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**ANALYSIS OF FIELD AND FACTORY OPTIONS FOR
EFFICIENT GATHERING AND UTILISATION OF TRASH
FROM GREEN CANE HARVESTING**

by

D R Ridge and P A Hobson*

**Sugar Research Institute, Mackay*

SD00011

Principal Investigator:

Mr D R Ridge
Principal Research Officer
BSES
PO Box 651
BUNDABERG QLD 4670
Phone: (07) 41593228
Fax: (07) 41593383

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SUMMARY

The SRDC, BSES and SRI desktop project to evaluate options for utilisation of extraneous matter in the cane supply was completed in June 1998. The main aims of the project were to determine field, factory and industry costs and returns for different trash handling options; and to assess the impact of a mill cane cleaning plant and co-generation of power on these costs and returns.

A BSES developed harvest-transport spreadsheet model was modified by SRI in conjunction with BSES to incorporate costs and returns to growers, millers and the industry as impacted by varying levels of trash in the cane supply, varying cane loss and varying harvester pour rate. Recent BSES harvester trial data were incorporated into the model in the form of regression equations relating trash levels and cane losses with harvester pour rate and extractor speed setting. Data from Tully Mill productivity records were used to compute the impact of additional trash on transport capacity and establish appropriate levels of tops and dirt in the cane supply. Field sector costs and returns were considered to be affected by trash levels (through ccs effects), cane loss, harvesting costs and the agronomic benefits of green cane trash blanketing. Factory costs and returns were affected by any additional capital costs for crushing and recovery of sugar, transport costs and the value of recovered sugar and molasses. Both trash levels and cane loss during harvesting impact on all these components. In addition, the cost of installation and running of a cleaning plant and costs and returns with co-generation of power in the mill were incorporated in the model.

A range of scenarios was assessed using the model including the impact of varying cane loss and trash levels on field sector, factory, and industry returns; how these can be optimised by adopting best management strategies using the current harvesting equipment; potential returns from improvements in different aspects of harvester technology (reducing cane loss and EM levels and increasing pour rates); the benefit from cleaning at the mill; and returns from importing various levels of trash into mills for co-generation of power. The latter case included cleaning at the mill and the assessment of different efficiencies in steam generation (including a gasification plant) were assessed. As a side issue the possibility of baling trash and tops in the field was evaluated.

Some of the major findings include:

- Increased trash in the cane supply (achieved by an increase in harvester pour rate rather than a reduction in extractor fan speed) generally reduces industry returns, with the factory receiving a small benefit and the field sector losing income due to lower ccs. The costs apportioned to the factory for processing additional trash were found to be critical to the economic outcome.
- Returns to the industry are maximised where both trash and cane loss are minimised by operating harvesters at low pour rates and with low extractor speed settings. While this strategy has the highest economic benefit there are practical implications for the operation of harvesters. A more acceptable option of moderate extractor

speeds (around 1 000 rpm) and moderate pour rates (around 90 t/h) will still give significant industry benefits.

- Improvements in harvester design to reduce cane loss or trash levels are predicted to give greater benefits to the industry as a whole than are improvements in pour rates.
- A cleaning system at the mill operating with 5% trash in the cane supply was predicted to produce economic returns if between 14% and 68% of the trash was removed, depending on the cost of the cleaning plant.
- Importing additional trash, combined with factory cleaning and co-generation of power, increased returns with benefits going to the factory. Industry benefit declined at high levels of imported trash due to loss of agronomic benefits from the trash blanket. Co-generation returns were significantly increased by the use of advanced technology, such as biomass integrated gasification/combined cycle power generation, but only at higher prices for exported power (\$80 MWh⁻¹) due to the higher capital investment required. It should be noted that this technology is in the early stages of development.
- Baling of trash and tops in the field did not appear to be an economic proposition compared to using current harvesting equipment for collection of trash in the field and current field and mill transport systems. However, additional information is required on the cost and practicality of transporting trash to the mill by the latter method.

The above results are intended to be indicative of predicted costs and returns for a 'typical' 600 th⁻¹ factory situated in a predominantly green cane harvested district. In practice, the predicted economic implications associated with trash will be highly mill and region dependent. Sensitivity analysis has been carried out on a number of cost components in the model and model outcomes obviously depend on the relevance of 'best estimate' assumptions to a particular situation.

1.0 BACKGROUND

Current harvesting technology has been demonstrated to give a compromise between minimising cane loss during harvesting and an associated increase in extraneous matter levels in the cane supply (BS65S and BS82S). Leaf, trash and dirt levels have been shown to increase significantly at high harvester pour rates coupled with green cane harvesting, both of which are now standard industry practice in most districts. There is a need for re-assessing harvesting and processing strategies to determine potential benefits/costs from adopting harvester 'best practices' to reduce cane loss and extraneous matter; improving harvester design; or, alternatively, carrying out some of the cleaning at the mill so that additional extraneous matter can be utilised for co-generation of power and have less impact on processing costs and efficiency.

Any such assessment needs to consider the agronomic and environmental benefits of retaining extraneous matter in the field as mulch; current costs of extraneous matter for miller and grower; and costs/benefits of cleaning cane for co-generation of power. It should also be recognised that varying levels of trash in the cane supply will (in the absence of a factory cleaning system) impact on sugar quality, having an indirect but significant effect on sugar returns. The current study does not address the issue of sugar quality.

Several studies reported in the literature have focused on determining the cost of extraneous matter to the sugar industry. These include work by Brotherton (1980), Frost and Stevenson (1980), Clarke *et al.* (1988) and Brotherton and Pope (1995) in Australia, and Sloane and Rhodes (1972) and Hemaïda *et al.* (1975) for the Hawaiian and Egyptian sugar industries, respectively. These studies in general do not consider the impact of different components of extraneous matter (dirt, tops and trash) on costs and the effects on factory operations were determined through theoretical rather than empirical models based on direct measurements. While Ivin and Doyle (1989) differentiated between tops and trash they again used theoretical models to look at effects on factory operations.

Work carried out by Edwards (1994) established the effects of trash alone on industry costs via direct measurements of factory transport, crushing capacity and sugar recovery for 'normal' and 'high' levels of trash in the cane supply. The main conclusions from this study were that the complete removal of the measured level of 3.3 trash % cane would give the following effects.

- An increase in bin weights (nominally 4 tonne) from 3.8 tonnes to 4.3 tonnes.
- Factory crushing and low grade plant savings of \$0.23 per tonne of trash free cane.
- An increase of 1.5% in mixed juice purity.
- An increase of 1.7% in crystal sugar production.
- An overall increase in net returns of \$1.02 per tonne of trash free cane.

Prices of \$300 t⁻¹ and \$40 t⁻¹ were assumed for sale of sugar and molasses, respectively.

The benefits of reduced levels of extraneous matter in the cane supply to the industry as a whole are evident from all the above studies. However, with the exception of Brotherton and Pope (1995) who examined some effects of different levels of cleaning by the

harvester, these studies did not address the full range of factors affected by extraneous matter or the range of options for reducing extraneous matter levels in the cane supply.

The current project involves development of a single comprehensive model of the effects of trash on both factory and field costs and returns. The harvest-transport model developed in BS124S (Management assistance for optimised harvester/in-field transport productivity) has been expanded in a joint BSES/SRI project to include mill costs and returns, grower costs and returns, costs and benefits of cleaning at the mill, and returns from co-generation of power using trash. A majority of factory related additions and modifications to the model have been carried out by SRI under contract to BSES. The model is used to examine costs associated with a range of cleaning options including changes in current harvester practice and technology and secondary cleaning at the factory.

In this latter option, emphasis is placed on the opportunity for significantly boosting income from co-generated power sales by importing (and separating from the stalk) additional trash as a fuel source. Recent studies by Hobson and Dixon (1998) and Dixon *et al.* (1998) have highlighted the role of trash (combined with high efficiency advanced power generation equipment) in increasing potential power exports by the sugar industry. Dixon *et al.* (1998) predict that with the utilisation of 81% of the available cane trash as additional fuel, potential electrical energy export levels of 20722 GWh are possible using Biomass Integrated Gasification/Combined Cycle (BIG/CC) technology. At current power prices, this corresponds to a gross income from power sales equivalent to 30% of that currently received from sugar. While this technology is not yet proven in the Australian sugar industry analysis of BIG/CC as a future option was considered relevant in the desktop study.

With the continuing deregulation of the power industry combined with growing pressures to reduce greenhouse gas emissions, markets are emerging in which power generated using renewable fuels (such as bagasse and trash) attracts a premium price. The economics of cane cleaning, including the broader implications both in the field and factory will be pivotal in determining the viability of co-generation as an additional income stream for the industry.

2.0 OBJECTIVES

- To determine field costs for harvest/transport of cane with varying levels of cleaning by the harvester.
- To determine similar costs for field to factory transport.
- To establish the total industry cost of the various options.
- To determine the feasibility of cleaning at the mill.
- To determine the economic feasibility of importing and burning additional extraneous matter for co-generation of power.

In addition to the above there has been some analysis of options for improved cleaning by the harvester as an alternative to cleaning at the mill.

3.0 METHODOLOGY

A model of field, factory and industry costs has been developed within a spreadsheet framework using Microsoft Excel 97 to assess a range of scenarios for processing trash at sugar mills. The spreadsheet based model was adopted because of the existence of a detailed harvest-transport model developed by BSES in Excel format, and the convenience of this package in linking individual model components.

In determining an approach to assessing factory costs and returns the following options were considered.

1. The cost of the capital investment required to maintain constant sugar recovery for a fixed crushing season length.
2. The cost of maintaining season length without additional capital outlay on equipment by allowing sugar recovery to change.
3. The cost of maintaining constant sugar recovery and capital equipment investment by allowing the crushing season to be extended.

Option 1 has been chosen for this study to cost the effects of extraneous matter on factory costs and returns. This option is considered more appropriate to managers who may be contemplating an expansion of their factory and is therefore of greatest relevance as a long-term decision making tool. However, it is evident that options 2 and 3 will have relevance for particular mill areas and the model should be expanded at a later date to consider these options.

All costs and returns in the study are considered relative to a reference industry scenario to avoid the need for calculating mill operating costs. This means that factory operating costs are assumed to remain constant at different trash levels or changes are negligible relative to capital cost changes. There may be some increase in operating costs with scaling up of the mill to process the additional trash but it is felt that this will be minor compared to capital costs and will not increase in proportion to capacity. The model has been developed to evaluate a range of scenarios where trash is transported to the mill as part of the normal cane supply using the current mill transport system. However, costing of the alternative option of raking and baling trash and tops for removal of at least part of the trash blanket from green cane harvesting was also carried out to assess this option as an alternative.

A summary of the background to and contents of the individual model components is given below.

3.1 Field sector costs and returns

The net field sector returns were computed from gross returns less harvest-transport costs and agronomic costs. In all cases net returns are expressed relative to a standard scenario.

3.1.1 Harvest-transport costs

The harvest-transport model developed in BS124S (Ridge and Powell, 1998) was used as the basis for costing the impact of different harvest strategies on field costs. This is an Excel based spreadsheet model that predicts throughput, capital and operating costs for

different harvest-transport scenarios. The main cost drivers are the change in group size (and therefore capital costs) with cane loss and EM levels; and the change in the length of working day (and therefore wages) with pour rate and group size. It is assumed that any costs/savings associated with the above factors directly affect the field sector returns.

The original model has undergone some modifications, most notably the addition of a multiple linear regression relating trash removal capabilities of a harvester to both pour-rate and fan speed. The regression is based on trial work as part of the project BS189S during the 1998 season (Whiteing and Norris, personal communication). The trial data were obtained for late model Austoft 7000 and Cameco harvesters under commercial harvesting conditions.

$$\text{(Trash + dirt)} = 0.10 - 0.00395 \text{ (Extractor speed)} + 0.101 \text{ (Pour rate)}$$

Equation 1 $(R^2 = 0.88)$

where: (Trash + dirt) is as a percent of the cane supply, extractor speed is in RPM, and pour rate) is in th^{-1} .

In addition, cane loss is linked to extractor speed using the following exponential relationship developed using data from BS189S.

$$\text{Cane loss} = 0.044e^{0.0039 \text{ (Extractor speed)}}$$

Equation 2 $(R^2 = 0.67)$

Where: Cane loss is in tha^{-1} and extractor speed is in RPM.

Inclusion of these relationships in the model allowed adjustment of leaf and trash, cane loss and crop yield for different cleaning strategies. In addition, haulout capacity can be adjusted for leaf and trash levels using a relationship fitted to historic bin weights and leaf and trash data from Tully Mill (Figure 1). Nominal haulout capacity at 3% leaf and trash would be adjusted by 1% for each percentage increase or decrease in leaf and trash levels. This effect is not taken into account in some later conclusions but a sensitivity analysis indicates that this does not change conclusions.

The agronomic value of a trash blanket to the field sector and the industry is included in the model as:

- the value of nutrients returned to the soil through the trash blanket;
- savings in irrigation costs or, alternatively, yield benefits in dryland districts;
- savings in cultivation costs.

There are also less tangible benefits such as improvement in soil structure through the addition of organic matter to the soil; and reduced soil erosion, but these are not included in the model. Where part of the trash blanket is sent to the mill for co-generation of power this should not affect benefits from reduced soil erosion significantly if the soil is not cultivated (Anon,1984).

The recycling of nutrients from trash blankets left in the field after green cane harvesting has a potential agronomic value for growers through reduction in fertiliser requirements. While there is some uncertainty about the rate of re-cycling of nutrients, nutrients in tops and trash and cane lost during in-field harvester cleaning were assigned a monetary value using the data in Table 1. These data were used to cost the benefits of trash retention to growers when assessing different leaf and trash cleaning strategies. Typical nutrient analyses for each component were derived from BSES soil monitoring site crop analyses, and a percentage availability of these nutrients was assumed, based on preliminary data from BSES trials. Costs were assigned to available nutrients using current prices of equivalent commercial fertiliser.

TABLE 1

Fertiliser requirements, availability and costs used in the model

Element	Cane plant requirements (kg/ha)	Contained in trash and tops (kg/kg)	Contained in stalk (kg/kg)	Availability (%)	Unit cost of chemical (\$/kg)
N	160	0.002168	0.000685	30	1.01
P	20	0.000275	0.000109	25	3.35
K	100	0.003668	0.00113	75	0.85
Ca	-	0.000664	0.000092	-	-
Mg	20	0.000321	0.000096	25	1.29
S	-	0.000389	0.000156	-	-

Irrigation cost due to increased trash removal and therefore moisture loss was assumed to be negligible above a defined threshold ground covering of trash. Below this threshold ground covering, irrigation costs that varied linearly up to a maximum value (corresponding to zero trash on the ground), were assumed to be incurred. The threshold covering and maximum incurred cost used in the model were 5 tha^{-1} and $\$100\text{ha}^{-1}$ respectively. This is mainly relevant to districts with a significant annual irrigation demand. Trial data indicate that there would be a similar value in improved cane yield in unirrigated districts due to improved rainfall utilisation. The threshold

value of 5 tha^{-1} is based on experience in the field of the effectiveness of a trash blanket in controlling weed growth in the absence of definitive data on the required trash blanket for control of soil moisture loss. There is a need for better definition of the critical level of trash for improved soil moisture utilisation.

A similar approach was employed in the model to simulate cultivation costs. The corresponding threshold for avoiding additional cultivation costs was set at 5 tha^{-1} trash and the cost of cultivation at $\$9\text{ha}^{-1}$. This is based on figures published by Hardman, Tilley and Glanville (1985).

3.1.2 Field gross returns

The gross returns to the grower are computed in the model from the average ccs of the cane supply and cane yield using a standard formula for price of cane:-

$$\text{Price of cane} = \text{Price of sugar} \times 0.009(\text{ccs}-4) + 0.578$$

The average ccs of the cane supply is calculated using the harvest-transport model estimate of tonnes cane per hectare and percent tops and trash; and the standard composition for each component given in Table 2.

