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Modelling and monitoring for strategic yield gap diagnosis in the South African sugar belt

M. van den Berg[a,*], A. Singels[a,b,c]

[a] South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe 4300, South Africa
[b] Department of Plant Production, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa
[c] School of Agriculture, Earth and Environmental Sciences, University of Kwazulu-Natal, Private Bag X01, Scottsville 3209, South Africa

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ABSTRACT

This paper revisits the diagnostic use of industry-wide sugarcane (*Saccharum* sp. hybrid) modelling and monitoring in South Africa for gaining a better understanding of production trends and the strategies required to address temporal and spatial yield variation.

Such reviews have been conducted annually since 2008, by comparing the ratio of actual to simulated (potential) average sugarcane yields for 14 sugar mills with that of preceding seasons (since 1980). Actual yields are determined from total amount of cane crushed at the mill and the estimated area harvested as determined from mill records and grower surveys. Potential yields are determined by using the Canesim model with daily weather data for 48 homogenous agro-climatic zones. Widening yield gaps in some key producing regions and significant differences between regions indicated the need to investigate the impact of non-climatic factors such as pests, diseases, and sub-optimal agronomic management, even though this analysis is still qualitative and incomplete, and not fully objective. Factors that were highlighted as likely causes of suboptimal production were damaging effect of a new pest (sugarcane thrips), inadequate nutrition and inadequate replanting, apparently linked to unfavourable socio-economic conditions; even more so for small-scale growers than for large-scale growers. In addition to providing a service that is valued by the industry, the annual reviews have contributed to strengthening co-operation between researchers of distinct disciplines as well as between researchers and canegrowers, and to help identify priorities for further research. The quality of the analysis could be further improved by more accurate and timely estimates of the area harvested, improved resolution of yield data and extended surveys of pests, diseases and other yield limiting or reducing factors.

1. Introduction

In South Africa, sugarcane is of great agricultural and economic importance and a major provider of jobs in rural areas. It is the second largest South African field crop, by gross value surpassed only by maize (SASA, 2012). Being introduced more than 150 years ago, today, the South African sugar industry is considered a mature industry. It is well organised with research, extension and other services provided by the S.A. Sugar Association (SASA) and funded by growers and millers. Good quality production data at mill level are available, while many large-scale growers keep accurate production records.

In 2007, industry-wide concern about poor performance in the 2006/07 milling season triggered a request by the SASA CEO to the South African Sugarcane Research Institute (SASRI, a division of SASA), for a review of sugarcane production. The objective of this first review was to explain the discrepancy between the production realised and the much higher expectations. Could this be due to pest outbreaks? or to poor weather conditions affecting yields or harvest operations?; or was it part of a declining trend; and if so, what would be its cause? Obviously, different answers to these questions would call for different types of industry action. The review was conducted by comparing historic yield records with simulated potential yields, alongside additional data such as on the incidence of pests and diseases and extreme weather events and other anomalies during the harvest period. It was noted then that "*available information to do this is largely informal, incomplete, scattered around the industry and of varying accuracy*". The results of this first assessment were published and presented internally (van den Berg and Singels, 2007). The authors were then requested to prepare similar overviews annually to be presented at the conferences

* Corresponding author. Present address: PBL Netherlands Environmental Assessment Agency, PO Box 303, 3720 AH Bilthoven, The Netherlands.
Tel.: +31 30 274 7064.
E-mail address: maurits.vandenberg@pbl.nl (M. van den Berg).

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of the SA Sugarcane Technologists' Association (SASTA) as agronomic counterpart to the industry reviews, published through the same vehicle since 1926 (e.g. Smith et al., 2011).

While the use of crop models as a tool to analyse temporal variation of yield gaps appears to be straightforward, relatively few examples of this type of application were found in literature. Matthews and Stephens (2002) mention only one case, for a region in Mexico (Bell and Fischer, 1994) where the CERES-wheat model was used to demonstrate a narrowing gap over a twelve year period between farmers' yields and modelled potential yields of a reference variety, which more than compensated for worsening climatic conditions over the same period. The most comprehensive study found, however, was that of Brisson et al. (2010) who compared wheat yield statistics from France with yields from variety trials as well as with modelled yields (by STICS and PANORAMIX) and agronomic data to explain why yields are stagnating over the last two decades. They concluded that genetic improvements have been counteracted by the negative effects of climate change in addition to other factors, such as possibly a decrease of rotation of wheat with legumes. For sugarcane, Marin and Carvalho (2012) compared data from official yield statistics with water limited yield potentials calculated with a model derived from FAO 33 (Doorenbos and Kassam, 1979; Jensen, 1968) and found that the yield gap in São Paulo State (Brazil) fluctuated between 51 and 58% of the potential between 1990/'91 and 2001/'02 followed by a steady decrease, to 42% by 2005/'06; a trend which was attributed to the ethanol boom and improved sugar prices forming an incentive for better management. Cheeroo-Nayamuth et al. (2011) compared simulated sugarcane yields using an adapted DSSAT v3.5 sugarcane model with recorded yields in a region of Mauritius, and found that actual yields were stagnating in spite of a positive trend in potential yields. This was attributed to insufficiency of irrigation and other management practices to meet the higher demands of the increasing potential.

