LINKING AGRONOMIC AND ECONOMIC MODELS TO INVESTIGATE FARM-LEVEL PROFITABILITY UNDER A BIOENERGY-ORIENTED SUGAR INDUSTRY IN SOUTH AFRICA

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Abstract

In South Africa, the opportunity for bioenergy production from sugarcane is becoming increasingly realistic. However, many questions remain regarding the extent to which agronomic practices need to be adapted, and the related economic impacts and tradeoffs, bearing in mind that future economic conditions are highly uncertain. To address these issues, a model chain was developed consisting of the Canesim crop growth model, the Economics of Trashing model, and the farm and sector-level models of the Bureau for Food and Agricultural Policy (BFAP). The model chain was applied to construct a virtual, plausible farm for each of the main South African production regions (irrigated north, midlands and coastal dryland). Agronomic practices for each farm were set up according to current practices, and were varied to suit different mill processing strategies, including sugar production, electricity co-generation from bagasse with or without trash, and bio-ethanol production. Yields were simulated using historical weather data for the period 1998 to 2007. The BFAP sector model was used to simulate four plausible macro-economic scenarios for 2008 to 2017, for which the different agronomic and mill processing strategies were compared. Results suggest that the additional revenue from co-generation or bio-ethanol production will increase farm-level profitability, while requiring few adaptations. The performance of these production strategies was surprisingly robust across the strongly contrasting economic scenarios. The model chain could be further developed and used as an interactive tool to contribute to farm and mill level discussion and decision making regarding alternative sugarcane production and processing strategies under future economic and policy conditions.

Keywords: farm-level economics, scenario modelling, bioenergy, co-generation, bio-ethanol

Introduction

In South Africa, the main focus, by far, of sugarcane processing is the production of sugar. Ethanol is produced at relatively small levels by one company for the beverage and industrial markets (Anon, 2006). Co-generation, i.e. the combined generation of heat (steam) and electricity, takes place in most mills, but mainly to drive the mill's own operations.

Industry decisions to invest – or not – in bioenergy depend on the expectations of getting a handsome return on investment and perceived risks related to any decision or indecision, which are all difficult to assess. Mac Nicol *et al*. (2007) conducted a survey among sugarcane producers in South Africa, and concluded that the perceived key risks faced by sugarcane producers were land reform, minimum wage legislation, and volatility of the sugar price. Today, only two years later, they might well have added the volatility of the prices of fertilisers, oil and other energy carriers to this short list. Price volatility and its impacts may be better assessed through understanding the drivers behind it. Models can assist in predicting the effect of certain conditions on farm-level economics, hence providing a powerful basis for decision making at farm-level as well as at the higher industry policy level.

The objective of this paper is to demonstrate the potential of this approach by linking different types of models to create an agro-economic modelling chain that is used to compare the economic performance of different sugarcane production and processing strategy combinations under several scenarios of future economic conditions, for the main South African sugarcane production regions.

Methodology

General approach

The study comprised the following steps:

- A chain was constructed of four existing models that, together, cover the entire sugarcane production and processing system.
- Three realistic sugarcane production and mill processing strategy combinations were identified for each of three main production regions of the South African sugar industry.
- Four contrasting, yet plausible, scenarios were developed of future micro-economic and macro-economic conditions impacting on sugarcane production in the South African sugar industry.
- The model chain was applied to compare the agronomic production and mill processing strategy combinations under the economic scenarios developed, and to assess the farm-level financial implications, for a series of 10 years with different climatic conditions.
- Robustness of the production and processing strategy combinations for each production region was assessed as an indication of those strategies which performed well in most years under all scenarios.

The production and processing system analysed

Figure 1 provides an outline of the *sugarcane production and processing* systems considered in this study.

The sugarcane production system includes operations such as the planting, growing and harvesting of sugarcane. Transport is considered as the interface between the production system and the milling system. The milling system includes all operations involved in processing sugarcane to produce sugar, molasses, heat, electricity and/or ethanol.

The system boundary encapsulates the eight operations that were focused on in the study. These operations are represented by thick solid-lined boxes and arrows in Figure 1. External to the system boundary, the processes impacting on the operations are represented by the smaller solid-lined boxes and arrows. Direct inputs and outputs to the operations are represented by the dashed boxes and arrow connectors.