3.2 Factory costs and returns

Factory components and operations affected by varying trash levels that are included in the model are the transport system, crushing plant, sugar extraction, recovery of sugar and molasses, and the low grade recovery stages of the mill. *Capital investment for increased capacity of the mill is considered as directly proportional to the expansion of capacity required for a particular cane rate rather than in a stepwise manner. In this respect the report is a starting point only and each mill would have a different outcome depending on where there was excess capacity or a bottleneck.*

3.2.1 Bin weights and haulage costs

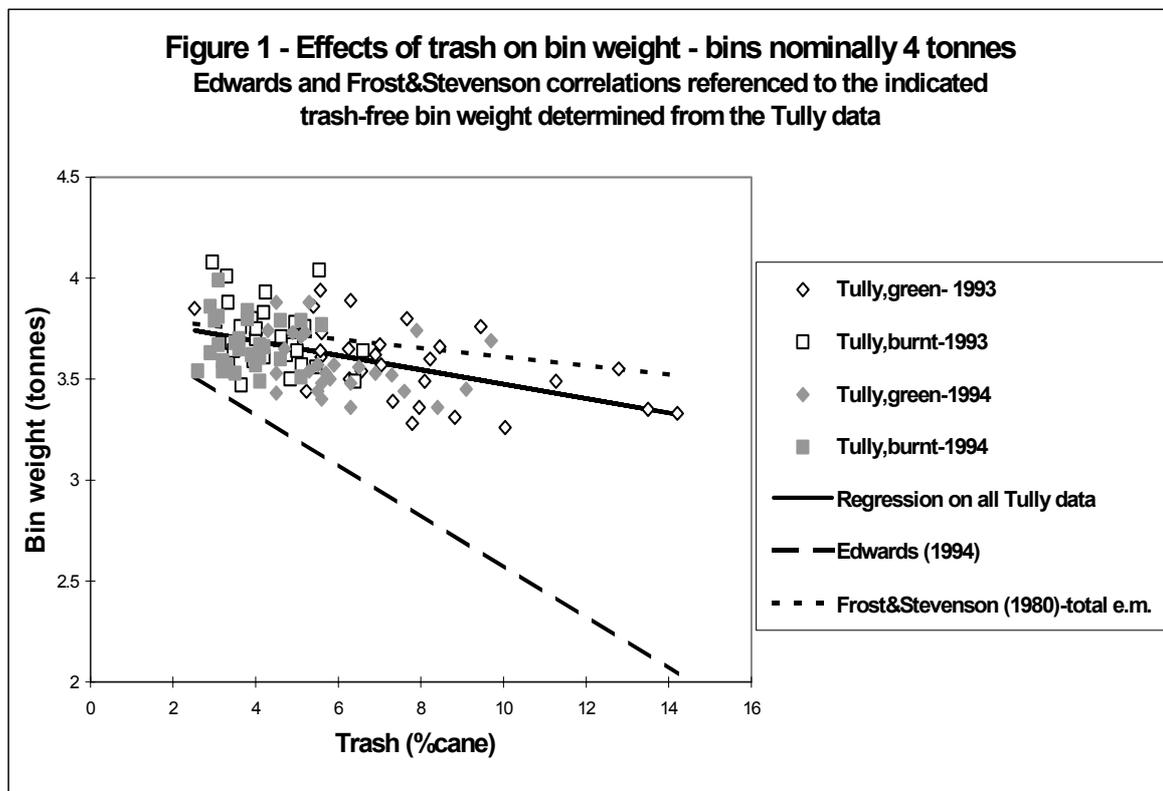
Data on the effects of EM on bin weight are available from a variety of sources. Productivity data published by Tully Mill record bin weights and EM levels over a number of years. The EM data for 1993 and 1994 (Anon, Tully CAPA, 1993 and 1994) give a breakdown of the figures into trash and dirt components for cane harvested burnt and green. These data and the regression line fitted to the data are shown in Figure 1. The regression lines for burnt and green cane considered separately are similar to the combined regression. By comparison, regressions established by Frost and Stevenson (1980) for burnt cane at South Johnstone Mill and Edwards (1994) for green cane at Macknade are also shown. The Tully data were used in the current model because of the amount of data available under commercial operating conditions and the fact that both green and burnt cane figures are available.

The data cover a trash range of 2-14% of the cane supply. The regression line for Tully is:

$$\text{Bin weight} = 3.83 - 0.04 (\text{Trash}\%) \quad \text{Equation 3} \quad (R^2=0.22)$$

Where: bin weight is in tonnes.

A tare weight of 1 tonne and a gross haulage cost of $\$2t^{-1}$ were assumed (Edwards, 1994). There is some unpublished trial evidence apart from that of Edwards (1994) that the Tully relationship may underestimate losses in bin weight at very high trash levels with little or no cleaning by the harvester. Appendix 1 includes sensitivity analysis based on Edwards' figures.



3.2.2 Composition of cane and EM components

Edwards (1994) presents data on brix, pol and fibre for trash from his trial work at Macknade. However, he concludes that the data should be discarded due to the variability of individual measurements. The values for trash used in the current study are taken from Clarke *et al.* (1988), Ivin *et al.* (1990) and Scott *et al.* (1978). Unless stated otherwise, the composition of all cane components used in the current study are those given in Table 2. Results of recent work by BSES in north Queensland indicating higher pol values of trash in association with cane loss during harvesting could easily be incorporated in the model when trials are fully analysed.

TABLE 2

Cane component composition used in the model

Component	Cane	Tops	Trash
Brix (%)	17.06	7.00	9.00
Pol (%)	15.35	1.70	0.63
Fibre (%)	13	11.75	44.4

Dirt was also included as a component possessing mass but not contributing to the sugar balance. Analysis of Tully EM data shows a significant correlation between trash% cane and dirt% cane (Figure 2).

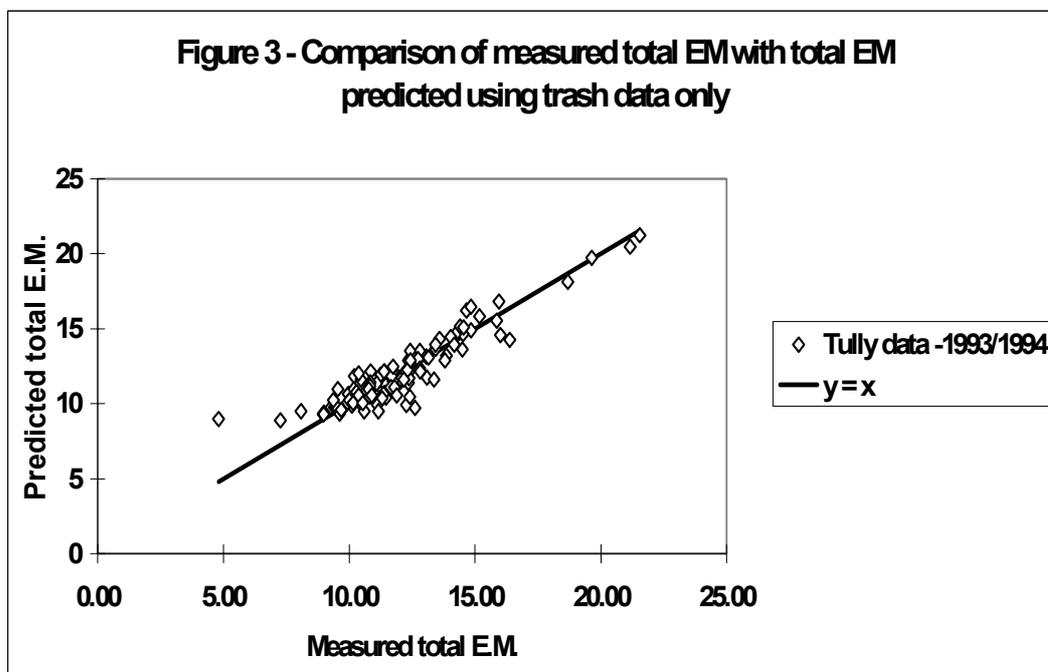
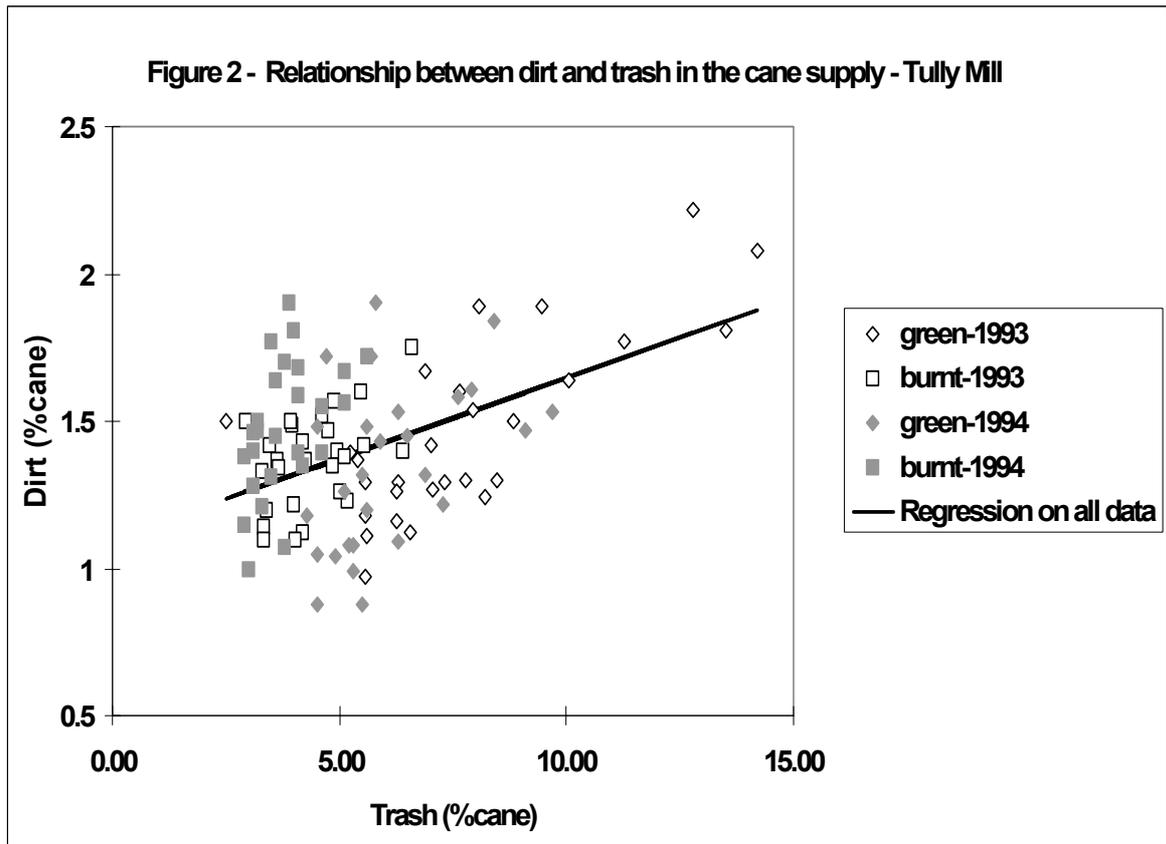
The regression on this data used in the model is:

$$\text{Dirt} = 1.10 + 0.055 (\text{Trash}\%) \quad \text{Equation 4 (R}^2=0.18)$$

where: (Dirt) and (Trash) are expressed as a percentage by mass of the total cane supply.

Further examination of the Tully data set indicated that there was no obvious correlation between the level of trash in the cane supply and the percentage of tops. Tops were therefore considered to constitute a constant percentage by mass of the cane supply. Unless otherwise stated, this was set in the model at the mean value from the Tully data of 6%.

Equations 1, 4 and a constant value of 6% tops were used in the model to predict total EM as a function of trash. Figure 3 shows a comparison of predicted and measured (from Tully data) total EM. The R^2 value for the relationship is 0.87. Tops are considered as the top material with minimal attached leaf left after processing by the harvester.



3.2.3 Cane feeding (tippler) capital costs

The cane feeding station (tippler) capacity is directly related to the amount of trash being transported into the factory. This is simulated in the current analysis by scaling capital costs with both the total mass of cane being transported into the factory and bin weight. In reality the latter is manifested as a change in the number of bins required as a result of changes in the cane bulk density.

Discussions with mill staff who have been involved in costing recent expansion activities indicated a capital cost (extrapolated back to a 0% trash supply) of \$21,000 per tonnes cane/hectare for cane feeding equipment. This figure is used in the present analysis and scaled linearly as described above.

3.2.4 Crushing rate and capital costs of milling units

When estimating the effects of trash, Clarke *et al.* (1988) assume that the crushing rate is proportional to total fibre present. Direct measurements by Edwards (1994) indicate that for a 370 th⁻¹ factory, there is a 2.5 th⁻¹ reduction in milling rate for each percentage increase in trash %cane. This corresponds to an effect approximately 25% less than that using the assumption of Clarke *et al.* (1988). The explanation offered by Edwards for this discrepancy is that leaf fibre is more easily milled than stalk fibre.

A very recent study of the effects of trash on crushing rate and ccs at Mossman Mill has been carried out by Allen *et al.* (1998). Rakes of 'clean' cane were obtained by operating a conventional harvester at lower than 'normal' pour rates. Adjacent rakes of 'dirty' cane were obtained by turning down the harvester primary extractor. A mean difference was measured between the 'clean' and 'dirty' supply of 6.5% by mass of the billet cane collected. The effect of reduced trash in the cane supply was to increase the crushing rate from 338 th⁻¹ to 368 th⁻¹. Measurements made during these trials indicated, contrary to the findings of Edwards (1994), that despite significant differences in crushing rates, there were no significant differences between the 'clean' cane and 'dirty' cane fibre rates. The results of Allen *et al.* (1998) indicated that trash had a larger effect on crushing rate than that given by Edwards (1994). Over five paired trials there was a mean drop in crushing rate of 3.3 th⁻¹ for each percentage increase in EM% cane. Given the scale of the Mossman trials and the agreement between the Mossman (Allen *et al.* 1998) and Clarke *et al.* (1988) studies, a fibre dependant crushing rate was incorporated in the current analysis.

For crushing costs, a capital expenditure of \$44,000 per th⁻¹ is assumed. The capital cost (associated with restoring the milling capacity to a level footing with sugar production) is amortised over the annual sugar production. A 15% return on investment (ROI) before tax is assumed. The figure used for capital to upgrade milling capacity was confirmed by recent estimates by Mackay Sugar Corporation for upgrading capacity of one of their mills. It could also be argued that operating and maintenance costs would change with a change in milling capacity and these costs are included in sensitivity analysis in Appendix 1.

3.2.5 Extraction

Calculations made by Clarke *et al.* (1988) on extraction used a formula based on fibre rate and ratio of added water to fibre. Trash was assumed to have negligible sugar content but leave the factory milling train with a (higher) sugar content equivalent to the mean value for the bagasse. This equates to a reduction in extraction of 1.2% for a 5% increase in trash.

Measurements by Edwards (1994) on extraction give a 0.05% reduction in extraction for 1% increase in trash. This is a lower rate of change of extraction with trash levels than that calculated by Clarke (1988). Edwards explains this result by stating that in reality bagasse losses are due to sugar leaving mainly in unopened cells; unopened cells in trash contain little sucrose and therefore losses are smaller than those predicted by Clarke *et al.* (1988).

Allen *et al.* (1998) found no significant difference in total pol extraction between low and high levels of trash in the cane supply. They also found that pol% bagasse was significantly lower in the high EM treatments. These results are similar to those of Edwards.

The experimental data of Edwards (1994) have been adopted in the current study. A constant difference between the values of pol and brix extraction is assumed.

3.2.6 Low grade recovery and the value of sugar and molasses produced

The low grade recovery calculation is a modified version of the technique adopted by Edwards (1994). Recovery of sugar is dependent on both juice and final molasses purity. The cane composition (pol and brix) based on the figures given in Table 2 is used to estimate mixed juice purity. The brix extraction relative to the pol extraction has been adjusted to simulate the removal of impurities at the clarification stage. The numerical value of this adjustment has been set by comparing the resulting predicted sugar production with historical data supplied by a mill group.

In calculating the molasses purity, the correlation of Ivin *et al.* (1990) is used, that is,

$$rs/ash = 0.75 + 0.007 (\text{trash \% cane supply})$$

where: (rs/ash) is the dimensionless ratio of reducing sugar to ash and (trash) is expressed as a percentage by mass of the total cane supply. The computed rs/ash ratio is used in Equation 5 to compute final molasses purity.

$$\text{final molasses purity} = 40.7 - 17.8 \log_{10}(rs/ash) + 3.5 \quad \text{Equation 5}$$

It is assumed that raw sugar is produced at 98.9 pol and 30 DI (Dilution Index). The sugar recovery is then calculated from the SJM formula (Anon, 1970).

The model assumes the production of a brand 1 sugar and molasses with a value of \$330 per tonne and \$40 per tonne, respectively.

3.2.7 Low grade station costs

In line with the approach taken by Edwards (1994), the capital costs associated with low grade pans, crystallisers and mixers and low-grade fugals are assumed to be directly proportional to the rate of processing of impurities. The capital costs associated with low-grade station equipment is taken as \$11,250 per th^{-1} for trash free cane. It could also be argued that operating and maintenance costs would change with change in low-grade capacity and these costs are included in sensitivity analysis in Appendix 1.

As with the crushing costs, the capital cost of equipment is amortised over the sugar produced and a 15% ROI before tax is assumed.

3.2.8 Factory cane cleaning costs

The predicted dimensions of a factory cane cleaning plant in the current study is based on the results of a study by Hobson (1997). The basic configuration assumed is that of a 'horizontal' cleaning system in which cane is injected at high speed (about 9 ms^{-1}) through the top of the cleaning chamber and in a direction counter to that of the air flow. The cane falls through the air stream and is cleaned. The trash is conveyed pneumatically to a settling chamber and the clean cane removed by conveyor from the floor of the chamber. Regardless of the throughput of the cleaning system, the height and length of the system remain fixed at 5 m and 4 m, respectively. These dimensions are those calculated as being necessary to clean an incoming cane supply with 7% trash by mass such that the out-going cane stream has only 0.1% trash by mass. Subsequent work carried out under project SI061 (in which the assumed cleaning chamber concept has been developed further and a 100 th^{-1} system built and tested), indicates that a more compact system is possible in which cleaning chamber cross section and therefore air flow requirements are significantly reduced. It is assumed that there is no significant cane loss during cleaning and no benefits from removal of soil from cane apart from changes predicted from the regression relationship between trash content and soil levels. The cleaning plant dimensions assume a 20 ms^{-1} airflow through the chamber. The width of the cleaning system is determined by the cane throughput.

