in their predictive capability. Simulation models often improve both the interpretation and extrapolation of experimental data. CANEGRO and APSIM-Sugarcane have captured the current state of knowledge of the workings of important parts of the sugarcane cropping system. Most deficiencies in the models are deficiencies of our knowledge not the models themselves. Research should be directed at rectifying deficiencies that most affect the economically and environmentally important components of the system.

Some current limitations include our inability to adequately address root water and nutrient uptake, and DM partitioning. There is a need for dedicated experimental facilities and well designed experiments to help remedy this. We also need to be investing in development of more appropriate upscaling models that link the farm enterprise and catchment scale. This is needed to help predict likely effects of actions carried out on farm, and their potential offsite impacts on the wider ecosystem.

It should be evident from the examples of model application in this paper that client focus and participation has been in the forefront of model development. We propose going a step further in participatory research, to use the development and application of models as a way of helping educate and empower people to think more creatively about how to better manage their sugarcane and associated environmental systems. An industry that is tuned in to current modelling technologies and that can use them effectively to explore the future, and potential repercussions of implementing particular decisions, will without doubt have an advantage in terms of its longer term sustainability.

REFERENCES


MODELISATION DE LA CANNE A SUCRE:
ETAT DES LIEUX, APPLICATIONS ET IMPLICATIONS

N.G. INMAN-BAMBER1,5, S.N. LISSON1,5, M. McGLINCHEY2, A. SINGELS3 et K.L. BRISTOW4,5

1CSIRO Sustainable Ecosystems, Davies Laboratory, Townsville, Australia
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4CSIRO Land y Water, Townsville, Australia
5CRC for Sustainable Sugar Production, Townsville, Australia

Résumé
La modélisation théorique ou mathématique a aidé à comprendre les systèmes biologiques complexes qui nourrissent et font vivre la population mondiale. Des logiciels modélisant la croissance de la canne à sucre ont été développés en Australie (APSIM-Sugarcane) et en Afrique du Sud (CANEGR0) durant la dernière décennie. CANEGRO a été utilisé pour estimer les rendements potentiels et réalisables et pour évaluer la performance des systèmes de production commerciaux. Les deux logiciels ont été utilisés de façon extensive à des fins stratégiques et tactiques sur l’irrigation. APSIM-Sugarcane a été relié à des logiciels qui modélisent le ruissellement dans les bassins versants, et adapté à l’utilisation des données l’hydrologiques du stockage de l’eau au niveau des fermes, afin que des données biophysiques pour la modélisation économique des investissements dans l’irrigation soient disponibles. Cette communication passe en revue l’utilité, les forces et faiblesses de ces modèles. Ces derniers prennent en considération les facteurs les plus importants dans la plupart des systèmes de production, mais ne tiennent aucunement compte de tous les facteurs, même si ceci était possible. Nous soutenons que des modèles imparfaits et incomplets peuvent compléter les “modèles” conventionnels de parcelles aux champs qui, par définition, sont eux-mêmes incomplets et rarement parfaits. Nous utilisons l’expérience acquise lors de la dernière décennie pour démontrer que des modèles correctement validés ont largement contribué à comprendre et améliorer les systèmes de production de canne à sucre dans trois pays.

Mots clés: Irrigation, modélisation, rendement.
Resumen

La simulación teórica o matemática de los modelos ha mejorado el entendimiento de los sistemas biológicos complejos que alimentan y visten a la población mundial. Los modelos de crecimiento de la caña de azúcar han sido desarrollados en Australia (APSIM-Sugarcane) y en Sur África (CANEGRO) en la década anterior. CANEGRO ha sido usado para estimar las producciones potenciales y obtenibles y para referenciar los sistemas comerciales de producción. Ambos modelos son usados extensivamente para la toma de decisiones tácticas y estratégicas para el manejo del riego.

APSIM ha sido usado con otros modelos para simular la escorrentía de una cuenca, y configurado para capturar la hidrología de los embalses en las fincas y para proporcionar datos biofísicos para los modelos económicos que evalúan las inversiones en riegos. Este artículo revisa la utilidad, fortalezas y debilidades de los modelos de crecimiento de la caña. Los modelos incluyen los factores más importantes que afectan el desarrollo de la caña en la mayoría de los sistemas de producción.

Nosotros argumentamos que los modelos incompletos o imperfectos complementan a los modelos convencionales de producción de parcelas, los cuales por definición también son incompletos e imperfectos. Nosotros usamos la década anterior para mostrar que los modelos validados apropiadamente han contribuido considerablemente para el entendimiento y mejoramiento de los sistemas de producción en tres países.