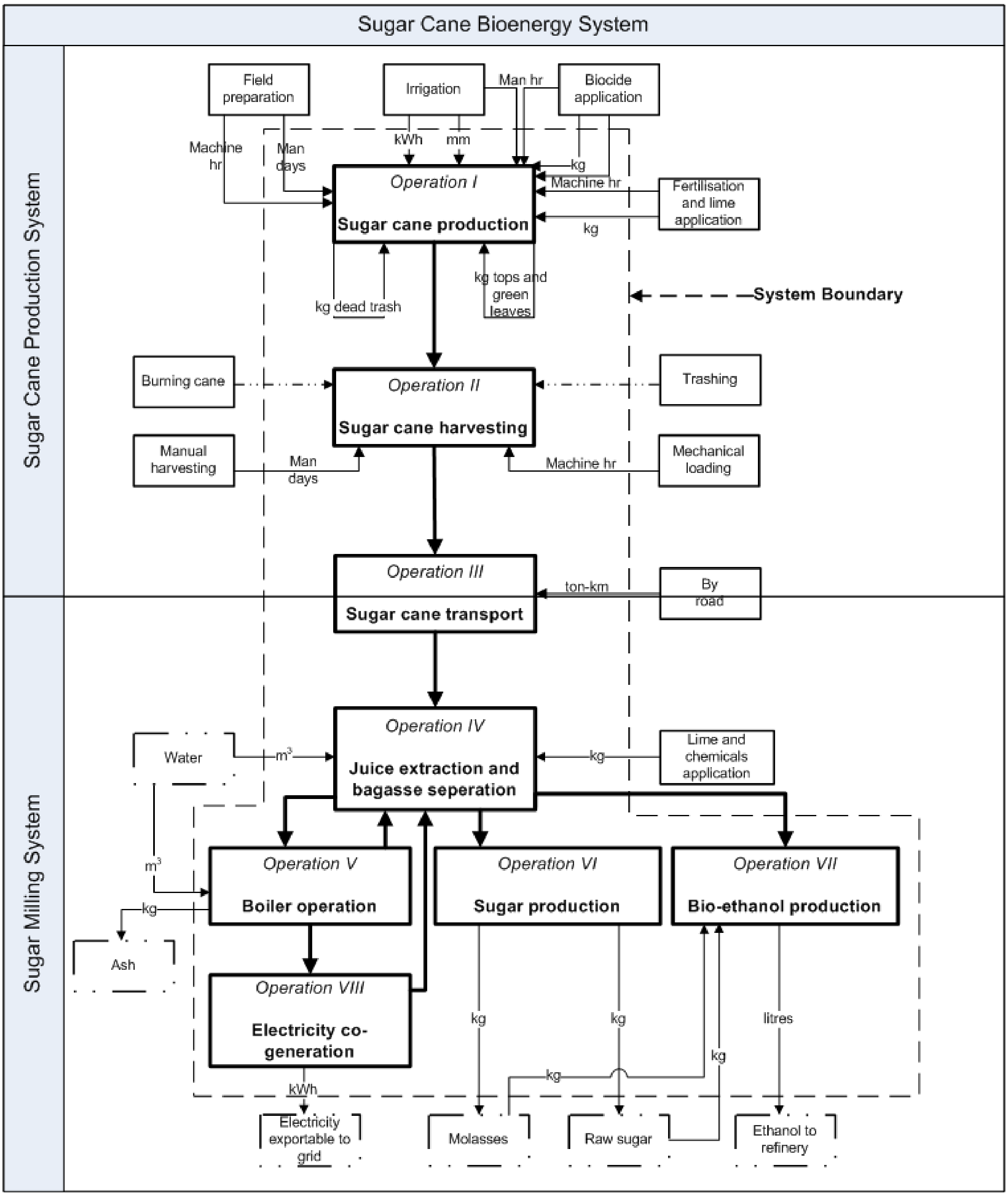

Figure 1. The sugarcane bioenergy system.
Source: Adapted from Mohee and Beeharry (1999).

Sugarcane production regions considered

Three broad production regions were considered for the study. These are coastal (dryland), midlands (dryland) and northern (irrigated) regions.

Coastal (dryland) region

Sugarcane production in this region is predominantly rainfed, with average cutting cycles of approximately 12 months, partly to minimise crop damage caused by the sugarcane borer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Atkinson *et al.*, 1981 *in* Inman-Bamber, 2000). Mill areas situated in this region include Umzimkulu, Sezela, Maidstone, Gledhow, Darnall and Amatikulu. Conditions in Felixton and Umfolozi are 'transitional' to the irrigated areas, and were not included in the study.

Midlands (dryland) region
The midlands region is situated inland from the North and South coast of KwaZulu-Natal. This region is predominantly rainfed. It has a much cooler climate than the other South African sugarcane production regions. Cutting cycles are usually close to 24 months in length. The Noodsburg, Union Co-op and Eston mill areas are situated in this region.

Northern (irrigated) region
Mill areas in this region include Pongola, Komatipoort and Malelane. A sunny, warm and dry climate prevails in this region, making irrigation indispensable. Cutting cycles in this region are usually around 12 months in length.

Each production region is represented by one virtual farm. These were created and evaluated through consultation with extension specialists employed in the respective regions, as well as experts from the South African Cane Growers' Association (SACGA).

Agronomic and mill processing strategies

Two varieties were studied. The reference model variety was NCo376, which is normally used in the Canesim model. This cultivar is grown in all three production regions. The second cultivar is a hypothetical high fibre variety, capable of producing an above average yield of sugarcane biomass, yet with relatively low sucrose content.

The amount of fertiliser applied was assumed to be linear across cutting cycle lengths. Although this assumption is inaccurate, no more correct method could be found during consultations with soil scientists at the South African Sugarcane Research Institute (SASRI).

The size of the farming operations were taken from the results of the 2007/08 Grower Cost Survey conducted by SACGA. The coastal farm was assigned 190 hectares under sugarcane. The midlands virtual farm has 257 hectares under cane. The northern irrigated farm has a total of 200 hectares under sugarcane. An assumption was made that 1% of the area under cane (AUC) in each region would be left fallow.

Three mill processing strategies were considered in this study. The assumptions made for each were adapted from Jones *et al.* (2006) and are listed below.

SUGAR - Business as usual
This strategy is predominantly employed in the South African sugar industry today. Dead leaf material is burned before harvest. Cane tops are left in the field. At the mill, bagasse is combusted to produce heat and process steam to generate power for own consumption (Bhatt and Rajkumar, 2001). The main product is raw sugar. Farm-level incomes were estimated using the RV concept.

COGEN - Sugar and co-generation
In this strategy the sugarcane is not burnt, but harvested green. Of all plant residues, 70% are baled at harvest, and transported to the mills. At the mills, co-generated power is used for mill

operations, and the surplus electricity is exported to the grid (e.g. to Eskom or local municipalities). Income from electricity was assumed to be divided up into 64.07% to producers, and 35.93% to millers, similar to the division of proceeds (DOP) ratio.

SUGETHCO – Sugar, ethanol and co-generation
Sugarcane is harvested green and all residues are left in the field as a trash blanket. Final products in this strategy are raw sugar, ethanol, and electricity derived from bagasse. The ratio between ethanol and sugar production is linked to macro-economic trends. For example, if the economic model (described below) projects that 30% of South Africa's sugarcane supply will be used to produce ethanol, then 30% of the virtual farm's sugarcane supply will be diverted to ethanol production.

Economic scenarios

Four economic scenarios were developed for this study, covering the period up to 2017. The first is the so-called 'Baseline' scenario, taken from *The South African Agricultural Baseline June 2008* (Bureau for Food and Agricultural Policy, 2008b), the only changes being updated 2008 values for sugarcane production, exports, imports and the RV price.

Three other scenarios were developed, using the Baseline as a starting point, in accordance with the story lines below:

US Hiccup
In this scenario, the US economy was assumed to be in a slight and temporary recession. The European Union (EU), India and China are only slightly affected. The oil price decreases slightly to US$95/bbl by 2011, after which it slowly increases to reach US$130/bbl in 2017. The Rand weakens against all major currencies, as risk-averse investors prefer the stable and growing economies of the EU, China and India. The depreciating Rand initially causes high inflation rates of up to 10%. South Africa stabilises its electricity supply and starts attracting foreign investment. Coupled with relatively low oil prices, this causes inflation to drop to 6% by 2012.

Global Cold
The USA is in a deep economic recession. Consumer spending is down, thus China, India and the European Union cannot sustain their economic growth rate. Investors are risk-averse and invest in gold and other precious metals. This keeps the exchange rate of the Rand against the US$ between R7 and R8. Inflationary pressures from high food prices are mitigated by the significant drop in oil prices (to $65 by 2011) due to decreased demand from the major fossil fuel consuming nations. After 2011, a strong recovery by the US and other leading economies leads to increased energy prices.