Based on the fixed and throughput related dimensions, construction materials (concrete and steel), conveyor requirements (to move cane components to and from the cleaning plant and prepared trash to storage), fan requirements are determined and costed together with construction costs. Preliminary costing for a cleaning plant is \$0.9 million. The capital costs are amortised over the cane cleaned by the system and a 15% ROI is assumed. Later sensitivity analysis compares costs of \$1m, \$3m and \$6m for the cleaning. The figure of \$3m corresponds to estimates of costs for a third generation cleaning plant in Brazil and the \$6m to a more complex cleaning system evaluated in an SRDC commissioned study.

Annual maintenance is set at 5% of total capital costs. Running costs are assumed to be dominated by power requirements, and are calculated assuming power has to be purchased from an external supplier. This last assumption simplifies the costing by decoupling the cleaning from co-generation activities and was deemed acceptable because if anything it would produce conservative (high) operating costs.

3.2.9 Co-generation

As a precursor to power export calculations, the factory fuel and steam requirements are calculated and displayed on the co-generation and spreadsheet page. Factory low pressure (LP) steam requirements are calculated from a steam-on-cane (SOC) value. The SOC value is an input to the program. The total factory power requirements are calculated from the crushing rate dependent power requirements of the shredder, milling train, boiler and other ancillary demands. By comparing steam requirements, steam generation efficiencies and available fibre (from trash and bagasse), the bagasse and power consumptions and surpluses are determined.

Steam power generation is calculated from program input values representing steam conditions (enthalpies) at the high pressure (HP), low pressure (LP) and condensing stations. An option for high efficiency biomass integrated gasification/combined cycle (BIG/CC) power generation systems is included. While it is recognised that this system is as yet untried in Australian mills it is felt that its potential warrants inclusion in the desktop study. For this latter option, the heat and power output of the gas turbine is determined in the program from a simple efficiency term. In the case of the combined cycle option, depending on the amount of available fibre and the steam demand of the factory, some portion of the bagasse may have to be sent to an auxiliary boiler in order to meet factory steam demand. A more complete discussion of this issue can be found in Hobson and Dixon (1998). They report that for the same bagasse consumption a BIG/CC system will produce approximately 250% of the power of a conventional steam system. The program calculates the relative sizes and therefore capital costs of combined cycle and conventional boiler units.

The total capital expenses and operating expenses cost of generating power from bagasse fired BIG/CC and more conventional high pressure steam cycle is taken as \$53 and \$40 per MWh, respectively (Dixon *et al.*, 1998). Both the BIG/CC and conventional steam system costs include an allowance for upgrading the mill to 35% SOC.

The total capital cost of all power generation plant in the factory is subtracted from the total returns from power sales to give net returns from co-generation activity. There are, however, problems associated with these net return values. The main problem is that there is an implicit assumption that all steam and power generating capital should be costed against the power export activity, whereas some of the power and steam goes into making sugar.

These problems disappear to a great extent if, consistent with other (non-cogeneration related) costs, the outputs from the model are expressed as a difference between a current and some reference case. Assuming that the fraction (an unknown quantity) of the steam and that of the power generation costs that should be associated with sugar production are identical, the difference in power generating costs (and net returns) between the current and reference cases can be wholly and more correctly attributed to power export activities alone.

A more detailed explanation of operating parameters used in the co-generation model is given in Appendix 2.

3.3 Investigation of baling as an option for transporting trash to the mill

The practice of baling trash and tops following green cane harvesting is common in the Rocky Point area and data were obtained from two large-scale operators on capital, maintenance and operating costs for raking, baling, loading and transport. Details of a typical large-scale operation are given in Table 3. It is assumed that the large ‘square’ bales are produced weighing 700 kg/bale at 10% moisture and having a volume of approximately 3.3m³ (2.3 m x 1.2 m x 1.2 m). In addition to the information presented in Table 3, it is estimated that storage costs in a conventional shed system are approximately \$0.70 per bale or \$1 per tonne.

The data used in compiling Table 3 are given in Table 4.

TABLE 3

Costs of raking, baling, loading and transport of trash and tops in the Rocky Point Mill area (700 kg square bales)

Operation	Cost component	\$/tonne
Baling	Maintenance	6.57
	Wages	1.43
	Fuel	0.71
	Twine	2.86
	Capital	7.71
Raking and loading	Maintenance	0.43
	Wages	3.36
	Fuel	0.81
	Capital	4.36
Cartage		5.71
Total		33.95

Details of operations- Baler produces 10,000 bales/year, 200 bales/d; loader handles 50 bales/h; there are 22.5 t/ha leaf, trash and tops at 60% moisture reducing to 10 t/ha at 10% moisture prior to baling.

TABLE 4

Detailed costing for baling, raking and loading operations

Cost category	Components	Cost basis
Capital investment	Baler	\$132,000
	Tractor for baler	\$121,000
	2 row rake	\$16,500
	Tractor for rake	\$66,000
	Loader	\$16,500
	Tractor for loader	\$44,000
Capital costs	All	Depreciation to 25% of value in 5 years, interest on average capital value 10%p.a.
Maintenance	Baler parts	\$45,000 p.a.
	labour	1 h/day at \$20/h
Wages	Rake and loader	\$3000 p.a.
	Baling	10 h/d at \$20/h
	Raking	2.7 ha/h at \$20/h
Fuel	Loading & unloading	50 bales/h at \$20/h
	Baling	10 h/d at 25L/h, 40c/L
	Raking per pass	\$2.24/Ha
	Loading	\$2.50/h

4.0 RESULTS

As indicated in section 3.0, all data are expressed as values relative to those of a reference case. A macro has been set up within the spreadsheet such that any complete set of conditions can be recorded as the reference case. The variables which contribute to a particular set of reference conditions are too numerous to reproduce here as an exhaustive list. The main features of the reference case are:

- Cane supplied from harvesting group sizes of typically 70,000 tonnes.
- Harvester performance equivalent to that of a current model (such as a recent model Austoft 7000)
- 90 tha^{-1} recoverable cane stalk
- 19% by mass trash and leaf in the field
- 5% trash by mass in the cane supply
- 4% cane loss during harvesting
- Factory crushing rate of 600 th^{-1}
- 3,000 hours crushing season
- Factory steam demand of 52% SOC

Where relevant it is assumed that any savings or increases in harvesting costs for a particular scenario are shared by the field sector. *Unless otherwise specified the co-generation of power at 52% SOC is active for all calculations.*

The model generates results in the form dollars per tonne of trash-free cane, dollars per tonne of cane supplied and dollars per hectare. The dollar per tonne of cane supplied,

although a commonly used term, is considered a poor indicator, as the tonne of cane to which the value is being referenced varies with trash levels. The dollar per tonne of billets is a better comparative index, but is not commonly used. The results presented in this report are therefore in $\$/\text{ha}^{-1}$.

4.1 Breakdown of current industry trash related costs and returns

The relative contributions of trash associated costs and (where relevant) returns for the main activities and processes in the manufacture of raw sugar are given in Table 5. These are obtained by increasing the simulated harvester pour rate such that the trash level relative to the reference case increases by 1%. Cane loss during harvesting (and by implication the harvester extractor fan speed) is assumed to be unchanged and there is no cleaning at the mill.

Table 5 indicates that the industry as a whole loses over $\$30 \text{ ha}^{-1}$ for each percentage increase in trash in the cane supply. The largest single contributing loss is the reduction in sugar recovery (negative relative sugar and molasses returns). This loss is apportioned to the field sector via a lower ccs and therefore monetary value being attributed the cane delivered to the mill.

The gain to the field sector in terms of reduced harvesting costs (about $\$3 \text{ ha}^{-1}$ less than the reference case) is greatly exceeded by the reduced return on cane.

TABLE 5

Change in costs and returns (expressed in $\$/\text{ha}$) for the field, factory and total industry as a result of a 1% increase in trash in the cane supply

Cost item	Field	Factory	Industry
Price of cane	-24.95	24.95	
Harvest costs	2.89		2.89
Agronomic costs	-3.67		-3.67
Power returns		4.95	4.95
Sugar and molasses returns		-14.16	-14.16
Rail transport costs		-3.60	-3.6
Cane feeding		-1.60	-1.6
Milling train capital costs		-9.30	-9.30
Low grade station capital costs		-5.96	-5.96
Net return	-25.73	-4.72	-30.45

Other important factors affecting the losses to the industry as a whole are the additional agronomic costs incurred by the grower as trash is removed from the field and the potential increase in returns to the factory from increased power sales (due to the additional available fibre). The projected power sales make an important contribution to net factory income.

4.2 The effects on industry sector returns of changing levels of trash in the cane supply

The effects on the field sector, factory and the industry as a whole, of increasing the levels of trash supplied to the factory were investigated by simulating changes in harvester

operation to vary trash in the cane supply. Two options are available for varying trash levels:

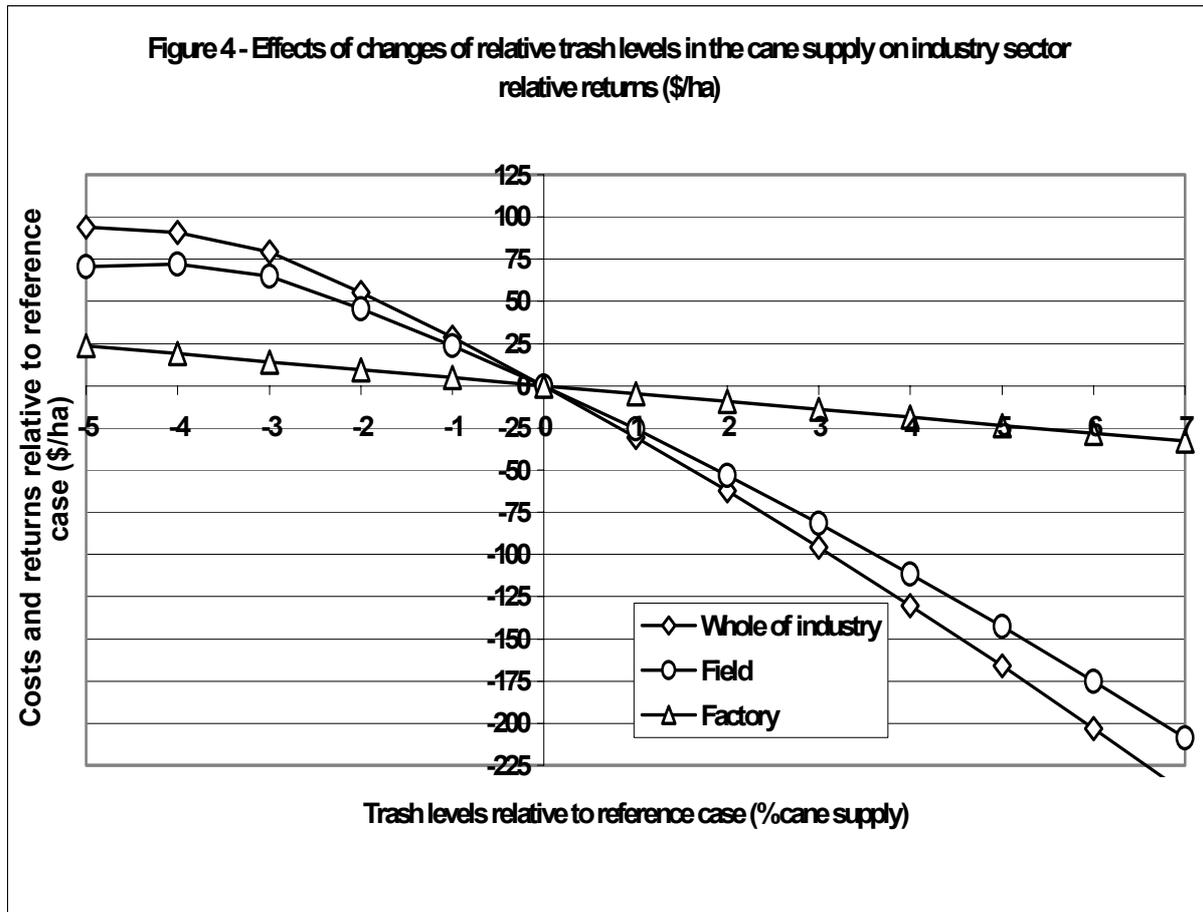
1. varying the harvester extractor fan speed; and
2. varying the forward speed of the harvester (pour rate).

The second option was chosen as trial results indicate that trash levels are highly dependent on pour rate with current harvester designs; and, varying extractor speed has a large effect on cane loss during harvesting but a smaller effect on trash levels. This option affects field sector costs to some extent due to changes in harvesting costs with pour rate. In the model, it is assumed that changes in contractor costs as group size and hourly throughput changes with trash levels, are shared with the grower. This does not occur in practice but is considered to be a true reflection of the effect of trash on costs.

Figure 4 shows the effects of varying trash levels on the individual sectors of the industry and the industry as a whole. The trend suggested by Table 5 is confirmed in Figure 4 in that as increasing levels of trash are sent in to the factory, there is a continuing drop in net returns for all sectors of the industry. The factory continues to make less sugar per hectare as trash levels increase, but is compensated to some extent by the cane payment system. *This assumes no change in sugar quality and therefore net sugar price as trash increases.*

At the other end of the scale, the field net returns plateau as trash levels drop. This plateau occurs as the cost of harvesting cane increases with reduced harvester ground speed. For the harvesting scenario represented in Figure 5, the field sector and whole of industry returns are maximised at a harvester pour rate of about 68 th⁻¹. The reference case is equivalent to a pour rate of about 110 th⁻¹. *These figures are relevant to current late model harvesters operating in average commercial conditions in north Queensland and are useful for promoting harvester best practice.*

It is worth remembering when making comparisons with other studies that the change in trash level has been achieved in the current study by changing harvester ground speed. The effect of changing trash levels by changing the harvester extractor fan speed will reflect a change in the level of cane loss as well as trash levels. If, for example, the level of trash is increased by turning the extractor fan down, then losses to the field sector incurred due to increased fibre in the cane supply will be reduced (or even turned into additional profit) by reductions in cane loss.

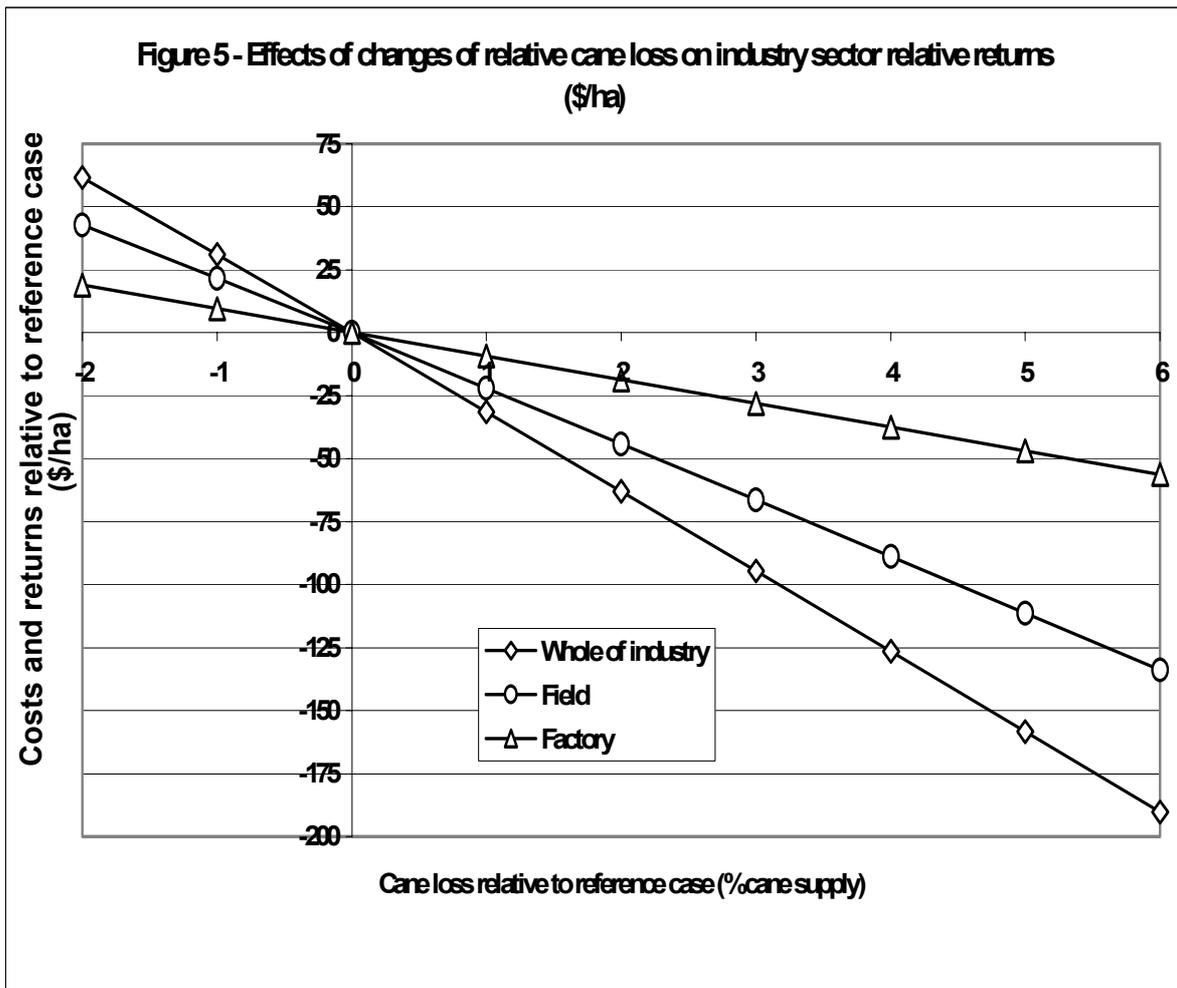


Various assumptions based on industry data were used in compiling Figure 4 and sensitivity analysis of the main assumptions is included in Appendix 1. In general, the sensitivity analysis does not alter the broad impact of trash on returns to different industry sectors. However, recent trials in the Mulgrave area indicate that trash can have significantly higher pol than assumed in the model and this may have a significant effect on returns at different trash levels. In addition, if the higher limits to possible factory costs (related primarily to including proportionally increasing operating costs) are used in the model, increased trash has a negative impact on factory returns (Appendix 1).