All these cases were once-off studies, whose main focus was the analysis of trends, rather than operational applications to diagnose each past season in the context of historic performance, as is the case in the South African reviews.

The objective of this paper is to review the use of industry-wide sugarcane modelling and monitoring in South Africa (S.A.) to diagnose sugarcane yield gaps. The evolution of the methodology and the main results of annual reviews of S.A. sugarcane production are described and their impact on production and research strategies are looked into. Strengths, and opportunities for improvements are explored.

2. Context of the study: sugarcane production in South Africa

South Africa produced 16 million tonnes of sugarcane from approximately 380,000 ha under cultivation in 2011 (SASA, 2012). Sugarcane is grown by approximately 29,000 growers of which 95% are small-scale growers (SSGs) producing 8% of the crop. There are 1550 large-scale growers (LSGs) that produce 85% of the crop, while the remaining 7% of the crop is produced by milling company sugar estates. Small-scale growers are classified as such when they produce less than about 2000 tonnes of cane for three years (S.A. Cane growers, Pers. commun.). Their average area under cane is about 4 ha and they are spread throughout the industry (Armitage et al., 2009).

The cane is milled by 14 mills situated in five distinct production regions (Fig. 1). The South coast and North coast regions have a warm (annual heat units of between 3500 and 4000 °C, base temperature of 10 °C, according to Inman-Bamber, 1995), humid climate with about 1000 mm of annual rainfall, and predominantly annually harvested rainfed sugarcane production. Rainfall declines and temperature increases in a northerly direction, and irrigation is more prevalent in Zululand. Annually harvested sugarcane is fully irrigated in hot (4400 °C) and dry (mean annual precipitation (MAP) of about 650–600 mm) Northern Kwazulu-Natal and Mpumalanga. At high altitudes in the Midlands region of Kwazulu-Natal rainfed sugarcane is harvested at 18–24 months of age due to the cool (2500–3000 °C) and relatively dry (MAP of about 850 mm) climate.

3. Description of the approach, models and data used

The reviews were performed at mill-area level, aggregated to the five agro-climatic regions indicated in Fig. 1.

The general approach of the reviews consists of the following steps (van den Berg et al., 2008):

1) Compare historic yield records (since 1988) with simulated potential yields over the same period to detect long term trends in yields and yield gaps (i.e. potential-actual yields).
2) Compare changes in actual yields over the last two years with changes in simulated yields, to describe short term yield variations.
3) Explain the results of (1) and (2) with the use of other information, such as on the incidence of pests and diseases, extreme weather events, crop nutrient status and the socio-economics of sugarcane production.

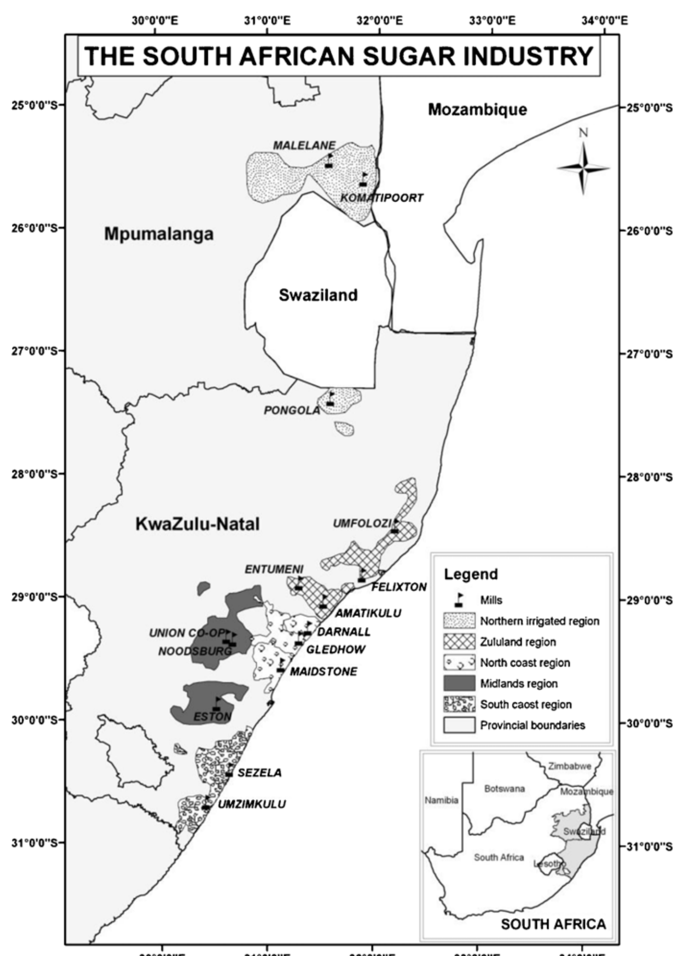

Fig. 1. Map of the S.A. sugar industry showing mill supply areas and agro-climatic regions.