Global Growth, except for Africa
The US presidential elections in 2008 bring forth a renewed sense of optimism among investors, causing the Dollar to strengthen against all currencies as the US economy becomes the global 'giant' of old. However, investors do not want to invest in Southern Africa, due to real or perceived 'problems'. The US spurs global economic growth, causing the oil price to rise to US$150/bbl by 2011, and keep on growing at an annual rate of between 5% and 6%. Inflationary pressure in South Africa is high (between 9% and 11%). The prime interest rate remains at a high 14.5%.

The agro-economic model chain

The model chain constructed and used in this study consists of the following models:

- The Canesim crop growth model (Singels *et al.,* 1998) to calculate yields of sugarcane and its components.
- The economics of trashing decision support program (DSP) (Wynne and van Antwerpen, 2004), to compare the economic implications of different types of sugarcane harvesting and residue management practices at field level.
- The farm-level economics model of the South African Bureau for Food and Agricultural Policy (BFAP) (Strauss, 2005).
- The sector-level model of BFAP (Meyer, 2002), to stochastically simulate future price and production levels and trends in the South African agricultural sector.

Figure 2 shows the interaction of these four models in the chain. The inputs for the Canesim crop growth model and the BFAP sector model were determined exogenously, while their output was used as input for the farm-level economics models. Results of the model chain runs were expressed as R/ha under cane.

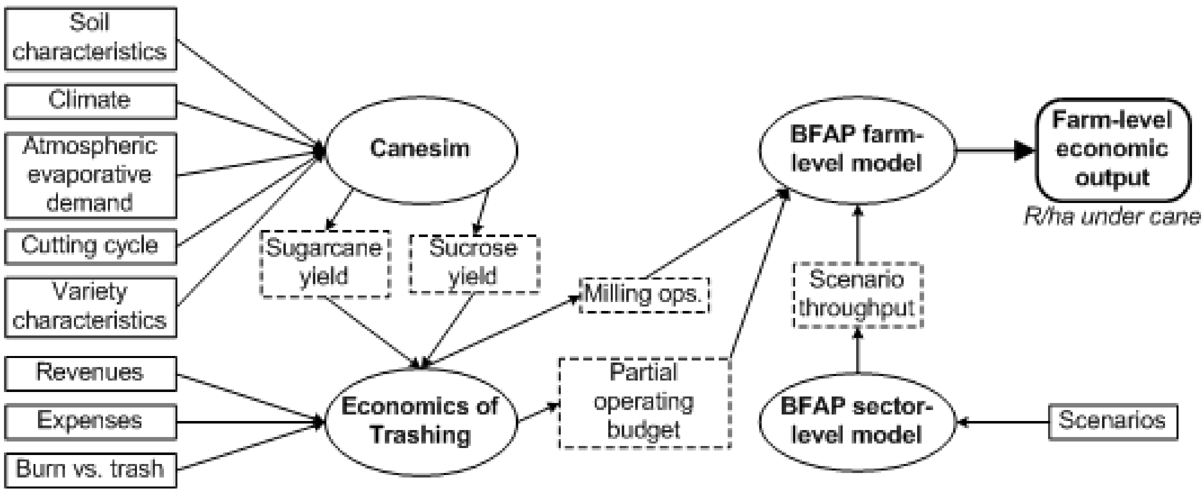

Figure 2. Flow of information in the agro-economic chain of models developed.

Canesim

The Canesim model, based on IRRICANE (Singels *et al.,* 1998), is a daily time step crop growth simulation model. Its main inputs are soil available water capacity (AWC) and daily rainfall, radiation and temperature (van den Berg and Smith, 2005). For this study, weather data for the period 1998 to 2007 were collected from the following weather stations to represent each of the production regions:

- Tongaat, for the coastal dryland region
- Amanxala, for the Northern irrigated region
- Jaagbaan, for the midlands dryland region.

These data were then used in Canesim as surrogate weather for the years 2008 to 2017. The hypothetical high-fibre variety N-HF002, was created for Canesim by changing two model parameters of variety NCo376: (i) the radiation use efficiency (RUE), which was increased from 1.7 to 2.04 MJ/m^2; and (ii) the maximum sucrose content of stalk dry matter, which was changed from 0.58 to 0.464 kg/kg.

The economics of trashing decision support program

The economics of trashing DSP (Wynne and van Antwerpen, 2004) calculates a deterministic partial budget for a farm. The output is presented in the form of the difference in costs and revenues of a farm that practices burning, versus a farm that practices trashing. Factors taken into account are mainly those that differ between burning and trashing practices, such as biocide application rates, yield responses, labour costs, transportation costs, and capital requirements for mills to adapt to the type of cane received.

The BFAP farm-level economic model

The BFAP system of farm-level models is deterministic, and uses partial budgets of individual farms and indices of price movements from the sector model to estimate the farm-level implications of the baseline assumptions (Strauss, 2005; Bureau for Food and Agricultural Policy, 2008a).

The objective of the farm-level models is to analyse the effects that changes in policies and macro and micro-economic conditions will have on a farm's financial state (Strauss, 2005).

The BFAP sector model

The BFAP sector model is a partial equilibrium model that contains different agricultural sectors, simulated with closed systems of equations (Bureau for Food and Agricultural Policy, 2007). The model is based on the work of Meyer (2002, 2006), and contains a regime-switching component, which entails that changes in one sector (e.g. grain) will have an effect on related (i.e. competing, substituting or downstream) sectors (e.g. livestock).

The sector model was used to simulate a baseline, a projection of what could happen in the future, given certain assumptions (Bureau for Food and Agricultural Policy, 2008a). The baseline incorporates future macro-economic, policy and demographic conditions into all of the farm-level models (Bureau for Food and Agricultural Policy, 2007).

Model runs and interpretation

Figure 3 presents a diagram of how the various model runs were set up.

The Canesim model was run with four different starting dates for each year. The average of these four runs was calculated and used as input values for the rest of the model chain. Information on agricultural practices in each production region was obtained through consultation with extension specialists from these regions. Due to a lack of information, only manual harvesting was considered.

It must be noted that the costs of depreciation, interest, and other capital expenditure were disregarded for this study; i.e. only operational costs were taken into account. All financial results are given in nominal terms for the period 2008 to 2017.