4.3 Harvester cane loss

Extraneous matter levels and cane loss are intimately linked in the harvester cleaning process. If extractor speed settings are changed both cane loss and extraneous matter normally change, but extraneous matter can be kept constant in the model by varying the harvester pour rate appropriately. When assessing grower returns in this case harvesting cost is affected by pour rate and group size, and gross returns are affected by cane loss.

Figure 5 shows the impact of varying extractor speed (and therefore cane loss) on industry returns where trash levels are kept constant. Constant trash levels for different extractor speeds are achieved by adjusting the harvester pour rate. The figure clearly demonstrates the role that increased cane loss plays in reducing net returns for all sectors of the industry. In absolute terms both the losses and potential gains associated with cane loss are greatest for the field sector due to the distribution of income from raw sugar sales.



4.4 Strategies for increased industry sector returns using current harvester technology

Clearly, current harvesters can be operated in such a way as to significantly affect net returns to both the field sector and factory by changes in pour-rate and extractor fan speed. These two operating parameters are the primary controls relating to trash in the cane supply and cane loss in the field, respectively. There is a secondary effect of fan speed on trash in the cane supply (accounted for in the model) and, at the extremes of pour-rate, there is a tertiary effect of the latter on cane loss (not accounted for in the model).

The combined effects of pour rate and extractor fan speed on whole-of-industry returns are shown in Figure 6. The fan speed settings used in the figure are set on the lower boundary by the limits of available trial data and the upper boundary by harvester design. The results of Figure 6 indicate that at each fan speed setting a drop of about 40 th^{-1} from the reference pour rate of 109 th^{-1} will optimise industry returns. Where primary extractor speed was also reduced by 663 rpm relative to the reference speed of 1,207 rpm, industry returns were increased significantly. However, in order for this scenario to be acceptable a benefit to all sectors of the industry needs to be demonstrated. In Table 6 three scenarios are compared.

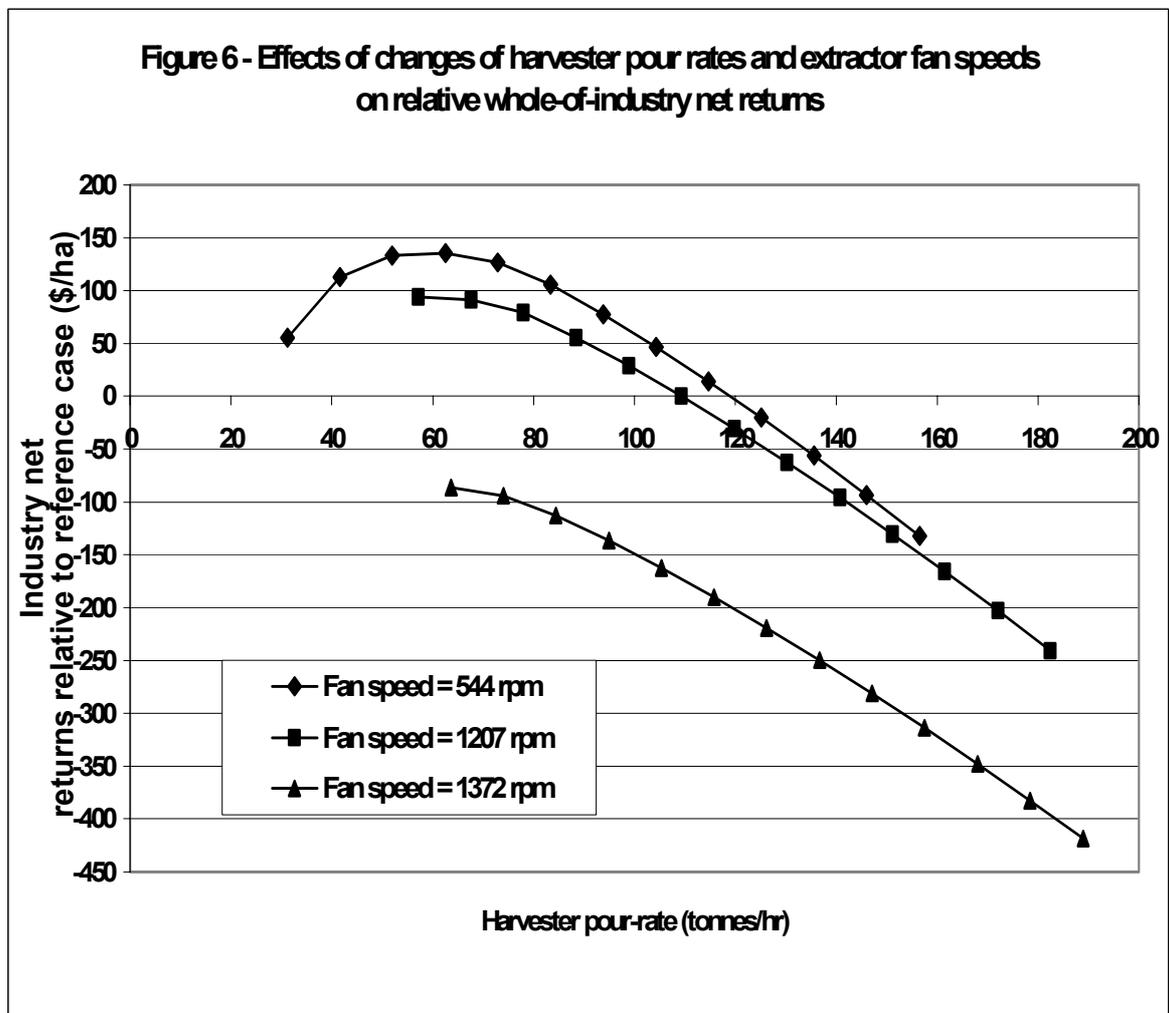
1. Reduction in harvester pour rate only such that trash% cane levels are reduced by 4 units corresponding to the optimum whole of industry net returns shown in Figure 4. The harvester fan speed, and therefore cane loss, remains fixed.
2. Reduction in fan speed only with no change in pour-rate such that trash levels increase by 2.5% but cane loss falls by 3.9%. This in terms of net returns to the industry, corresponds to where the low fan speed line crosses the reference pour rate line in Figure 6.
3. Reduction in fan speed and pour rate corresponding to the optimum relative net return at the lowest fan speed shown in Figure 6 (a decrease of 1.1% in trash levels and 3.9% in cane loss at a fan speed of 544 rpm and a pour rate of 78 th^{-1}).

Scenario 3 has the benefits of delivering the highest net return to the industry while providing both sectors of the industry with significant returns. A more typical field operating scenario with a fan speed of 1,000 rpm and a pour rate of 90 th^{-1} (1.1% less trash, 2.7% less cane loss) delivers less overall industry benefit (\$100 per ha), but has the benefits of a shorter working day and retention of improved bin weights associated with low trash levels.

TABLE 6

Relative industry sector returns for three scenarios aimed at maximising net returns using current technology and cane payment formula

	Harvester pour-rate (t/h)	Extractor fan speed (rpm)	Relative net field returns (\$/ha)	Relative net factory returns (\$/ha)	Relative net whole industry returns (\$/ha)
Scenario 1	78	1207	65	14	79
Scenario 2	104	543	20	27	47
Scenario 3	78	543	80	39	119



4.5 Improved harvester technology

Three possible improvements to cane harvester technology were considered as options for reducing the direct and indirect effect of trash on industry returns under the current harvesting system.

1. Improved removal of trash.
2. Reduced cane loss.
3. Higher pour rates.

In terms of what is being investigated, there is some overlap between the first and third options. The latter must represent an improvement in the former (if trash levels are kept constant) since any increase in pour rate would normally (in an unimproved harvester) be accompanied by an increase in trash in the cane supply. The third option was included as increased pour rate is perceived in the harvester manufacturing industry as one of the primary goals in terms of harvester development.

The model has been extended so that each of these features can be examined independently. That is, improvements in each of these features can be achieved without any detrimental effect on the performance characteristics relating to the other two attributes.

The improvements have been expressed as a percentage of the reference performance rating. So that a 100% improvement for the three options mean removal of all trash, zero cane loss and double the pour rate, respectively.

The expected relative net returns for these three cleaning options are compared from a whole-of-industry, field sector and factory perspective in Figures 7 to 9, respectively.

Although a direct comparison is difficult (is a 100% improvement in trash removal the same as a 100% improvement in cane loss?), Figure 7 indicates parity between the benefits of improving the trash removal and cane loss aspects of harvester performance.

With regards to increased harvester speed, there appears to be relatively little benefit to the industry as a whole in pursuing this strategy. This is particularly so when negative aspects of high speeds such as increased stubble damage and poor billet quality are taken into account.

Comparing field sector relative net returns (Figure 8) with those of the industry as a whole (Figure 7), three main conclusions can be drawn:

- All the benefits to the industry as a whole derived from increased pour rate flow to the field sector.
- Most of the benefits (about 95%) of improved trash removal efficiency are received by the field sector. However, there would be further benefits to all sectors of the industry through improved sugar quality.
- Some (about 70%) of the benefits to the industry as a whole of reduced cane loss are received by the field sector as expected.

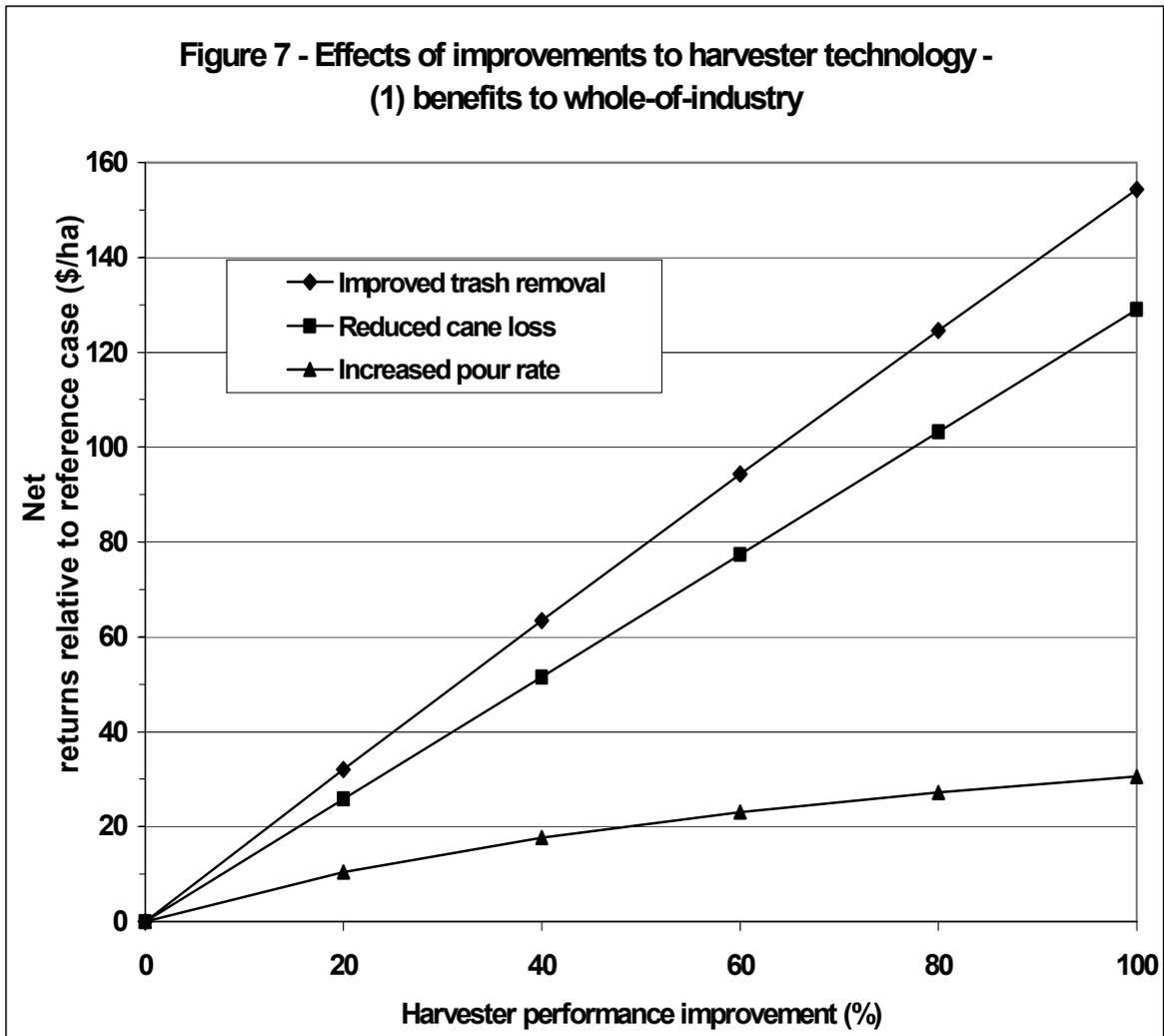
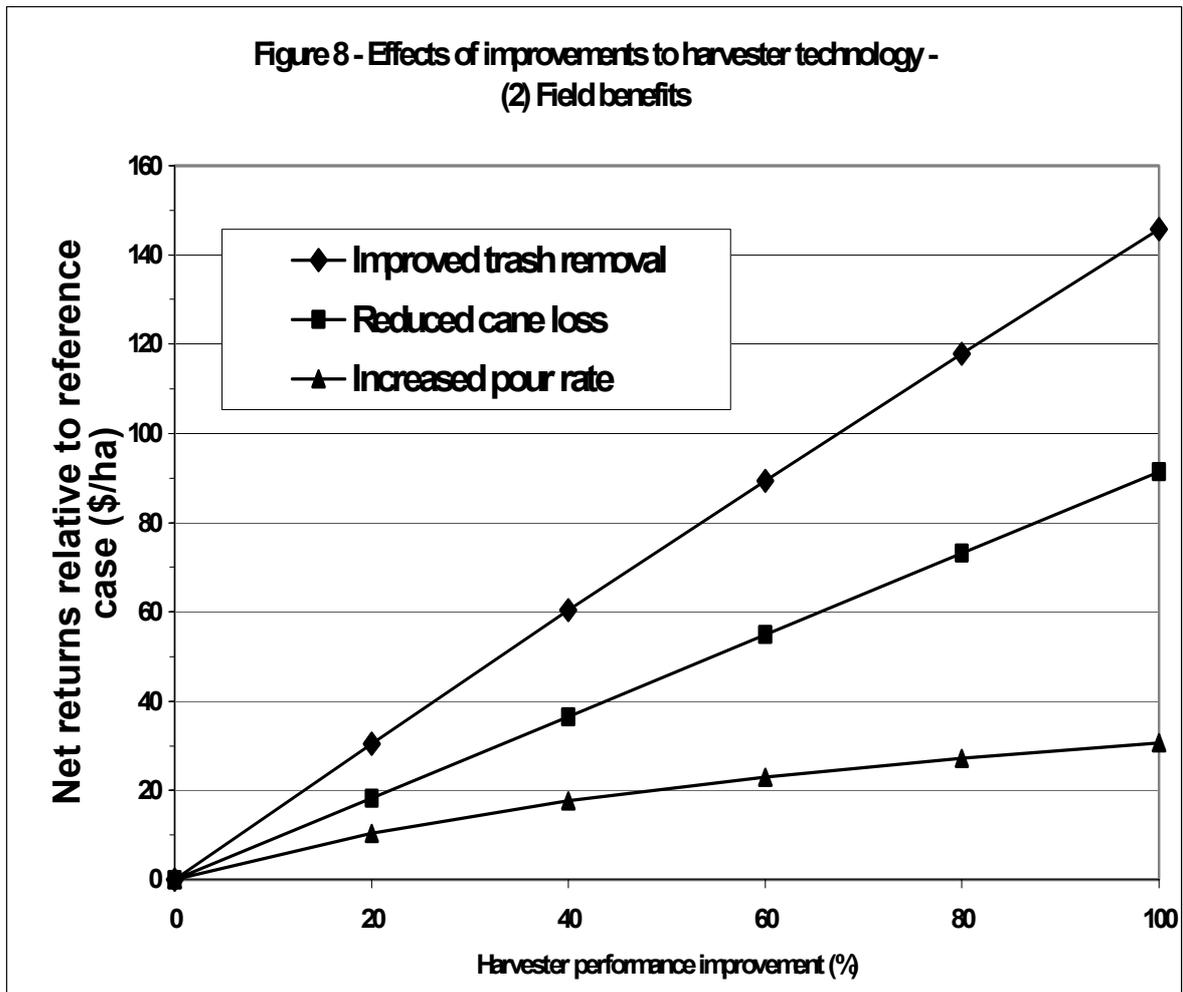
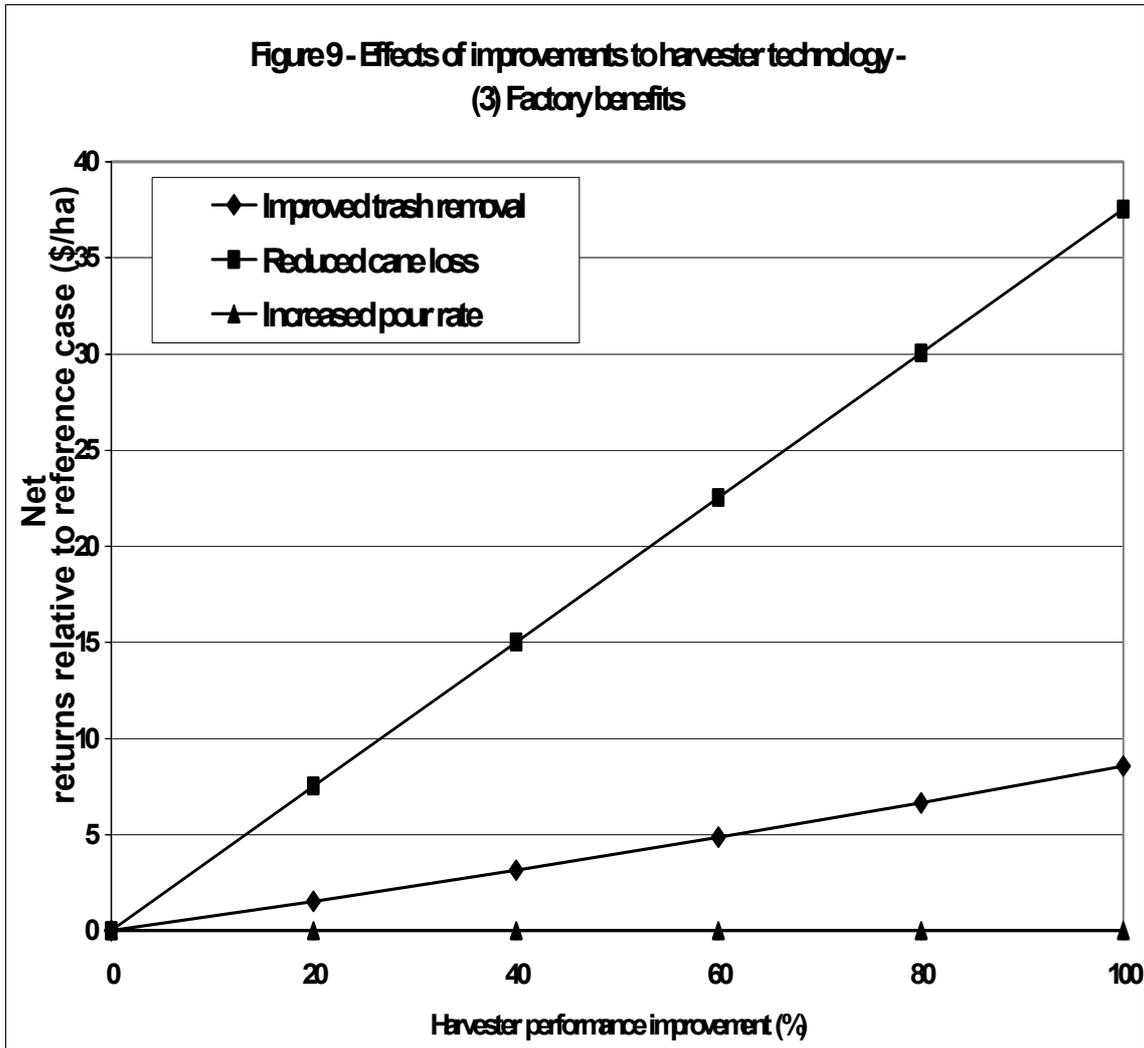