4) Make strategic recommendations on sugarcane management, research and extension priorities and suggestions to improve future reviews.

Information sources used for the reviews varied as the reviews evolved. The principle ones are:

- *Industry records of sugarcane supplies and quality at mill area level* were extracted from the database of the industry's Cane Testing Service (CTS). ERC % cane (estimated recoverable crystal, expressed as a percentage of fresh sugarcane stalk mass) was used as the indicator for cane quality. Specific data on small-scale grower (SSG) production were obtained from the Sugar Industry Administration Board.
- *Records of areas under cane and areas harvested* as captured in the database of the SASA Annual Survey of Cane Production based on mandatory information supplied by all LSGs—at the end of each season.
- *Potential yields simulated by the Canesim crop forecasting system* (Bezuidenhout and Singels, 2007a,b). This system makes use of the Canesim sugarcane model and daily weather data from 33 meteorological stations and between 66 (in 1988) and 75 (since 2010) rainfall stations in 48 homogenous climate zones to simulate the growth and yield of 1431 hypothetical crops for each season (159 unique production scenarios harvested in each of the nine months of the typical milling season: $159 \times 9 = 1431$). For the purpose of this study, the crop forecasting system was run in back-casting mode, using historical weather data only to estimate potential yields at regional and industry level. Potential yields correspond to the conditions for which the model was calibrated, i.e. experiment sites with fertiliser management according to SASRI recommendations, careful control of pests and diseases, negligible harvest losses, cutting cycles according to regional averages, and for one reference variety (NCo376).

The Canesim model was preferred over the more sophisticated DSSAT-Canegro model (see Singels et al., 2008) because (i) it was already configured for operational crop forecasting in South Africa and required little effort to implement in this study, and (ii) the more detailed input data required by Canegro are not available at the scale of application used in this study.

Canesim is a daily time step, point-based simulation model. For input, it requires soil available water holding capacity and daily temperature, rainfall and atmospheric evaporative demand. The model calculates canopy cover from thermal time and relative soil water content, and evapotranspiration following the dual crop coefficient approach. Cane yield is calculated as a non-linear function of transpiration. The water balance of Canesim is described by Singels et al. (1998), canopy development is described by Singels and Donaldson (2000) and the yield calculation by Singels et al. (1999). These publications also report on the validation of various aspects of the model against observed data.

Bezuidenhout and Singels (2007b) reported on the accuracy of Canesim for estimating mill average yields using root mean square error (RMSE) expressed as percentage of the long term mean observed yield. It should be noted that the mean bias in simulated yields were removed before calculating RMSE, so that it reflects the ability of the model to capture variation in yields between years or between mill areas but not the ability to predict absolute yield levels. They found an industry level RMSE of 6.6%, and an average RMSE at mill level of 11.1%. Mills in rainfed areas tend to have lower RMSE (7.8–11.9%) than mills in the irrigated areas (12.1–15.8%). This was ascribed to difficulty in representing irrigation practices in the model, especially during periods of legally imposed water use restrictions.

The quality of input data for the Canesim crop forecasting system has since improved, and the mill average RMSE calculated in 2010 (unpublished) was 11.0%, with a range of 7.6–14.9%. The industry level RMSE has improved to 4.5%. Area weighted average RMSEs for the production regions were 5.5, 8.7, 10.4, 8.9 and 9.1% for the Northern Irrigated, Zululand, Midlands, North Coast and South Coast regions respectively.

This information suggest that, generally, the model is well suited for estimating weather driven variation in regional average yields, and that it performs better for rainfed regions than for irrigated regions.