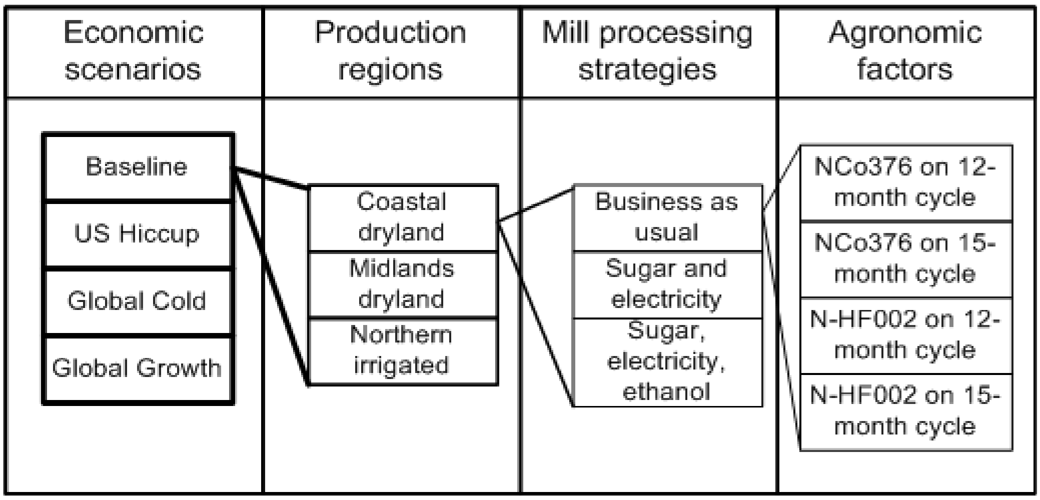

Figure 3. Unbundling the various agronomic, economic and processing combinations.

Results and Discussion

Figure 4 presents the sector model outputs for RV prices and retail petrol prices in the various scenarios.

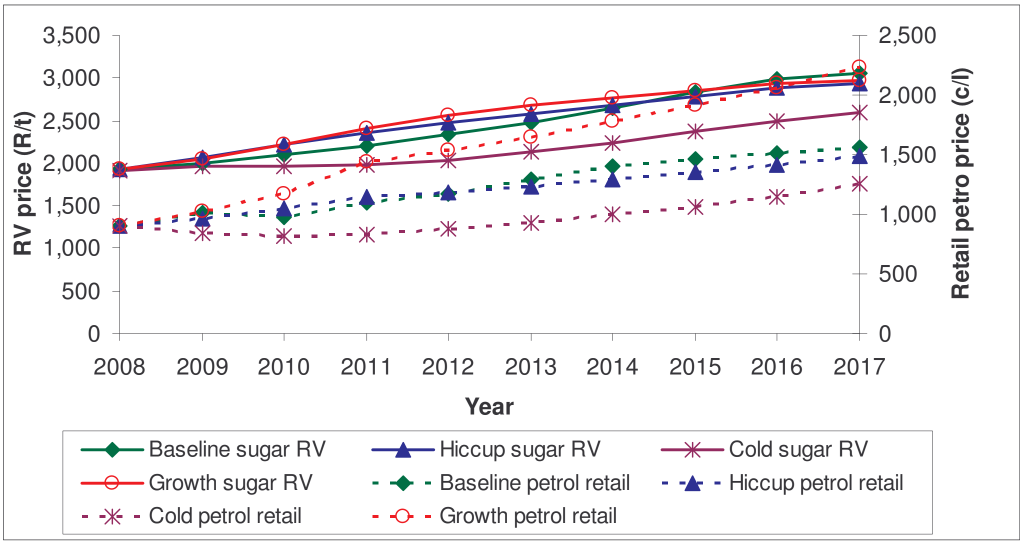

Figure 4. Sector model outputs for RV prices and retail petrol prices.

Figure 5 depicts the partitioning of sugarcane for either sugar or ethanol production at a macro-economic level. The columns present the tonnages of sugarcane to be crushed for sugar, while the lines indicate the amounts of sugarcane to be used for the production of ethanol. These production levels are simulated by the BFAP sector model, which takes various factors into account, such as profit margins, input and output prices, and current production levels. Ethanol production from sugarcane is highest in the Global Growth scenario, due mostly to very high energy prices. Ethanol production in the Global Cold scenario is marginal, with oil prices being low due to decreased global demand.

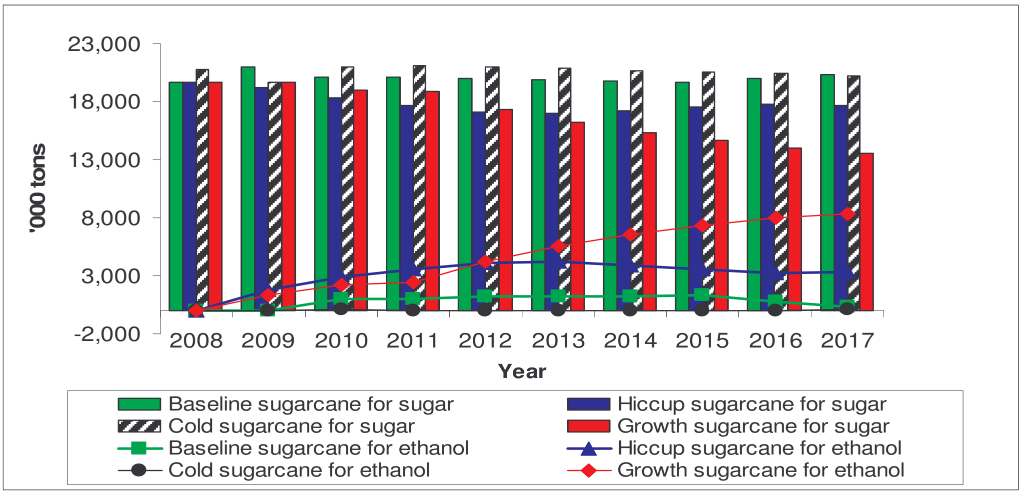

Figure 5. Macro-economic utilisation of sugarcane for sugar and ethanol production (2008 to 2017).

Coastal dryland

Figure 6 presents the results of the Canesim model runs for both the reference variety NCo376 and the hypothetical high fibre variety N-HF002 on a 12-month cutting cycle at the coast, projected for the years 2008 to 2017 (using the weather data from 1998 to 2007). Variety N-HF002 clearly achieves larger yields, while at the same time producing a lower sucrose percentage.