Figure 8 - Effects of improvements to harvester technology -
(2) Field benefits





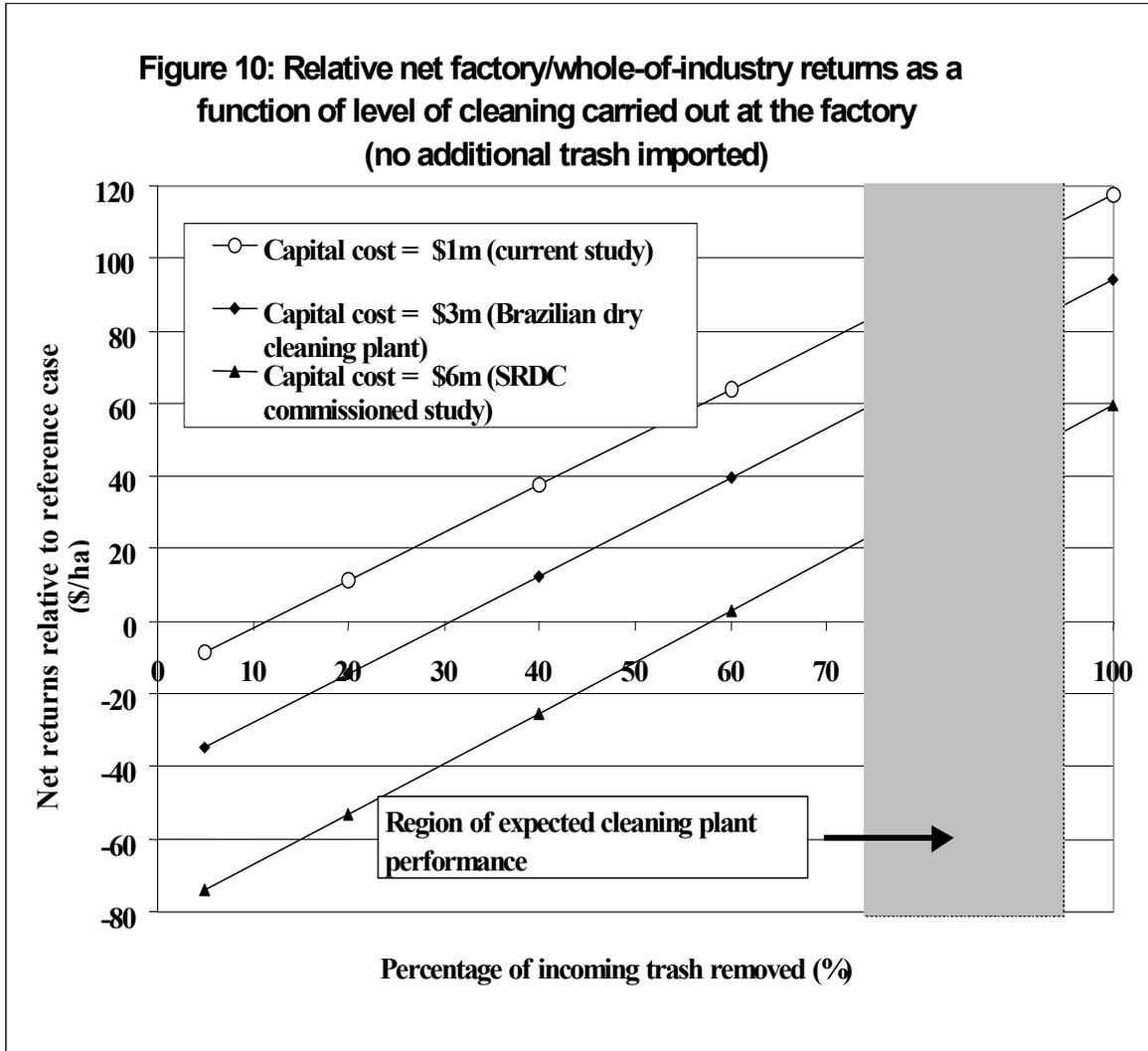
The above three conclusions are mirrored in the benefits to the factory of harvester improvement strategies (see Figure 9). There would be some additional benefits to the factory (not accounted for in the current model) through improved sugar quality.

However, Figure 7 indicates a substantial total potential benefit (ie implementation of 100% improvements in all three aspects of harvester performance) to the industry as a whole of the order of \$315 per hectare relative to the reference scenario from improved harvester technology.

4.6 Secondary cleaning at the factory without additional co-generation

The costs and benefits of carrying out additional cleaning at the factory were investigated by balancing costs of the cleaning plant against benefits in mill operational costs and sugar recovery. These include reduced capital investment for crushing capacity, increased extraction, reduced low-grade station capital investment and increased sugar recovery. The scenario considered here is the operation of a cleaning plant to remove all or part of the current trash in the cane supply. *Further, in working out miller's costs the cane is assumed to be valued according to the CCS of the cane prior to cleaning.* One implication

of this latter assumption is that factory cane cleaning has no effect on field sector returns (remembering that in this simple scenario, the amount of trash that comes in with the cane remains constant).



Costs relating to the construction and operation of a real factory scale cane cleaning plant of any description are not available in the open literature but as indicated in section 3.2.7 projected costs range from \$1m to \$6m. To investigate the sensitivity of factory net returns to the cleaning costs predicted in this study, the capital costs have been varied from \$1m to \$6m. In Figure 10, industry returns for capital costs of \$1m, \$3m and \$6m are compared.

The trash removal rate is varied from 0%, corresponding to all incoming trash in the reference cane supply (ie 5%) being processed by the factory, to 100% corresponding to all of the incoming trash being removed.

Figure 10 indicates that based on the model predictions of cleaning costs and benefits, only modest levels of factory cleaning are required to justify the installation of a factory cleaning plant. Such a plant would start showing a net positive return if 14-68% of the incoming trash is removed, depending on capital costs.

Cleaning costs are relatively insensitive to the level of cleaning being carried out. This insensitivity is due primarily to the fact that the costs are dominated by capital and that the majority of the capital cost is itself dominated by the cost of cane and bagasse carriers (conveyors). These items would need to be installed regardless of the trash removal rate or size of the cleaning plant.

As indicated in Figure 10, cleaning plant performance is expected to be in the range 75-95% trash removal. At the lower end of expected cleaning efficiency, the factory returns increase by from \$7 to \$56 per hectare depending on capital cost of the cleaning plant. These returns are based on benefits derived from trash removal only. In practice, a factory based cleaning plant would almost certainly incorporate an integrated facility for the removal of dirt, a feature that would have significant further economic benefits in terms of factory capacity and maintenance related costs.

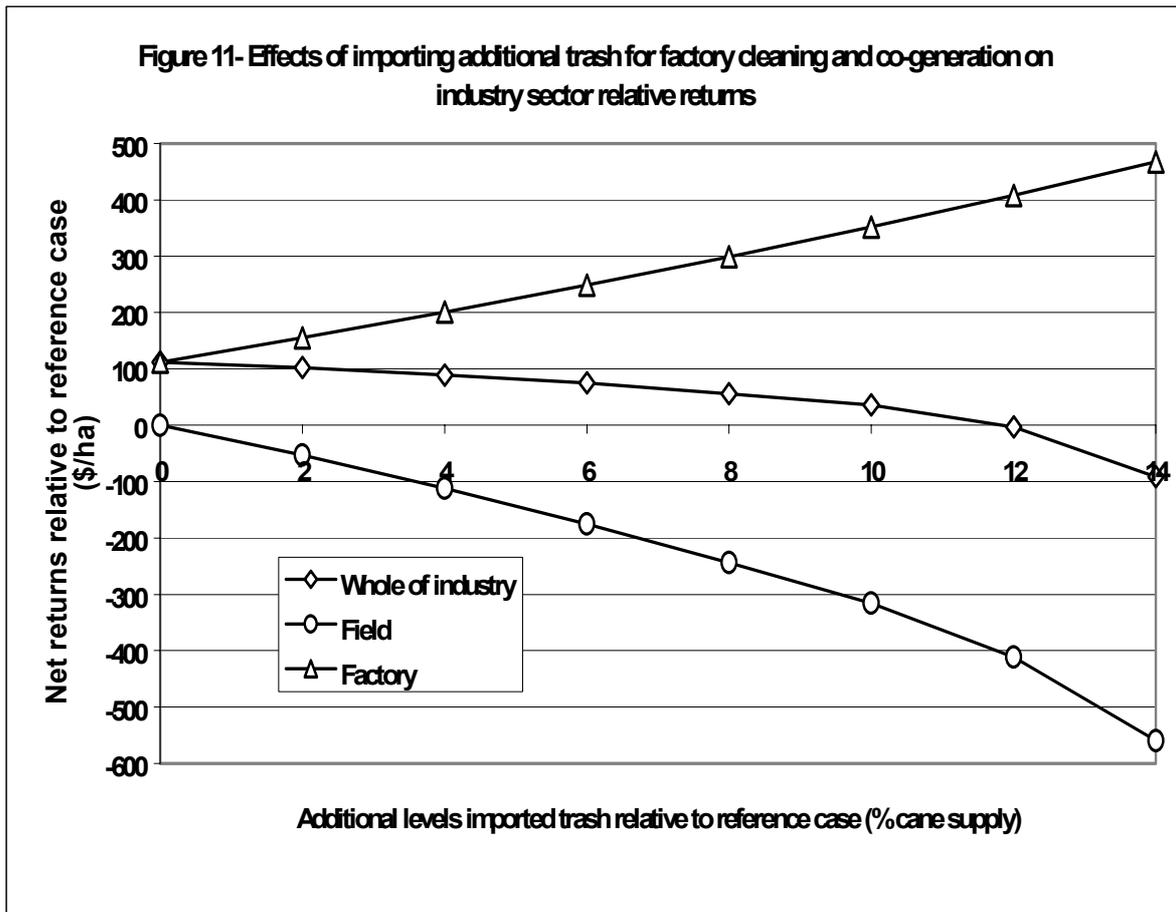
4.7 Secondary cleaning at the factory and co-generation

The effect of importing additional fibre (trash) to boost co-generation, combined with a factory based cleaning operation, has been investigated. As a starting point, it has been assumed that conventional high pressure steam plant is employed to generate power. These plants when integrated in a factory with a steam consumption of 52% SOC, have a power export efficiency averaged over the crushing and maintenance seasons of about 13% [based on the higher heating value (HHV) of bagasse]. More details of the co-generation model are given in Appendix 2.

Unlike the scenarios investigated in section 4.6, the importation of additional trash impacts all sectors of the industry. These effects are shown in Figure 11.

Inspection of the whole-of-industry relative net returns indicates a slow decline as trash levels increase. Comparing this trend with that in Figure 4, the decline in the former is significantly less rapid. This slow rather than rapid decline can be attributed to the effects of the decreased impact of trash on sugar production as a result of the cane cleaning plant, combined with increased income from power sales. The effect of power sales can be seen in the greatly increased net returns to the raw sugar manufacturer.

As in Figure 4, the returns to the field sector decrease, due to the lower ccs and therefore returns from the sale of cane, when additional trash is sent in to the factory. At about 10% additional trash, the losses to the field sector and industry as a whole decline more rapidly due to exceeding of threshold conditions beyond which additional irrigation and cultivation costs are incurred (ie the trash blanket left in the field is less effective in controlling weeds and improving water use efficiency). *In importing additional trash to the mill, assumptions regarding the ability of the harvester elevator to handle high levels of trash, and the capacity of mill and field transport systems at high trash levels are critical in costing, and additional field testing is advisable.*



From earlier sections, the field sector and the industry as a whole can offset loss of trash to some extent by turning down the extractor on the harvester to reduce cane loss. In practice, this strategy is not incompatible with increased levels of trash in the cane supply. However, for a fixed (low) fan speed, the trash in the cane supply when increased by increasing pour rate, will still result in a progressive decrease in relative net returns for both the field sector and the industry as a whole. This again provides no incentive for additional trash to be sent in to the factory.

The presence of a cane cleaning plant almost removes the effect of trash on sugar production. The main trade-off occurring in determining the profitability of the industry as a whole is between power sales by the factory and agronomic costs incurred by the farmer. Strategies aimed at increasing power sales are therefore a possible means of reversing the (albeit shallow) downward trend for the whole-of-industry net returns shown in Figure 11. Higher efficiency power generation cycles have been investigated together with more favourable tariffs based on a premium being paid for power generated by renewable means.

The division of revenue from co-generation of power is beyond the scope of this study and the results of the remaining investigation of co-generation scenarios are therefore presented solely in the form of returns to the industry as a whole.