- *Weather data*. Daily rainfall, radiation and temperature data from the SASRI meteorological database, aggregated to the mill area level.
- *Soil information*. The Canesim model requires plant available soil water holding capacity (PASWC) as soil input. One value per homogenous climate zone was used (see Bezuidenhout and Singels, 2007a for details), which was based on information from regional extension specialists regarding the dominant soil type in the given zone. Soil variation within the main production regions has thus been taken into account in a limited way. It is believed that this would not compromise the study significantly because inter-seasonal variation in mill average yields is analysed and soil input data remained mostly constant from one season to another.
- *Database of Local Pest, Disease and Variety Control Committee* (LPD&VCC) of annual field survey results from across the South African sugar industry with information on current and long-term infestation and damage levels (Way, 2007; Way and Goebel, 2007). For the industry reviews, only the most common and/or damaging pests and diseases were investigated: the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae), the fungal disease smut (*Ustilago scitaminea*) and sugarcane thrips (*Fulmekiola serrata* (Kobus) (Thysanoptera: Thripidae)). Surveys for *E. saccharina* are conducted in around 15,000 fields per year; and smut in around 2300 fields per year. An industry-wide thrips survey was conducted in 2005/06 (Way et al., 2006). Since then, thrips has been sampled each month in 18 fields at Umfolozi.
- *Trends on the economics of sugarcane production* were derived from the annual LSG cane production cost surveys, conducted by the South African Cane Growers' Association (CANEGROWERS) since 1997/98. Per year, around 280 large scale growers from across the industry participate. More information about these surveys can be found at http://www.sacanegrowers.co.za/facts-figures/surveys/.
- *Data on crop nutrient status* were obtained from records on leaf samples submitted by growers, processed by SASRI's Fertilizer Advisory Service.
- *Questionnaires* were sent to some 20 regional experts in the mill areas, mostly Extension Specialists. In the questionnaires, the respondents were asked to characterise the preceding harvest season, in terms of carry-over cane, the quality level of sugarcane husbandry, trends in farm management practices, pest and disease incidence, burning and harvest-to-crush delays, and the incidence of extreme events such as floods, hailstorms and runaway fires.

4. Results obtained and how these were interpreted

Evolution of sugarcane production in South Africa between 1990 and 2010 is shown in Fig. 2; in terms of area used and cane produced by large-scale growers – including sugar company estates – (LSG, Fig. 2A) and small-scale growers (SSG, Fig. 2B). The area cropped with sugarcane by LSG remained fairly stable over this period. The volume of LSG sugarcane produced shows

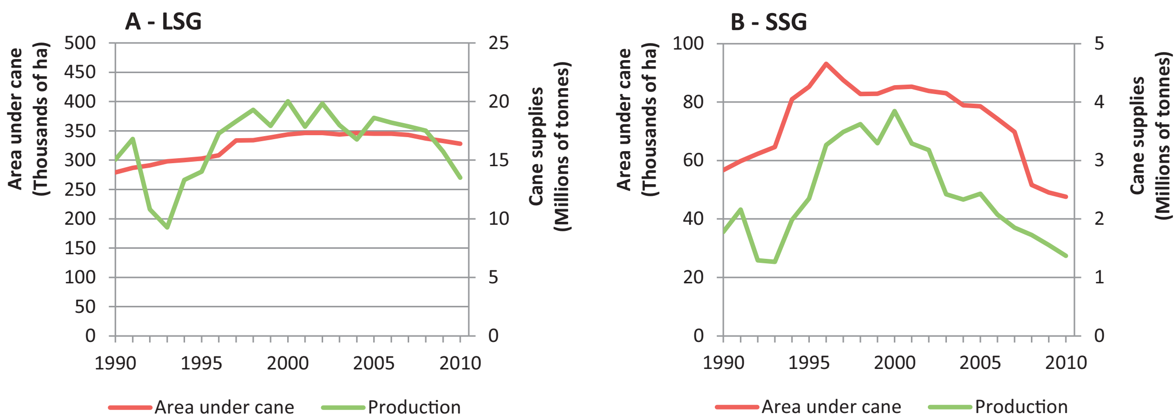

Fig. 2. Total area under cane and cane supplies, 1990–2010. (A) Large-scale growers (LSG); (B) small-scale growers (SSG). Note that the scales of the axes are different but the proportion between the left and right axis in each graph is the same.

much stronger variation; with a prominent dip from 1992 to 1993, followed by recovery and oscillation around a plateau, but with an apparent tendency to decline after around 2003. The area cropped as well as the volume produced by SSG strongly increased until the late 1990s (mostly in the irrigated North), followed by a general decrease (mostly in the coastal areas).