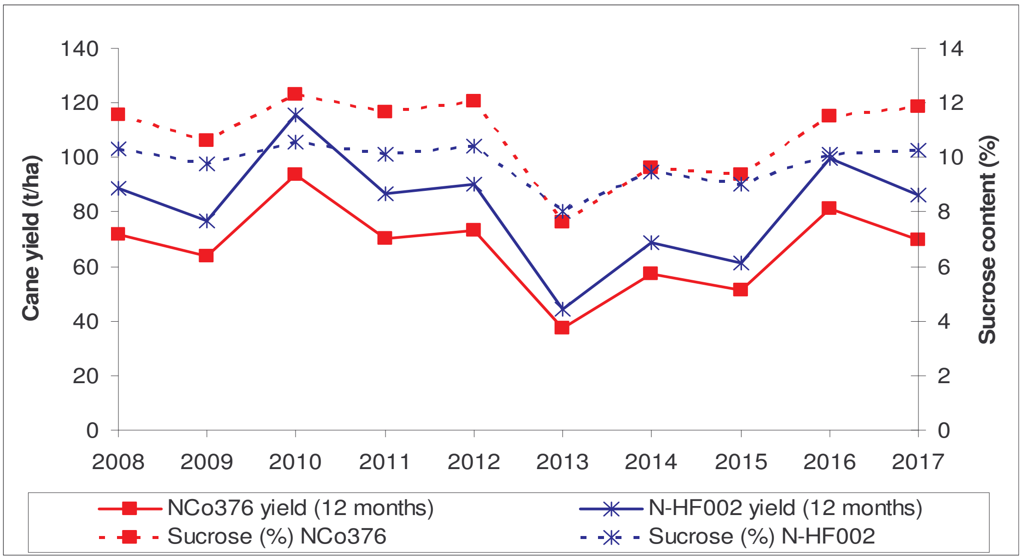

Figure 6. Canesim yields and sucrose % for NCo376 and N-HF002 on a 12-month cutting cycle at the coast.

Figure 7 presents the results for the three (economically) best and worst performing model chain runs in the coastal dryland region, on average over the four scenarios. Performances of the different production/processing strategy combinations vary widely, but the best performing model run is clear. The 15-month N-HF002 crop, processed to produce sugar and ethanol, and to generate electricity, was the best performing strategy in each year from 2008 to 2017, which seems to be due to the fact that income is generated in three sectors, namely agriculture, fuel and electricity. It must be borne in mind that capital investments to realise any of the strategies are not taken into account.

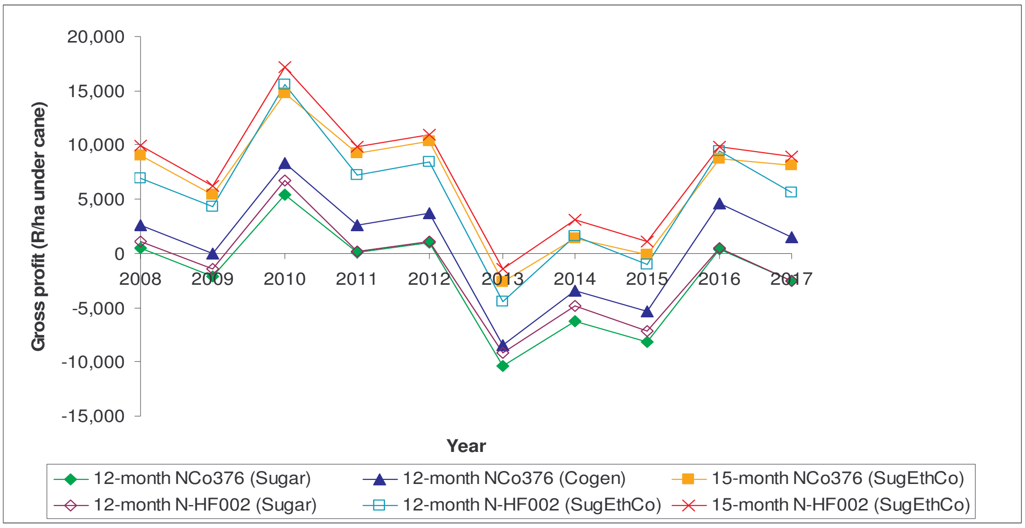

Figure 7. Gross profit margins for the three best and worst performing model runs in the coastal dryland region, averaged over the different scenarios.

Figure 8 presents the gross profit margins for each cultivar and cutting cycle length combination, averaged over the different scenarios and processing strategies. The best performing combination is the N-HF002 crop on a 15-month cutting cycle, with an average gross profit margin of R4218 per hectare under cane over the 10-year period. The worst performing cultivar combination was the 'benchmark' NCo376 on a 12-month cycle, with a 10-year average gross profit margin of R692 per ha under cane.

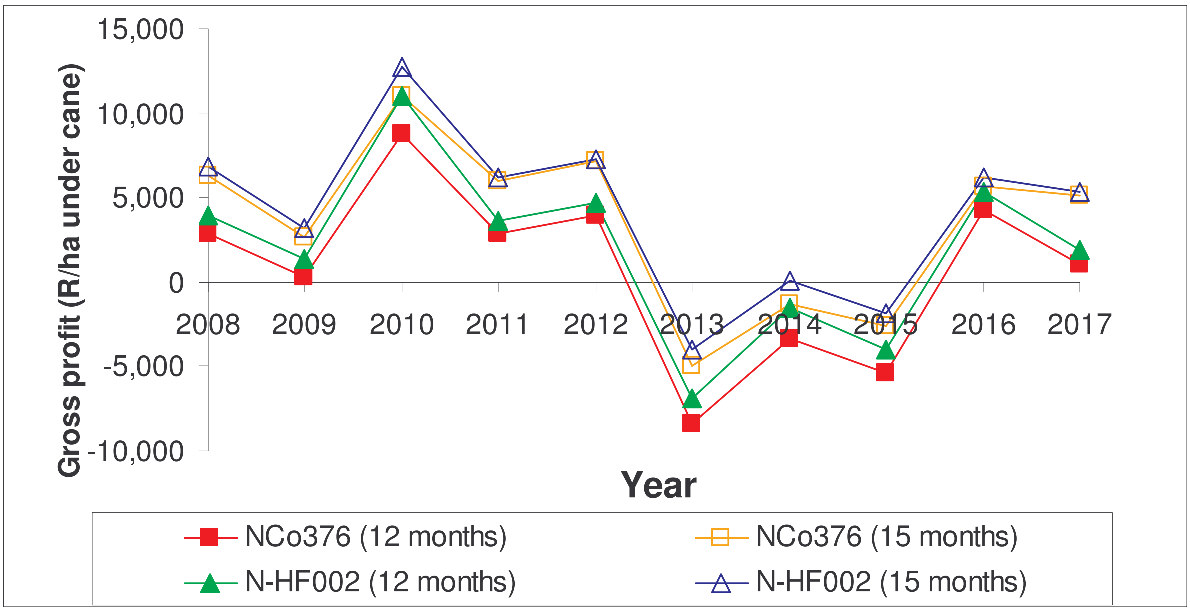

Figure 8. Gross profit margin for each cultivar/cutting cycle combination - coastal region.