A comparison of high pressure steam and BIG/CC power plants for increased power generation efficiency has been carried out. *In addition, in to order achieve the full*

efficiency gains from a BIG/CC system, the factory steam demand has been reduced to 35% SOC and to make a meaningful comparison the same SOC has been used for the conventional steam plant. Estimates of the cost of power production using BIG/CC technology have been given in section 3.2.8 as \$53 per MWh. This compares with a cost of power production of \$40 per MWh for the conventional steam cycle. Clearly, if any profit is to be derived from the installation of a BIG/CC system, a higher value has to be placed on the power produced. With continuing deregulation of the power market and options such as direct supply contracts with major consumers and an emerging market for “green” power, a higher price is not unrealistic.

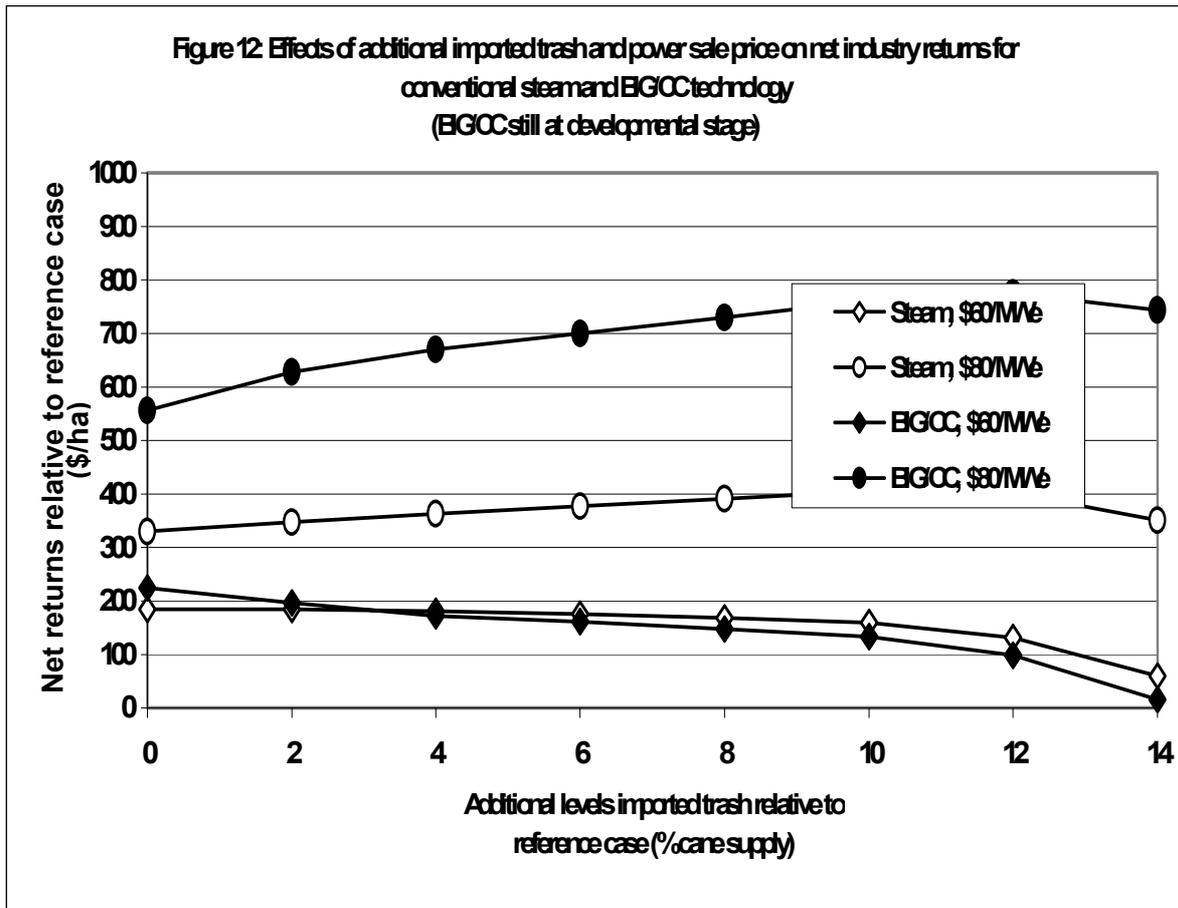
A comparison of net relative returns to the industry for conventional high pressure steam and BIG/CC power generation in the factory is shown in Figure 12. The effect of power sales prices of \$60 per MWh and \$80 per MWh are shown.

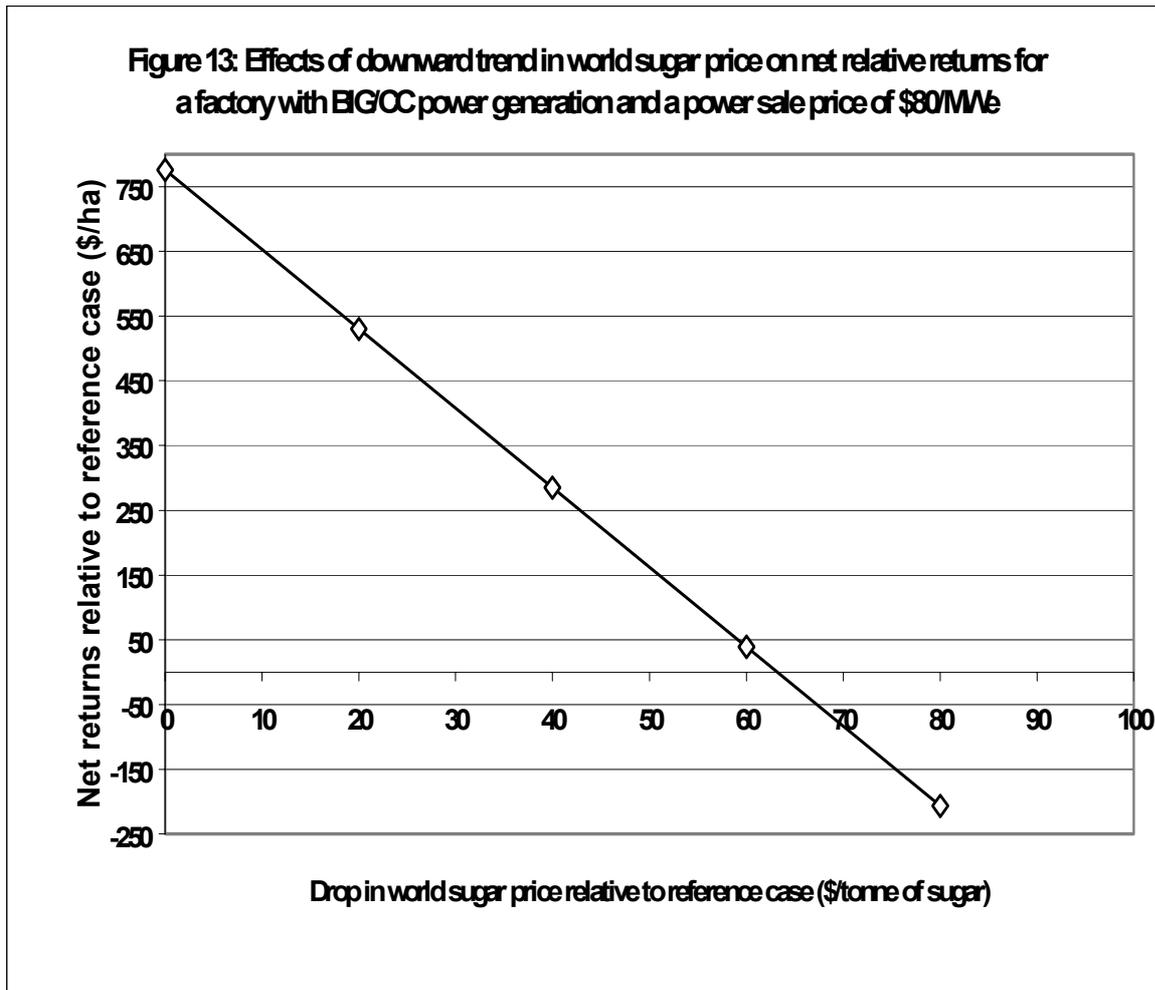
Figure 12 indicates that for a power purchase price of \$60 per MWh and (by inference) below, the installation of BIG/CC technology cannot be justified. Although a larger amount of power is produced by a BIG/CC system compared with a conventional steam turbo-alternator, the profit margin for the former system is lower. The higher generating efficiency of the BIG/CC system starts to dominate at \$80 per MWh and the net returns per hectare are almost double that obtained using the conventional steam cycle.

It is also noticeable from Figure 12 that at a power sale value of \$60 per MWh, the net returns per hectare start to reduce significantly at high levels of additional trash import for the BIG/CC system. This is primarily due to the increase in net returns from power sales being exceeded by the increase in agronomic costs as more trash is transported into the factory. This trade-off between agronomic costs and return from power sales is critically dependent on the value placed on trash on the ground. This value varies from high in the more northern cane farms to a negative value in northern New South Wales (where burning is currently necessary). The scenarios investigated in this study are closer to farming practices and conditions experienced by the more northerly cane farms and factories.

One of the aims in developing co-generation as a business activity within the sugar industry is to provide a buffer against long-term downward trends and short-term fluctuations in the price of sugar on the world market. Figure 13 shows the effect of a decrease in world sugar prices on net whole-of-industry returns. The predictions assume the scenario equivalent to the optimum level of trash import (11% relative to the reference case) for BIG/CC power generating technology and a power sale price of \$80 per MWh shown in Figure 12.

The implication of Figure 13 in terms of the buffering effect of co-generation on net returns is that with high efficiency co-generation, the industry as a whole would be able to weather an \$83 per tonne drop in the world sugar price before returns drop below current levels (zero \$/ha relative).





4.8 Feasibility of baling as an option for transporting trash to the mill

The data in Table 3 indicate a cost of approximately \$34 per tonne for baling and transport of tops and trash from the field. For the reference case it was assumed that approximately 11% EM in the form of tops and trash is present in the cane supply after starting with 25% in standing cane in the field. This is equivalent to approximately 19 t ha^{-1} of fresh trash blanket in the field (at 60% moisture) or 8.4 t ha^{-1} at 10% moisture. Costs of baling and transport, assuming 90% recovery of the 8.4 tonnes, would be \$257 per hectare.

A similar costing can be carried out for infield and mill transport of the 19 t ha^{-1} fresh trash if it is taken direct to the mill. Two scenarios were considered for both field and mill transport of the trash blanket material: a loss of 1% transport capacity per % trash and the higher figure of 3% loss in capacity per percent trash found by Edwards (1994). In both cases pour rate was held constant to allow for loss of harvester capacity at high trash levels. The model was used to compare transport costs for each scenario with the standard 5% trash in the cane supply. For scenario 1, the additional transport cost was \$92 per hectare and for scenario 2 \$134 per hectare. If an extra infield transporter is used for scenario 2 to maintain a comparable working day the cost is \$170/ha.

A flat rate per tonne was used for estimating mill transport costs taking into account the tare weight of bins, and no allowance was made for any additional costs associated with

transport scheduling. (It is assumed that the capital cost for any additional rolling stock is accounted for in the flat rate per tonne.)

If co-generation out of season is considered as an option the cost of storage of material also needs to be taken into account. Storage on farm or at the factory would be carried out using similar techniques to those currently employed for bagasse storage at the factory, although there may be a requirement for some pre-drying of trash to avoid spontaneous combustion. Costs associated with factory storage would be similar to those currently established for bagasse storage.

4.9 A comparison of scenarios

This section explores the relative potential financial gains that can be made as a result of different strategy options for dealing with trash. Five different strategies are compared:

1. ***Improved harvesting practice.*** This strategy combines reduction of extractor fan speed and harvester forward speed. Fan and forward speeds are taken as corresponding to those of scenario 3 in Table 6.
2. ***Improve harvester technology and practice.*** In this option, both the cane loss and cane cleaning characteristics of the harvester are assumed to be improved by 70%. In addition, the pour rate is decreased to minimise trash in the cane supply without excessive increases in harvesting costs. With these improvements, the optimum level of trash in the cane supply is – 2% relative to the reference level.
3. ***Secondary cleaning at the factory combined with improved harvester technology and practice.*** This option involves changes to harvester technology and practice equivalent to those in strategy 2, with the exception that no improvement in cleaning capacity of the harvester is assumed. Final cleaning of the cane is carried out at the factory with minimal changes in the level of power generation.
4. ***Steam cycle power generation and harvester improvements and a higher power sale price.*** This involves trash separation at the factory and the use of trash for power generation in a steam cycle system. A sale price for power of \$60/MWh is assumed. Changes to harvester technology are in the form of a 70% improvement in cane loss characteristics.
5. ***Advanced cycle power generation, a higher power sale price, additional imported trash, and harvester improvements.*** This involves importing additional trash, trash separation at the factory and the use of trash for power generation in a BIG/CC system. A sale price for power of \$80/MWh is assumed. Changes to harvester technology are in the form of a 70% improvement in cane loss characteristics. With this change to harvester technology, the optimum level of additional imported trash remains at +11% relative to the reference level.

A comparison of the relative returns to the industry as a whole for these five options is shown in Figure 14.

By way of comparison with the reference case shown in Table 5, a break-down of costs associated with the high net return co-generation option is given in Table 7.

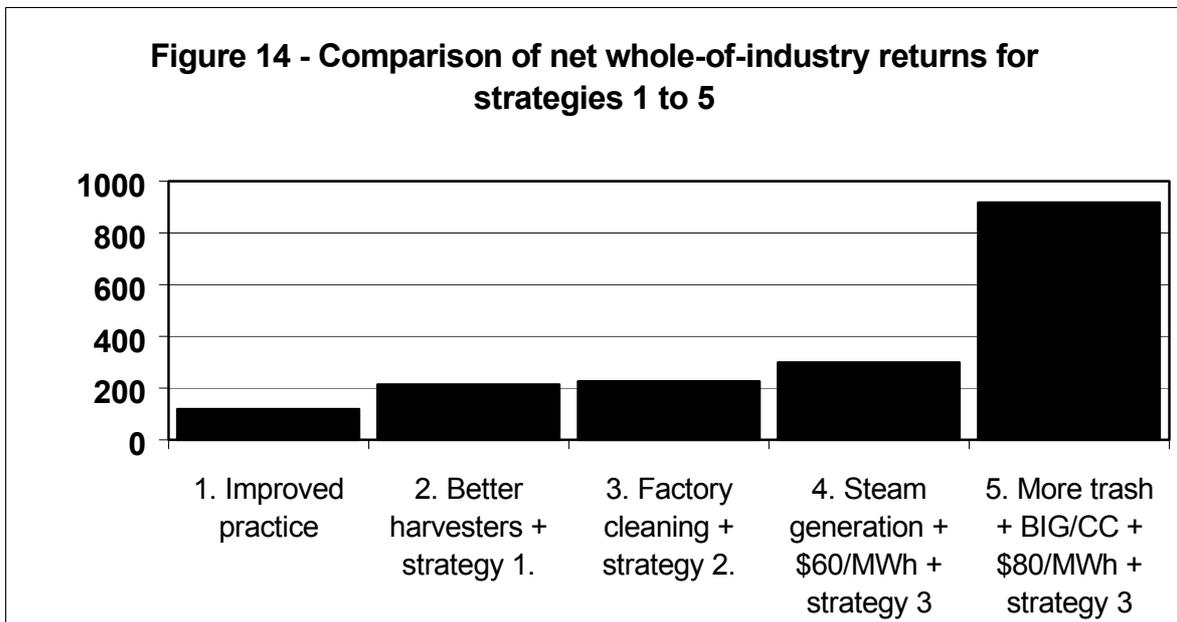


TABLE 7

Component costs and returns for strategy 5 relative to the reference case (\$/ha)

Cost item	Field	Factory	Industry
Price of cane	-247.68	247.68	
Harvest cost	-2.37		-2.37
Agronomic costs	-52.31		-52.31
Power returns		821.27	821.27
Sugar and molasses returns		171.29	171.29
Cane feeding capital costs		-14.6	-14.6
Milling train capital costs		43.24	43.24
Low grade station costs		17.22	17.22
Rail transport costs		-54.46	-54.46
Factory cleaning costs		-11.93	-11.93
Net return	-302.36	1,219.71	917.35

4.10 Conclusions

- A reduction in harvester pour rate, relative to the reference rate, will reduce the level of extraneous matter in the cane supply and produce an increase in net returns for the industry as a whole. An optimum pour rate is indicated below which the cost of harvesting reduces net returns for the industry as a whole. The field sector is the main beneficiary of this strategy. The optimum pour rate for the field sector corresponds

closely to that for the industry as a whole. Conversely if pour rate is increased relative to the reference conditions, all sectors of the industry will receive lower net returns.