Actual and simulated yields in the main production regions are compared in Fig. 3. The overall ratio between actual and simulated yields is 0.77 for LSG and 0.47 for SSG. In most regions, LSG actual yields follow the simulated yields fairly well, suggesting good model performance and an overriding influence of variations in climate and weather conditions on yields. For example, the 1992–1993 dip and the period of recovery thereafter, as well as the decrease in yield from 2009 to 2010 in most rainfed regions are well-reflected by the Canesim simulations. Interestingly, however, in the rainfed regions, yield dips associated with dry years tend to be more pronounced in the Canesim simulation results than in the actual yield records, resulting in relatively small yield gaps. This is the case, for example in 1992, 1993, 1994 and again in 2003 and 2004 (see North Coast, Midlands, and South Coast in Fig. 3). This narrowing yield gap in dry years could be associated with two possible causes: (i) We know from experience that the system has capacity to buffer impacts on production, which is not always accounted for in the simulations. For example, in dry years, more cane area is harvested, while in good years less cane is harvested because of limitations in harvesting, transport and milling capacity. Such effects are not always correctly reflected in harvest statistics, resulting in apparently less pronounced changes in yield from one season to another. (ii) In dry years, water availability becomes the overriding growth-limiting factor, to the extent that factors such as nutrients, are no longer limiting to sustain the lower water limited yield potential. The fact that nutrient availability is implicitly assumed to be always sufficient in the model, results in relatively stronger effect of drought on simulated yields than on actual yields. This is the same effect as noted by Twomlow et al. (2008) for maize simulations under conditions of different levels of nitrogen.

It is further noted that in the Northern Irrigated region, the trend in actual LSG yields appears to be much flatter than the simulated yields, probably because growers have more flexibility in their water management during times of water scarcity than assumed by the model (Bezuidenhout and Singels, 2007b).

A closer look at the rain-fed regions suggests a widening yield gap for LSG between 2004 and 2008. For SSG, widening of the yield gap started already around 2000, but was strongly corrected in some regions, such as the North coast and Midlands, in 2009.

Trends in Eldana sugarcane stalk borer infestation are shown in Fig. 4. All regions, except the Midlands, present a declining trend in incidence rates until 2009/10, followed by a sharp increase in the rain fed regions. Note that the latter would only affect yields in 2011, which are not included in Fig. 3. The long term decrease is ascribed to increasing adoption of control measures (Leslie et al., 2006; Leslie, 2009), while the recent sharp increase is ascribed to the severe drought conditions that occurred during 2010. Drought is known to exacerbate the damage caused by the insect (Atkinson and Nuss, 1989). A very concerning trend is the gradual increase in borer infestation and damage in the Midlands region. The Midlands region has a cool climate, traditionally considered unsuitable for Eldana, that has warmed significantly in the last 50 years, and this could be the primary cause of the increase. Clearly, these results indicate that recent yield gap trends since 2000 cannot be attributed to Eldana incidence which has shown very dfferent trends in most regions, except the Midlands, where, however, eldana incidence has been still too low to explain significant yield variation.

Trends in smut infestation are shown in Fig. 5. Most conspicuous are the increase in smut incidence in the Northern irrigated region from 2004/05; and the decrease in Zululand and in the Northern irrigated regions since 2007/08. Note that the high Zululand values are mainly due to surveys targeting fields with smut susceptible varieties. A (random) survey, as conducted in the other regions, would produce lower values. Again, these results indicate that yield gap trends since 2000 cannot be ascribed to smut incidence. In any case, while smut would have had a substantial economic impact on a number of individual growers (particularly in Mpumalanga), impacts on yield at regional level is likely to have been too low to explain significant yield variation. At the levels of infestations recorded, production losses of around 0.25% can be expected for every 1% stools infected in cane subjected to good growing conditions (Bailey, 1979, 1983; de Lange and McGugan, 1989). Moreover, for precautionary reasons, fields with a very high level of infestation (set in most regions at 3 or 5% stools infected) are subject to mandatory plough-out. The sugarcane in such fields is destructed in situ and not included in the yield statistics.

Fig. 6 shows the trends in LSG sugarcane farming economics at the S.A. industry level. These data suggest that sugarcane farming has not been profitable since 2002/'03. van den Berg et al. (2009) showed that the situation would have been worst for rainfed producers who harvest at a 12 month cycle, i.e. in the coastal production regions and Zululand. The economics would be even more unfavourable for small-scale growers, who are faced with additional challenges of raising costs or lowering returns, such as destruction of sugarcane by cattle and goats, high incidence of runaway fires, poor logistics, shortage of labour, theft of sugarcane