In summary, the high fibre variety on a 15 month cycle, with the SugEthCo production processing strategy consistently performs best. Variation between the relative performance of the different production and processing strategies across the different scenarios (not shown) is surprisingly little.

Figure 9 presents the operational expenses for each of the 12-month cultivars at the coast, under both the Baseline and Global Cold scenarios.

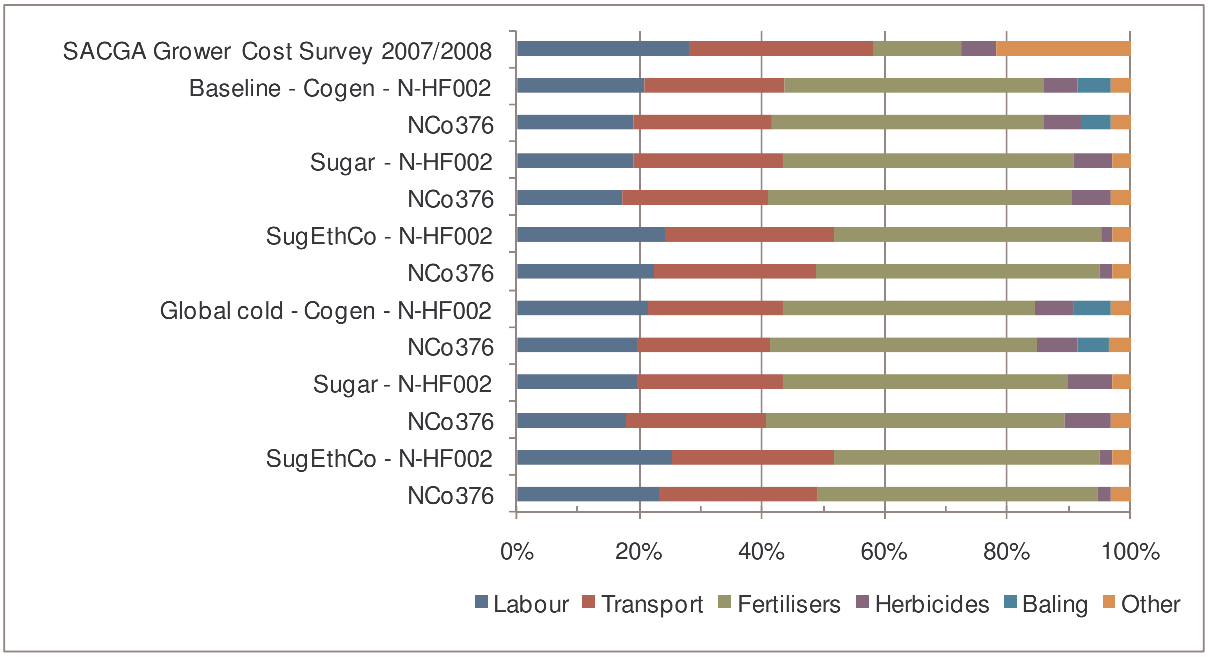

Figure 9. Expenses as % of total operating expenditure (10-year average) in the Coastal region, for each of the 12-month cultivars under the Baseline and Global Cold scenarios.

The percentages given in Figure 9 are the proportion of each cost category of the total operational expenses. Note that the composition of total operational expenditure into its various components is fairly similar across the different model runs. The expenditures differ greatly, however, from those obtained in the SACGA Annual Grower Cost Survey 2007/08, which is also shown in Figure 9. This can be explained mainly by the large differences between input costs in 2007 and 2008.

Midlands

Figure 10 presents the simulated yields for the midlands virtual farm, with a 24-month cutting cycle length. There is a substantial difference between the performances of the two cultivars assessed. The apparent sinus wave pattern to the yields is purely due to weather patterns, as there is no link between consecutive Canesim simulations.

Figure 11 presents the three best and three worst gross margins achieved in the midlands dryland conditions. According to these runs, gross margin losses occur in 2009, 2013, 2014 and 2015, whereas the highest average profit margin is achieved in 2016.

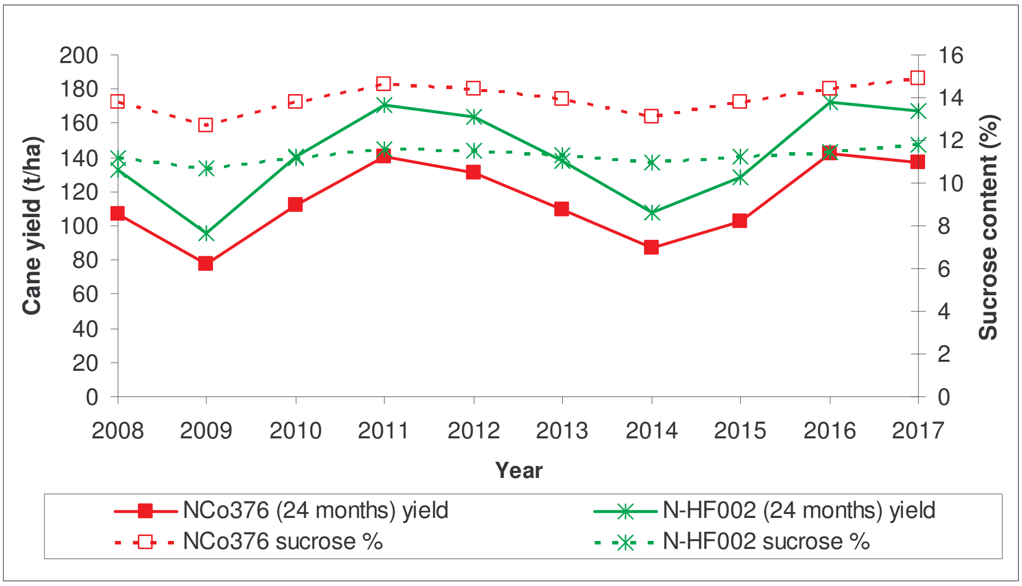

Figure 10. Canesim yields for 24-month crops of NCo376 and N-HF002 in the midlands.