- For the pour rates investigated, a reduction in harvester extractor fan speed (and therefore a reduction in cane loss) was always accompanied by an increase in net returns for both sectors of the industry. For all the fan speeds investigated, a reduction in pour rate would always increase the returns of the industry as a whole. By a reduction in both fan speed and forward speed it is possible to optimise returns to the whole industry. The optima indicated in the report occurred at the lower extremes of the extraneous matter/pour rate and fan speed/cane loss correlations and should therefore be treated with the appropriate caution. These lower ranges are evidently of interest in terms of the harvester operation and suggest the need for more performance data measurements in this region. This will allow assessment of the scope for incentives to encourage changes in harvesting practices.
- In terms of increasing whole-of-industry net returns by developing better harvesters, improved cane loss and improved extraneous matter removal had equivalent (positive) effects. Developments leading to increased harvester pour rate alone had a relatively small effect on net industry returns.
- The installation of a factory-based cane cleaning plant can be justified at relatively low rates of trash removal (between 10% and 60% removal of trash for the range of available capital cost estimates). Such plants are potentially capable of removing up to 98% of incoming trash.
- The importation and factory removal of additional trash for co-generation produce substantial increases in net returns to the factory. At an assumed price paid for power of \$50 per MWh, the revenue received is not sufficient to compensate for the agronomic costs incurred by the field sector. The net result is that of a negative economic impact on the industry as a whole. This result may only be relevant to the more northerly-located sugar companies. In northern New South Wales, the positive agronomic benefits of a green cane trash blanket are not clear cut and importing trash for co-generation becomes more attractive. *The agronomic value of trash is obviously strongly dependent on local terrain and weather patterns and is an area of knowledge requiring significantly further investigation. In addition, the effect of high levels of trash on bin weights is not well documented and further work is required to confirm transport costs.*
- The prognosis for the additional importation of trash to boost power production only improves significantly when the price paid for power increases to \$80 per MWh. At this price, the net returns with the installation of a cane cleaning plant and a conventional (high pressure) steam turbo-alternator, rises to an optimum of \$405 per hectare (for the industry as a whole) with the importation of an additional 10% trash (at a cleaning plant capital cost of \$1 million).
- The use of more advanced power generation technologies such as BIG/CC result in greater amounts of power being exported, but at a higher cost (and therefore lower net return) than for more conventional technology. At power prices of \$60 per MWh, the net returns from a conventional steam plant exceed those from a BIG/CC installation.

At \$80 per MWh, this situation is dramatically reversed with increases in net whole-of-industry returns of \$776 per hectare using BIG/CC technology, and the importation of 12% additional trash.

5.0 DIFFICULTIES ENCOUNTERED DURING THE PROJECT

Since this project was a desk top study, information included in the model is based mainly on published data and capital costing of new items such as the cleaning plant and co-generation systems is a best estimate only. There is some uncertainty in areas such as very low trash and cane loss scenarios in the field, the transport costs of cane with very high trash levels, the impact of agronomic factors associated with trash blanketing in different regions and the capital costing mentioned above. This will have some impact on the conclusions reached and sensitivity analysis has been carried out where feasible.

6.0 RECOMMENDATIONS FOR FURTHER RESEARCH

There is a need for better information on the effect of high trash levels on capacity of cane transport systems; the performance of harvesters at high trash levels and for low pour rate, low cane loss operating conditions; and better definition of the agronomic value of trash in different regions. Most of these factors are relevant to the scenario of importing more trash to the mill for high efficiency co-generation of power. There has also been considerable interest expressed in expanding the scope of the model to allow costing of different levels of soil in the cane supply and benefits from cleaning at the mill.

7.0 APPLICATION OF RESULTS TO THE INDUSTRY

Components of the model have been applied in the Mossman and Tully Mill areas to indicate the impact of harvest strategies for minimising trash levels and cane loss on harvesting costs, and potential grower and miller returns. Pilot studies are proposed for assessing the practicality of applying such strategies. It has considerable potential value for mills planning to utilise trash for co-generation of power.

The optimisation of field and factory operations will almost certainly need to be established at a local level and the results presented here are intended to be a guide only to the issues involved.

8.0 PUBLICATIONS

There have been no publications from the project.

9.0 REFERENCES

Anon (1970). Laboratory manual for Queensland sugar mills, Bureau of Sugar Experimental Stations, 5th edition, p157.

- Anon (1984). A review of results of trials with trash management for soil conservation. Proc Aust Soc Sugar Cane Technol, pp 101-106.
- Anon (1993). CAPA productivity review, Tully Sugar Industry Productivity Committee report for 1993.
- Anon (1994). CAPA productivity review, Tully Sugar Industry Productivity Committee report for 1994.
- Brotherton, G A (1980). The influence of extraneous matter on CCS; Proc Aust Soc Sugar Cane Technol, pp7-12.
- Brotherton, G A and Pope, G (1995). The financial implications of harvester characteristics. Proc Aust Soc Sugar Cane Technol, pp55-60.
- Clarke, W B, Player, M R and Weiss, G H (1988). Effect of extraneous matter on millers' and growers' costs. Proc Aust Soc Sugar Cane Technol, pp39-46.
- Dixon, T F, Hobson, P A, Joyce, J A, Pohl, J H, Stanmore, B R and Spero, C (1998). Electricity co-generation and greenhouse gas abatement in the sugar industry, report prepared by the Queensland Biomass Energy Group (August).
- Edwards, B P (1994). Trials on the effect of trash on factory operations in 1991 and 1992, SRI Technical Report number 8/94 (July).
- Frost M B and Stevenson, D M (1980). Cane quality in the South Johnstone area. Proc Aust Soc Sugar Cane Technol, pp33-20.
- Hardman, J R, Tilley, L G W and Glanville, T (1985). Agronomic and economic aspects of various farming systems for sugarcane in the Bundaberg district. Proc Aust Soc Sugar Cane Technol, pp147-153.
- Hemaida, S E A, Sayed, G E, Hussein, M A and El Badawi, A A (1975). Factors affecting sugar losses, the presence of cane trash with sugar cane during milling. The Egyptian sugar distillation (sic) company, sugar cane department research bulletin 51.
- Hobson, P A (1997). The use of a computer model to investigate improved cane cleaning systems, Proc Aust Soc Sugar Cane Technol, pp162-169.
- Hobson, P A and Dixon, T F (1998). Gasification technology- Prospects for large scale/high efficiency cogeneration in the Australian Sugar Industry. Proc Aust Soc Sugar Cane Technol, pp1-9.
- Ivin, P C and Doyle, C D (1989). Some measurements on the effects of tops and trash on cane quality. Proc Aust Soc Sugar Cane Technol, pp1-7.
- Ivin, P C, Corica, F, Cox, L M and Whayman, E (1990). Further measurements on the effects of tops and trash on cane quality. SRI annual Technical Conference.

- Kent, G A (1986). Chopped cane bulk density; SRI technical Circular No. 89, pp69-72.
- Kent, G A, Allen, W J, Hoare, C P and Dixon, T F (1999). The effect of extraneous matter on factory throughput and performance, Proc Aust Soc Sugar Cane Technol, pp38-43.
- Ridge, D R, and Powell, J (1998). Management assistance for optimised harvester/in-field transport productivity. Final report to the Sugar Research and Development Corporation on project BS124S.
- Scott, R P, Falconer, D And Lionnet, G R (1978). A laboratory investigation of the effects of tops and trash on extraction, juice quality and clarification. Proc. SASTA, pp51-53.
- Sloan and Rhodes L J (1972). A comparison of burned and unburned sugarcane. Hawaiian Planters Record 58, 14, pp173-182.

10.0 ACKNOWLEDGMENTS

The funding support from the Sugar Research and Development Corporation for this project is gratefully acknowledged, together with data provided by Chris Norris and Cam Whiting, Tully Productivity Committee and input of other BSES and SRI staff. Data provided by Peter Wright on operating and maintenance costs in the factory and editorial guidance arising from an industry panel review of the project are also acknowledged.

APPENDIX 1

SENSITIVITY ANALYSIS

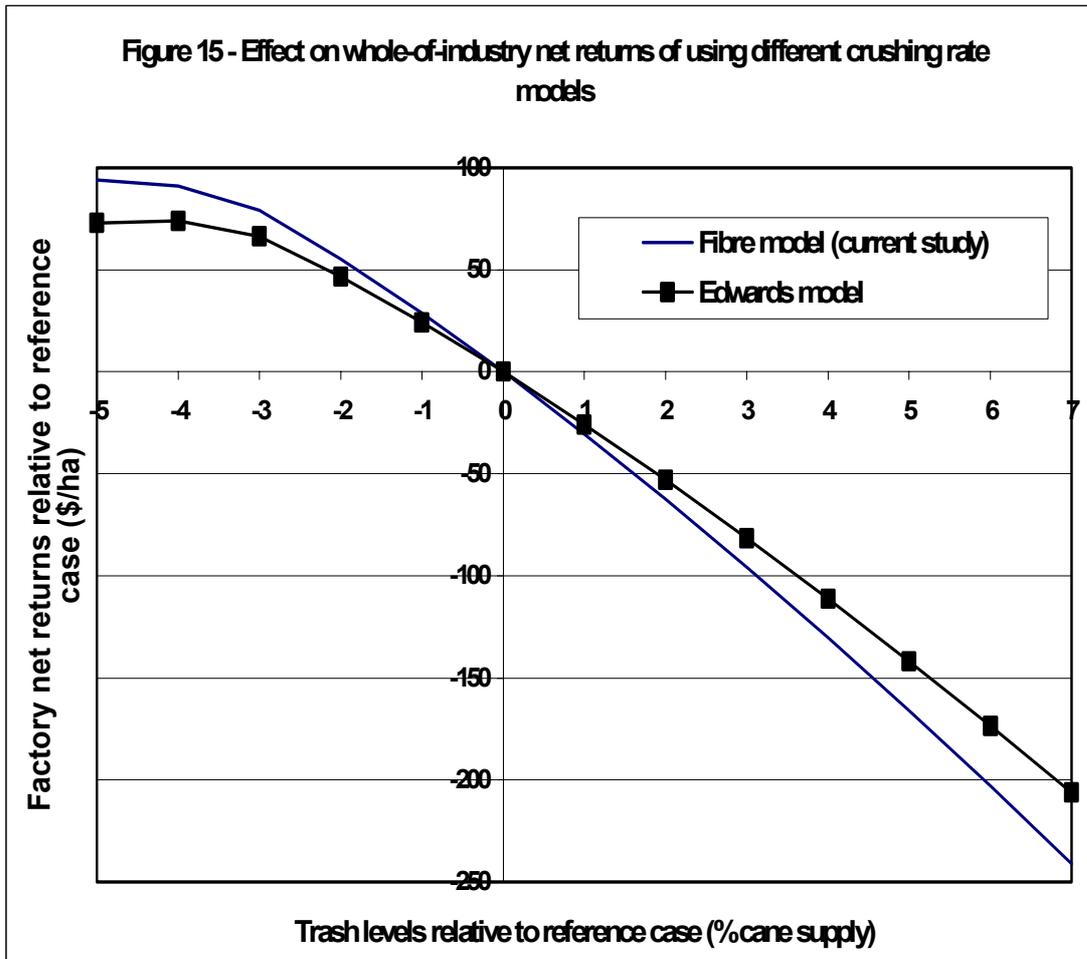
BACKGROUND

The sensitivity analysis was carried out on model outputs where alternative industry figures to those initially used were available for the impact of trash on model components. These components included:

- mill crushing rate;
- additional operating and maintenance costs where milling and low grade capacity was expanded to process additional trash;
- mill and field transport costs;
- mill extraction;
- pol of trash;
- economics of factory based cleaning.

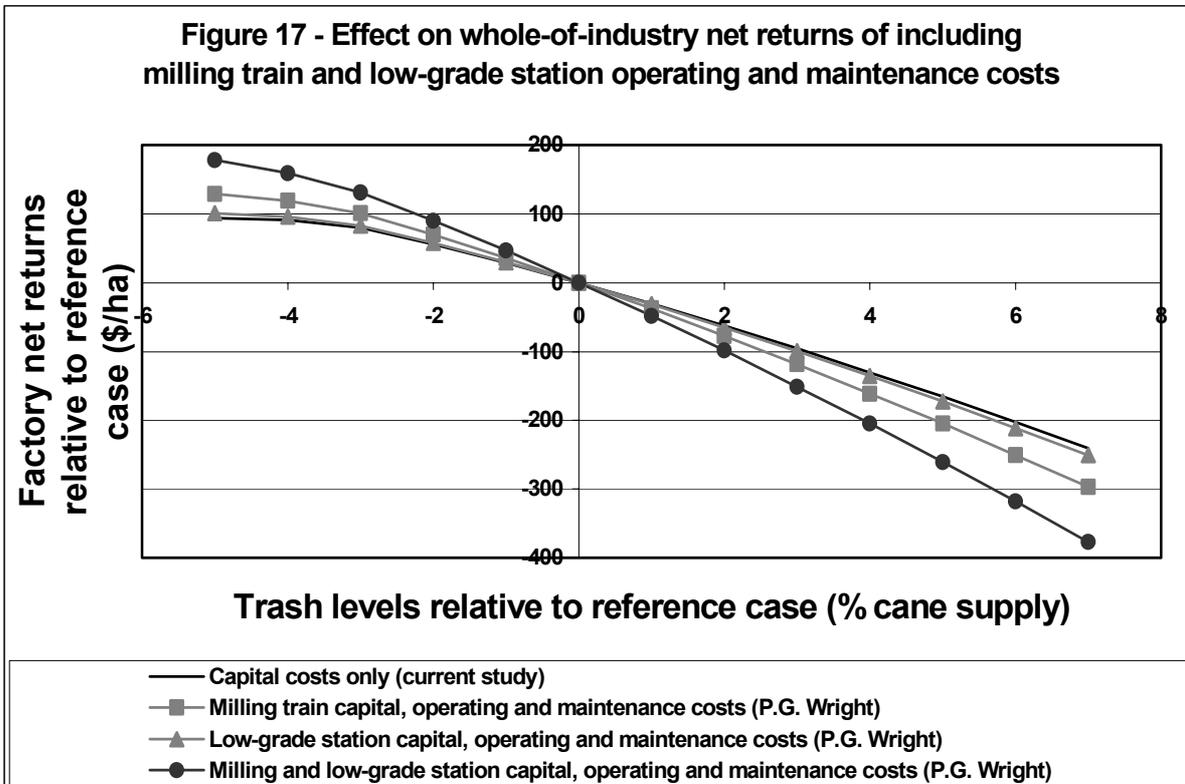
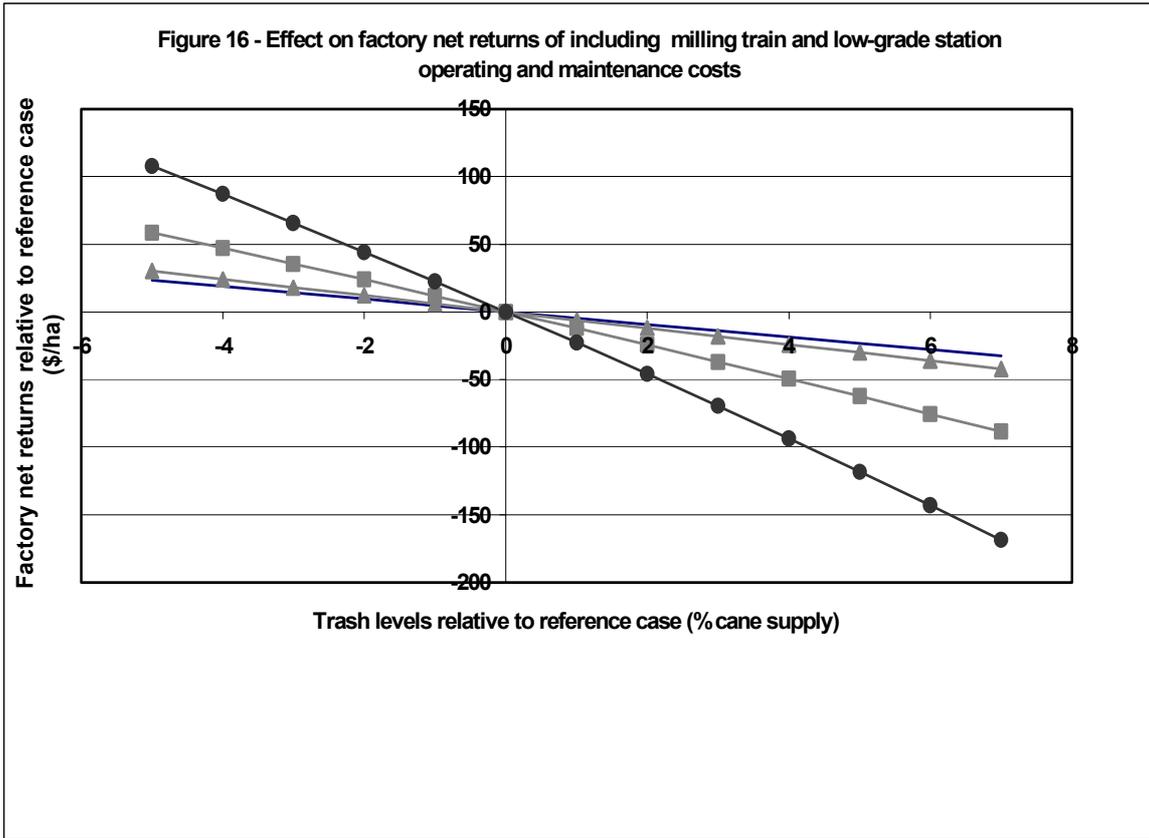
MILL CRUSHING RATE

Three main options for assessing the effect of trash on mill crushing rates were considered: the original model input based on Edwards (1994) indicating a change of 2.5 th^{-1} per percent trash at 370 th^{-1} , the data of Kent *et al.* (1999) indicating a change of 3.3 th^{-1} per percent trash at 370 th^{-1} and the fibre rate model of Clarke *et al.* (1988). In the fibre rate model, crushing rate is assumed to be directly proportional to fibre processing rate and dirt in cane was considered as fibre. Model outputs for the Edwards and Clarke models only are compared in Figure 15 as these represent the extremes. In the fibre rate model, industry returns are increased at lower fibre levels and reduced at higher fibre levels relative to the standard model due to increased mill crushing costs per %fibre, but this does not alter the general effect of changing fibre levels on returns.