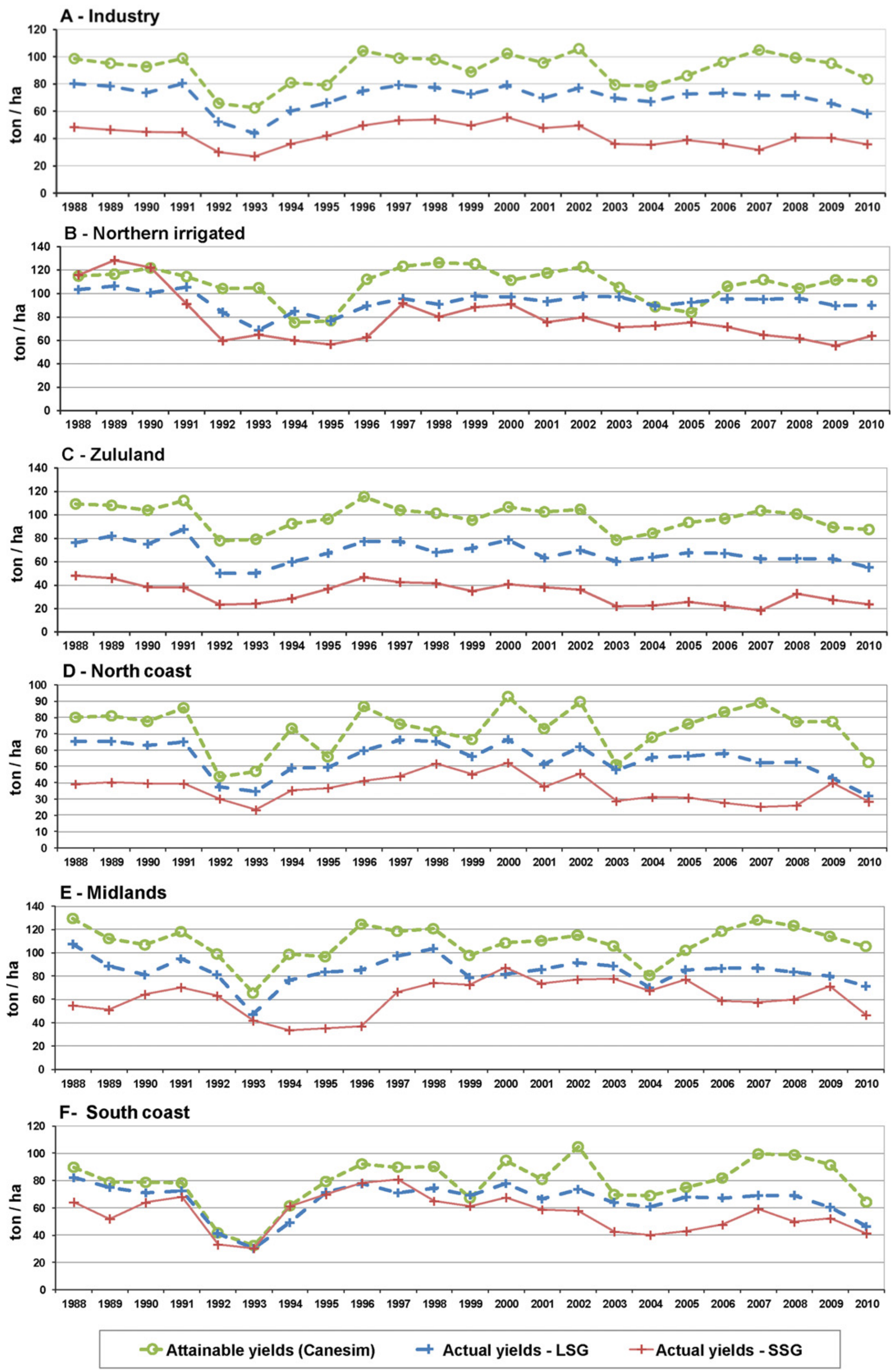

Fig. 3. Yield trends of large-scale (LSG) and small-scale growers (SSG) in South Africa's sugarcane production regions. Potential yields calculated using the Canesim model; actual yields calculated from industry production and area data.

for resale in urban areas, and high input and transport costs due to unfavourable economies of scale and poor infrastructure (Mahlangu and Lewis, 2008; Murray, 2010). This would not only affect yields of SSG: van den Berg et al. (2009) suggested that, what appeared to be extremely low yields in the Zululand and North Coast areas could in reality be unregistered land abandonment, which would be even more difficult to reverse. A large proportion of SSGs is relatively old, and they mostly do not have a title of the land (Eweg et al., 2009). Corrections to SSG area statistics were made in following years (Fig. 2B), which is reflected by an apparently