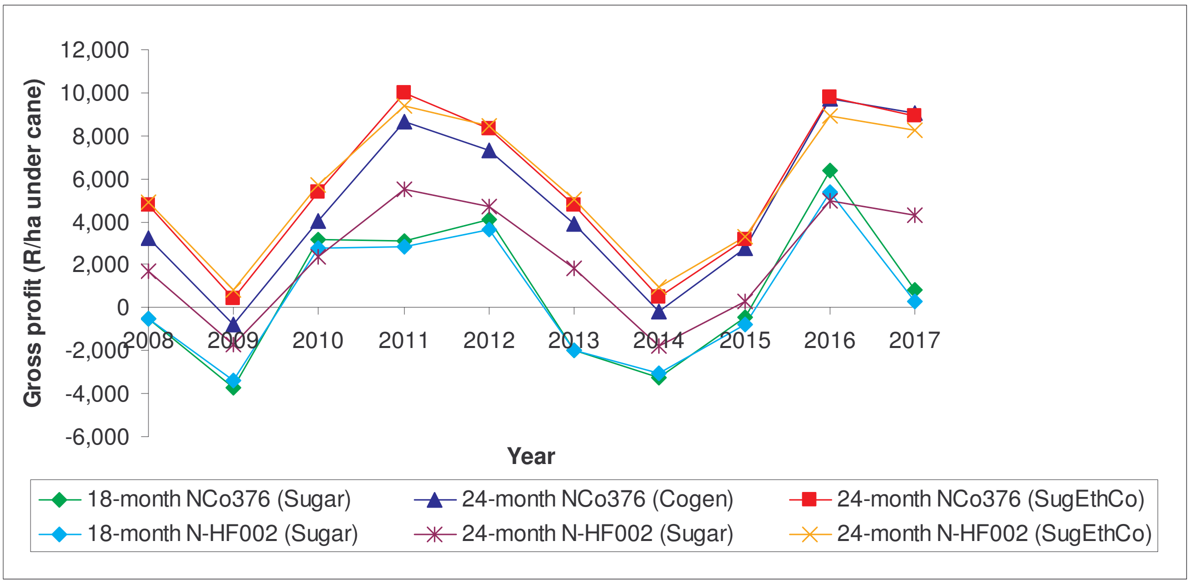

Figure 11. Three best and worst performing gross profit margin averages in the midlands region.

Figure 12 shows the performance of the cultivar/cutting cycle combinations on the midlands farm. The 24-month cutting cycle performs better than the 18-month crops, regardless of the cultivar. The best performing combination is the NCo376 model variety on a 24-month cutting cycle. This result differs from the coastal farm, where the high fibre variety N-HF002 was best suited to the agro-climatic conditions. It seems that the difference in sucrose percentages between NCo376 and N-HF002 is smaller at the coast than in the other regions, while yields obtained still differ significantly.

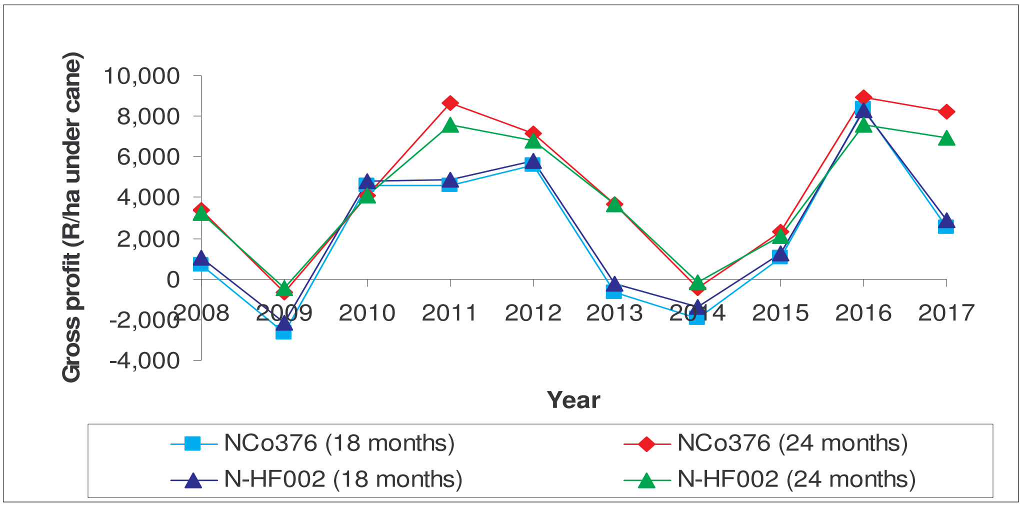

Figure 12. Gross profit margin averages for each cultivar/cutting cycle length combination (midlands).

Northern irrigated region

Figure 13 presents the Canesim simulated yields for the 12-month crops in the northern irrigated region. The 15-month cutting cycle length displays the same trends as in Figure 12.

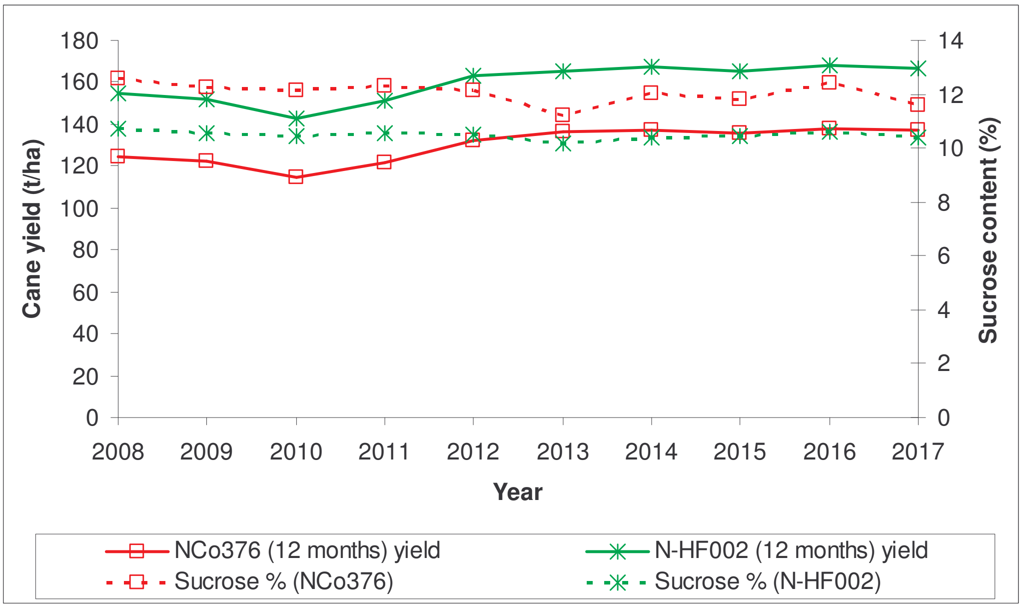

Figure 13. Canesim yields for 12-month crops of NCo376 and N-HF002 in the Northern irrigated region.

It is important to note that, according to the model, lodging was predominant in the northern region. This is only partly accounted for in the model chain (i.e. harvest and transport delays caused by lodging are ignored).