INCLUSION OF MILLING TRAIN AND LOW GRADE STATION OPERATING AND MAINTENANCE COSTS

The current study includes an allowance for additional capital costs in the milling train and low grade stations where extra trash is being processed. The implicit assumption has been made that operating and maintenance costs associated with an expanded capacity are negligible in comparison with capital costs. This may not be completely correct and sensitivity analysis of the potential impact of operating and maintenance costs on factory and industry returns has been carried out by assuming that costs are incurred in proportion to the expansion of capacity. In the following sensitivity analysis this has been achieved by simply inflating the capital costs appropriately. As expected both factory and industry returns are reduced significantly and additional fibre has a negative impact. The figures used were derived from the SRI factory model by Wright (personal communication). The model outputs with and without these costs are summarised in Figures 16 and 17 for the factory and industry on factory returns where these costs are included for both milling train and low grade stations.

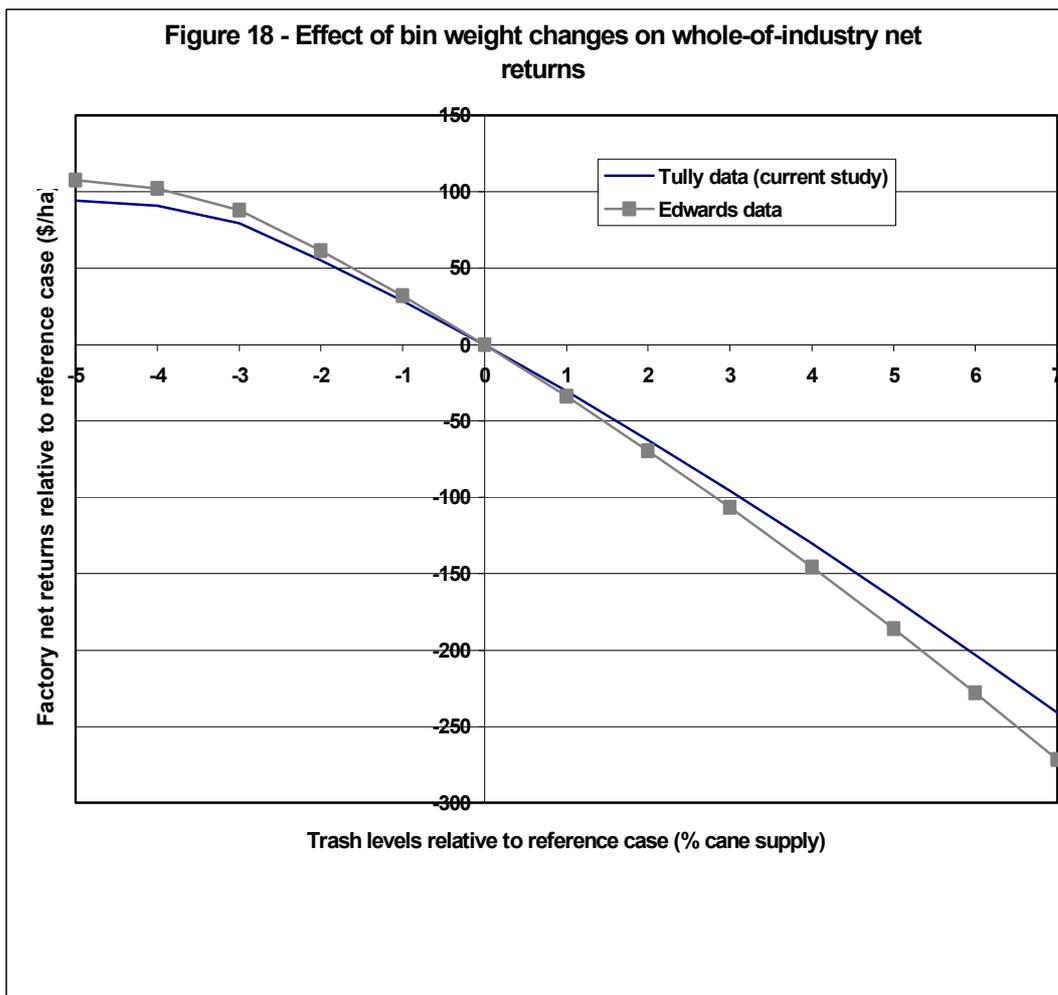


MILL AND FIELD TRANSPORT COSTS

The sensitivity of mill and field transport costs to varying trash levels was assessed using both data from Tully Mill Productivity Reports and trial data obtained by Edwards (1994). Changes in transport capacity, respectively, are 0.01% and 0.025% per % trash. Comparative figures for whole of industry returns are given in Figure 18. The effect of changing sensitivity of transport capacity to trash content is similar in magnitude to the crushing rate effect in Figure 15 but in this case both field sector and factory returns are affected by varying trash levels. While the Tully data are based on actual mill bin weights at different trash levels in normal operations over a full season, further investigation of bin capacity at high trash levels may be justified as trial results under controlled conditions suggest a larger effect than the mill figures.

MILL EXTRACTION

The work of Edwards (1994) used in the model suggests very little effect of trash on mill extraction and this is supported by Kent *et al* (1999). Edwards figure of 0.05% change in extraction per %trash was compared to a figure of 0.1% change per %trash and this was found to have negligible effect on whole of industry returns versus trash levels.



TRASH SUGAR CONTENT

Estimates of the impact of varying trash content of the cane supply on industry returns are based on a best estimate of the brix and pol of trash as indicated in Table 2. Recent extensive trials at Mulgrave mill (42 separate trials) provide a good estimate of trash composition for north Queensland (Norris, personal communication). In these trials, brix and pol of trash and cane were determined in the field prior to harvest and at the mill after harvest. Brix and pol of trash were found to increase after harvest and brix and pol of cane to decrease. Data from these trials and from other sources are summarised in Table 8.

Preliminary runs of the model indicate that trash composition can significantly affect the impact of varying trash levels on grower and miller returns. It will also impact on the operation of cane cleaning plants in that recovery of sugar from the trash may be justified.

TABLE 8

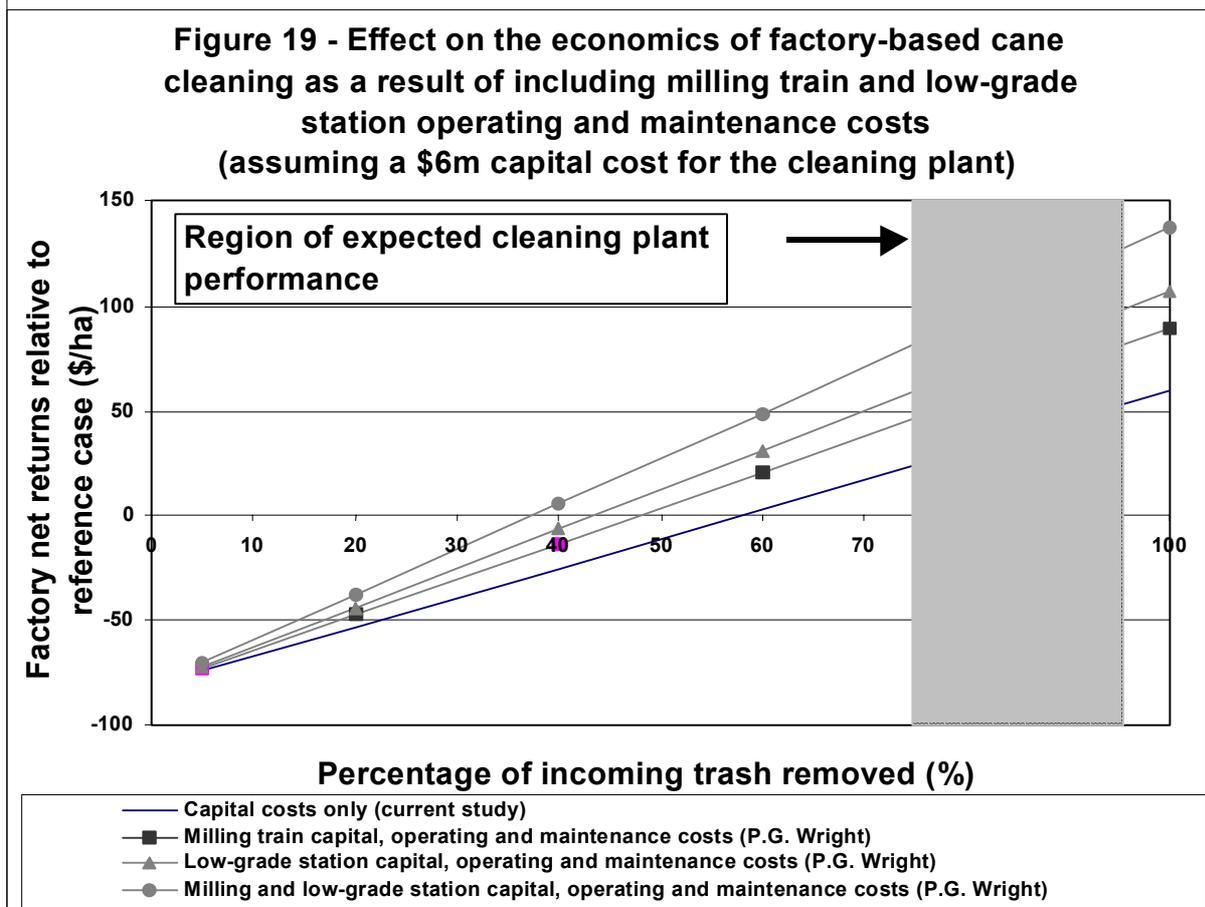
Data on trash composition from various sources and cane ccs from north Queensland trials and model input

Data source	Trash			Cane
	Brix%	Pol%	ccs	ccs
NQ Trials Field	5.36	1.92	0.2	14.94
Mill	6.54	3.38	1.8	14.37
Model	9.00	0.63	-3.56	14.50
Biomass Trials *	6.23	0.92	-1.7	
Clarke	10.6	4.4	1.3	

* Bundaberg data- mean of 16 harvests (Kingston, unpublished data)

FACTORY BASED CLEANING

The impact of including milling train and low grade station operating and maintenance costs in the assessment of the economics of factory based cane cleaning is indicated in Figure 19. In this analysis, it is assumed that maintenance and operating costs will be proportionately reduced relative to the reference case if the required capacity of the milling train and low grade stations is reduced by cleaning. The higher costs associated with the inclusion of operating and maintenance factors increase the predicted benefits of a factory cleaning plant. This ensures that the reported benefits in the main study (ie those due to avoided capital costs only) are on the conservative side. By including all the above additional costs, the 'break even' level of trash removal for a factory cane cleaning plant reduces to 47% of incoming trash.



APPENDIX 2

FURTHER DETAILS ON THE CO-GENERATION MODEL

The main steps in the calculation of revenue from exported power from a conventional high pressure steam system are as follows:

- The total energy of combustion (Higher Heating Value or HHV) of all trash and milled bagasse is calculated using standard relationships (eg Dixon *et al.*, 1999) between fibre, ash, bagacillo and moisture content. This 'standard relationship' has been developed for bagasse, but has been applied in the model to determine the HHV of the trash based on known fibre, ash and moisture content and an assumed percentage bagacillo.
- From an assumed constant boiler efficiency of 65% (this is a moderately efficient boiler given that fuel moisture contents are around 50%), the total amount of heat available to raise steam from the available bagasse/trash (less 5% set aside for start-up and maintenance) is calculated.
- Enthalpies associated with a condenser supply temperature of 90 °C and HP steam delivery pressure and temperature of 48 bar abs. and 380 °C, respectively, are used to calculate the total mass of steam generated over the season given the heat available from the boiler. These operating pressures and temperatures correspond to those of a boiler installed at Invicta and are the maximum (most efficient) currently in the industry.
- A typical factory steam consumption figure of 52 tonnes of steam for every 100 tonnes of cane processed is used to calculate the total seasonal steam consumption. All available steam is assumed to pass through an extracting-condensing turbine set with steam extracted at the appropriate pressure and in sufficient quantities to satisfy factory process heating demand. Any steam in excess of factory requirements is expanded further through the condensing set and exhausted at sub-atmospheric pressures (0.1 bar abs.). This condensing pressure is not as low as would be used in a high efficiency utility cycle but corresponds to that of the South Johnstone unit, the only condensing set in the industry.
- The calculated efficiency with which electrical energy is generated by the extracting-condensing turbine set are implicit in the turbine exhaust steam enthalpy values used in the current spreadsheet model. These values are taken from a more comprehensive co-generation model developed under SRDC project SI073 (Dixon *et al.*, 1999). In effect the enthalpy calculations from the latter are based on isentropic turbine efficiencies of 84% and 74%, respectively, for the high pressure and condensing sets. A mechanical-to-electrical conversion efficiency of 93% is used. From these figures, the total electrical energy generated from the available bagasse is calculated.
- Factory electrical energy requirements are calculated based (for simplicity) on the assumption that both the shredders and milling trains are fitted with electro-hydraulic

drives. The conversion efficiency for this transmission system is assumed to be 78%. The electrical energy requirements of boiler ancillary equipment are included explicitly, with all remaining demand included in the current program under '*other internal electrical requirements*'. The factory electrical energy demand rates are given in the program as a function of the crushing rate (th^{-1}). Figures used for the power requirements of the milling train, shredder, boiler ancillaries and '*others*' are 8, 10, 2.7 and 10 kWh^{-1} . These figures (used in developing the results presented in the final report for this current project) have been obtained from a number of sources within SRI (consulting reports, personal communications etc) and are deemed typical of current factory requirements.

The factory electrical energy requirements over the season are deducted from the total electrical energy generated to give the exported electrical energy available for sale.

- The cost of electrical energy generated from a conventional high pressure steam plant operating on bagasse/trash only and as an integral part of a 600 th^{-1} factory has been established by Dixon *et al.* (1999) as $\$0.04 \text{ kWh}^{-1}$. This figure is based on new generating plant and storage capital, as well as operating costs associated with year-round co-generation. The economic analysis used in determining the above figure is based on a zero net present value for the plant and has been carried out using the proprietary software package, ECLIPSE. The estimated uncertainty associated with the cost of energy figure is $\pm 30\%$. The effect of tax on revenue from power sales is not considered.
- The total annual net return from power sales is then calculated assuming (unless otherwise stated) a sale price of $\$0.05 \text{ kWh}^{-1}$.
- The co-generation model is at all times active. Any strategy which results in a change in the fibre level of the cane supply, will have the effect of producing a positive or negative change (relative to the reference case) in the net returns from co-generation. When the cane cleaning component of the model is active, it is assumed that all trash separated from the main cane supply will rejoin the main bagasse stream and ultimately be used for power generation. This means that for the same level of trash in the cane supply, the net income from co-generation alone remains constant regardless of whether or not a cane cleaning plant is in operation.

MAIN FEATURES OF THE CALCULATION OF POWER GENERATION FROM HIGH EFFICIENCY BIOMASS INTEGRATED GASIFICATION/ COMBINED CYCLE TECHNOLOGY

- The power generated via the gasification of the available bagasse and subsequent combustion of this gas in a gas turbine, is predicted in the current model from a given open-cycle gas turbine efficiency value. This value is taken from a more detailed thermodynamic model developed under SRDC project SI073. A gasifier/ gas turbine efficiency value of 25% (based on the HHV) has been used in developing the results presented in the current report.

- The gasifier/gas turbine efficiency value is also used to determine the heat available for high pressure steam generation from waste heat recovery from the gas turbine exhaust stream. The method of calculating electrical power and process heat developed using the steam raised by the waste heat recovery system, is identical to the conventional high pressure steam turbo-generator analysis described above.
- If there is not sufficient heat recoverable from the gas turbine exhaust to provide steam for the factory, the spreadsheet program assumes that a BIG/CC system and conventional steam generation unit (boiler) are present in the factory. The available bagasse is then assumed to be split and sent to the BIG/CC system and boiler in proportions that would ensure the combined steam output of these two units is just sufficient to satisfy the factory steam demand.
- An energy cost figure \$0.053 for a BIG/CC unit is used in this report. This value has been obtained by Dixon *et al.* (1999) using the ECLIPSE program and a similar set of economic parameters to those used for the above conventional steam cycle.
- Where BIG/CC and conventional steam units are both required (to generate the required factory steam), the cost of power generation per kWh is assumed to be an average value weighted in proportional to the quantities of bagasse being fed to the respective units. This approach has been taken in the absence of available cost data for the hybrid system.

REFERENCES

Dixon, T F, Hobson, P A, Joyce, J A, Pohl, J H, Stanmore, B A, and Spero, C (1999) '*A feasibility study of cane fibre gasification for increased co-generation*', Final report on SRDC project SI073.