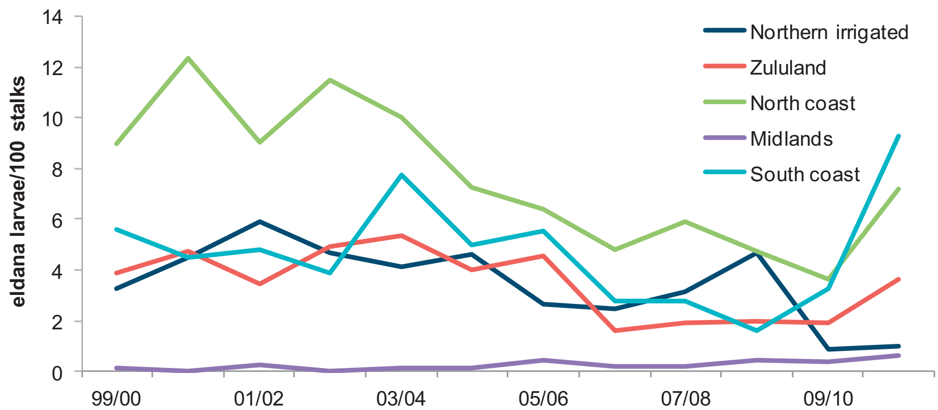

Fig. 4. Incidence of the Eldana sugarcane stalk borer, expressed as the number of larvae per 100 stalks examined. NB Regional averages were calculated as simple averages of the survey areas per region.
Data provided by M. Way, SASRI, 2012.

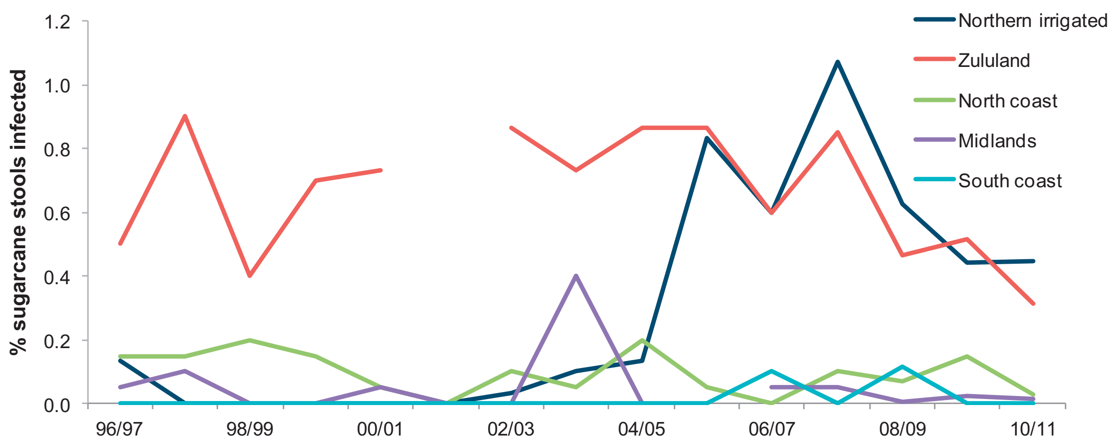

Fig. 5. Incidence of smut. *Note*: (a) Regional averages were calculated as simple averages of the survey areas per region; (b) in the Zululand region, fields with smut susceptible varieties are targeted for surveys; whereas fields are randomly selected in the other regions.
Data provided by S. McFarlane, SASRI, 2012.

narrowing gap between SSG and LSG yields in some regions (Fig. 3).

The review by Singels et al. (2011) highlighted the extent of crop nutritional deficiencies throughout the industry with about 50% of leaf samples indicating nitrogen deficiency in the 2009 and 2010 growing seasons. This could be a major cause of yield loss but it was not possible to investigate time and spatial trends due to inconsistent and sparse sampling.

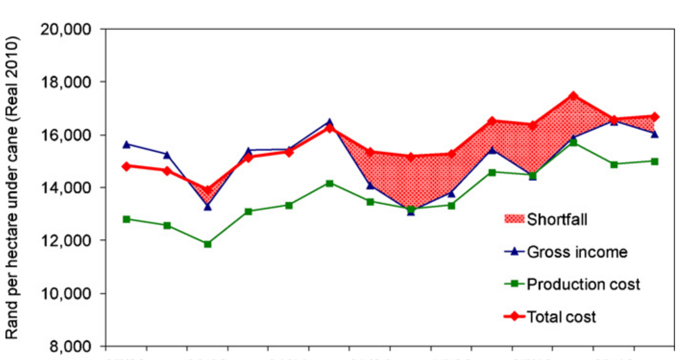

Fig. 6. The economics of LSG sugarcane, 1997–2011.
Source: Singels et al. (2011).

While no systematic industry-wide data are available to provide scientific evidence if, and to what extent, unfavourable economics would indeed have affected 'on the ground' operational management or long-term investments, additional information obtained in the surveys, and notably the personal engagements with regional extension experts, suggest that this may indeed have been significant; especially regarding delays in replanting, crop nutrition and overall dedication to farming. Sugarcane thrips is another perceived threat to sugarcane production, which incidence seems to have roughly followed the yield gap trends since 2004, except for the Midlands region, where thrips incidence has been minor. However, this information is based on only one monitoring site, complemented by expert judgements based on unstructured personal observations. Other factors that came to light with these engagements mainly concern local and/or incidental factors, which often helped to explain discrepancies at the mill level between modelled and recorded yields, between consecutive years or between adjacent mills. Such factors included, for example, damage due to floods, hail storms and frost; amounts of carry-over cane, and poorly recorded batches of cane delivered to another mill than their home mill.