The three best and three worst model run results for the northern irrigated farm are displayed in Figure 14. Results for this farm differ much more than those for the coast and midlands. Profit margins range from just below R5000 to over R20 000 per hectare under sugarcane. Profit levels are much more uniform in this region due to the irrigation practices, which limits the effects of climatic variation on the crops. The best performing production/processing strategy was SugEthCo with NCo376 on a 15 month cycle (note again that lodging is not properly accounted for); whereas Sugar production based on NCo376 on a 12 month cycle performs worst.

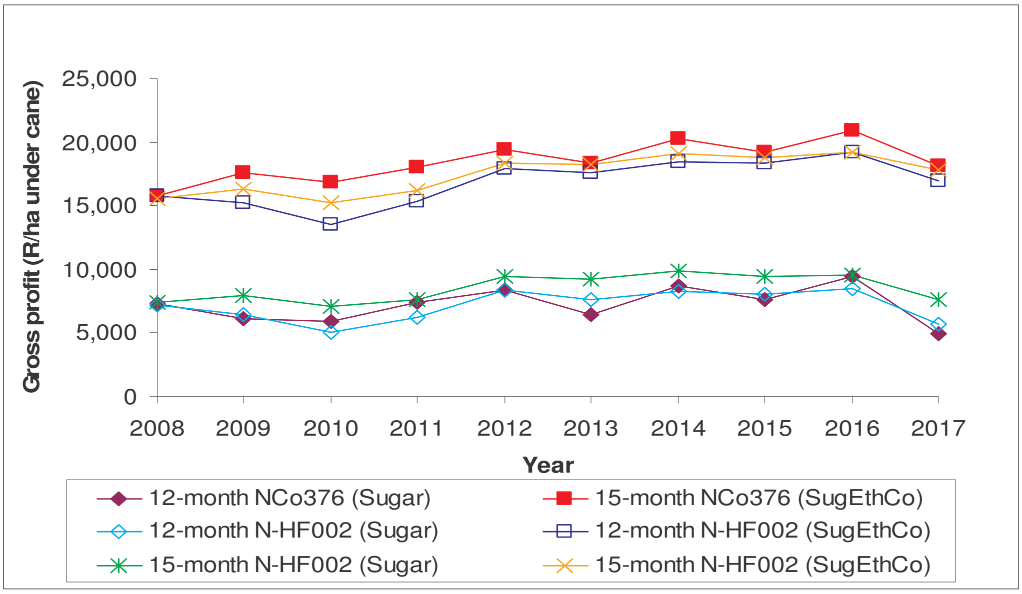

Figure 14. Gross profit margin averages for each model run in the northern irrigated region.

Gross profit margins for each cultivar/cutting cycle length combination averaged across the scenarios for the northern region are given in Figure 15.

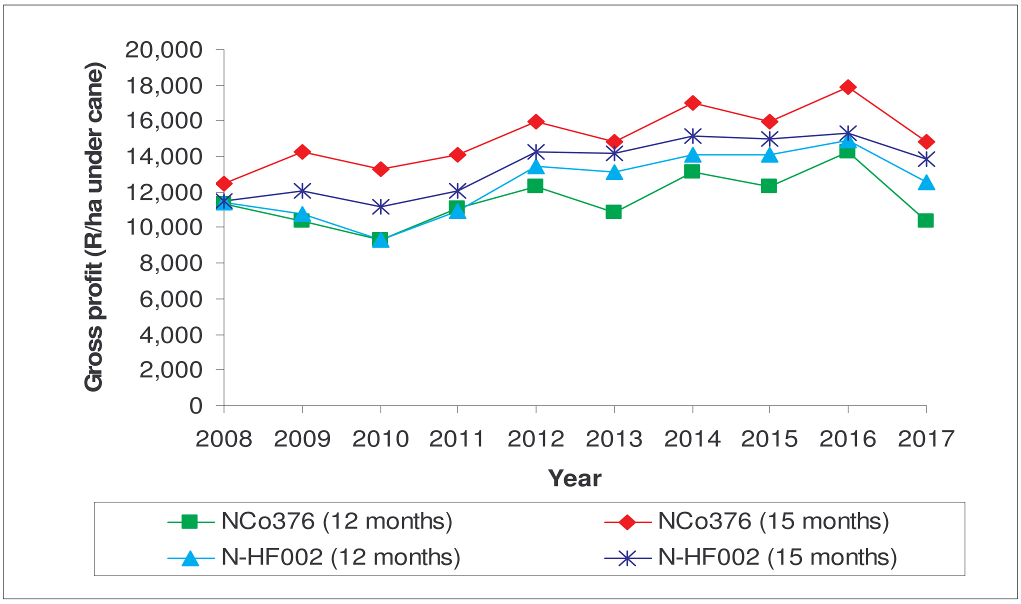

Figure 15. Gross profit margins for each cultivar-cutting cycle length combination (northern region).

A summary of the best performers for each region is given in Table 1. Results for the coastal farm were different than for the midlands and northern regions, with the hypothetical high-fibre variety emerging as the best cultivar choice. This may be due to the dry coastal climate reflected in the weather data for 1998 to 2007. The sucrose producing potential of NCo376 may have been curtailed by the relatively dry coastal climate, leading to less of a difference between the sucrose contents of NCo376 and N-HF002 at the coast. Recall that the model results reflect a potential situation, in which the negative effects of lodging are only partly accounted for, and pests such as *E. saccharina* have no effect at all.

Table 1. Brief summary of best performing model chain runs for all regions.

	Coastal dryland	Midlands dryland	Northern irrigated
Individual run	15-month N-HF002 (SugEthCo)	24-month NCo376 (SugEthCo)	15-month NCo376 (SugEthCo)
Agro-processing strategy	SugEthCo	SugEthCo	SugEthCo
Cutting cycle, cultivar	15-month, N-HF002	24-month, NCo376	15-month, NCo376

Conclusions

The analyses presented demonstrate that the model chain developed allows investigation of the economic performance of different combinations of sugarcane production and processing strategies in different regions and in different futures, in terms of operational expenditures and revenues.

The model chain could play a role in strategic discussions between different industry stakeholders. However, further improvements are required. These include:

- The calibration and population of the BFAP farm-level model's capital component.
- The development of realistic policies, in the model, regarding the expansion/adaptation of the DOP agreement taking account of energy products.
- Using the model chain to create case studies of actual farms, which could improve the calibration of the model chain.
- Automation of the links between the different components of the model chain, which would allow quick assessment of scenarios and strategies, e.g. in front of an audience.

The analyses presented suggest that, for the modelled conditions and assumptions, the SugEthCo strategy combination outperformed all other sugarcane production/processing strategies in terms of gross profit margins, making it the most attractive strategy for sugarcane producers in each of the three production regions. It is surprising to see that the model runs had little variation between the four economic scenarios.

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