5. Discussion

The results presented above demonstrate that the agronomic reviews helped to gain a better understanding of S.A. sugarcane production trends and industry functioning. The comparison of model results with industry production records, plus the complementary information described, help to separate important weather effects from other effects, and to identify trends in yield gap of concern, as well as to indicate plausible important non-weather related effects affecting agronomic performance in different mill areas. The latter, however, is still qualitative and incomplete, and not fully objective.

As a consequence, the insights provided by the reviews helped to draw attention to important factors that are likely to have affected industry performance. For example:

- The 2010 review (Singels et al., 2010) speculated that poor socio-economic conditions could cause suboptimal level of production inputs. The prevalence of sugarcane thrips was also highlighted as a possible cause of yield loss. In the 2009 review (van den Berg et al., 2009) these factors were also identified and in addition the declining yield for small-scale growers were highlighted as a cause for concern.
- The 2011 review (Singels et al., 2011) highlighted the incidence of the Eldana stalk borer) and brown rust in specific regions and widespread and long-term nutritional deficiencies as causes for concern. It also recommended that specific attention be paid to the rehabilitation of drought affected areas.

Most of these issues are currently being addressed by the industry. However, the weight that can be attributed to the reviews to prioritise these issues, is not clear.

Strengths of the approach are that it is systematic, that it provides a good basis for discussion between researchers, growers and other industry stakeholders, and that it is relatively cheap, as it makes use of data that are already available. However, there is also considerable room to improve the quality and usefulness of the yield gap diagnoses. For example, by:

- More accurate and timely estimates of areas harvested. Currently, reliable data only become available after two years. As a consequence, preliminary estimates for the most recent years are based on an assumption of no change from the last season with available data.
- Improved resolution of yield data. At present, reliable production data that cover the industry are only available at mill level. In some cases good quality production data are available at field level but this requires accurate area estimates at the same level. This is not available for most mill supply areas. Early attempts to establish, maintain and use a field record system for growers (see Culverwell, 1984; Hellmann, 1988, 1993) have not been successful. The Australian sugar industry seems to have up-to-date and accurate field production data for many mill supply areas that have been used for research and yield diagnosis purposes (see e.g. Inman-Bamber et al., 1998; Higgins et al., 1999; Lawes et al., 2001; Lawes and Lawn, 2005).
- Developing a standard format for reporting quantitative information on production conditions from the different regions, extending surveys of pests and diseases to include sugarcane thrips and by encouraging a uniform methodology for these surveys.
- More reliable data on fertilizer use and on soil health and nutritional status, which would shed more light on the reasons for large yield gaps.
- More reliable data on water use, which would improve the accuracy of potential yield estimates in the irrigated areas.

We also believe that the reviews have contributed to the quality of SASRI research, by stimulating collaboration between researchers of distinct disciplines, as well as collaboration between sugarcane researchers and other industry stakeholders. Growers exposed to the annual presentations of the reviews appear to be more supportive for SASRI research. Furthermore, working with industry records and yield gaps at mill level help to see the bigger picture of important areas where further research is needed. For example:

- Effects of stalk death on subsequent ratoon growth. This was highlighted as a likely contributing factor to low 2011 yields but due to lack of knowledge it was impossible to quantitatively predict its impact on yields.
- Effect of pests and diseases (e.g. thrips, rust) on yield, as highlighted in the 2008 review. Two research projects on this topic have since been initiated at SASRI.

Again, these statements are somewhat speculative. In reality it is a combination of factors that determine the selection of research topics. The agronomic reviews are believed to have contributed but it is difficult to indicate exactly by how much.

6. Conclusions

- The diagnostic use of industry-wide sugarcane modelling and monitoring in South Africa contributes to a better understanding of production trends, by separating weather effects from other effects, and by indicating important non-weather related effects affecting agronomic performance.
- In addition to their value to the industry, the reviews contribute to strengthening co-operation between researchers of distinct disciplines as well as between researchers and other industry stakeholders and to identify priorities for further research.
- The quality of the analyses could be further improved by more accurate and timely estimates of areas harvested, improved resolution of yield data and extended surveys of pests, diseases and other yield limiting or reducing factors.
- The results of the reviews indicate that, while varying weather conditions explain most of the differences in sugarcane production between consecutive years, they do not explain the gradual trend of yield decline of the last decade or more.
- Poor financial returns on sugarcane production could well have been the main underlying reason for the trend of declining yields and, in the case of SSG, of land abandonment.

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