

BIOENERGY FOR SUSTAINABLE DEVELOPMENT AND GLOBAL COMPETITIVENESS: THE CASE OF SUGAR CANE IN SOUTHERN AFRICA

A COMPILATION OF RESULTS FROM THE THEMATIC RESEARCH NETWORK:
Cane Resources Network for Southern Africa (CARENSA)



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Thematic Report 1: Agriculture



This report along with related information is available on the CARENSA website:
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This report is a part of the series of five Thematic Reports compiled under the CARENSA work programme, and should be thus cited.

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ISBN: 978-91-86125-00-4

ACKNOWLEDGEMENTS AND DISCLAIMER

This report was the result of several years of fruitful collaboration among the thirteen CARENSA partners along with subcontractors and others who contributed valuable ideas and detailed data. Many persons gave their time above and beyond what was called for in order to evaluate the role that sugar cane and other productive energy crops can play in supporting sustainable development and global competitiveness in southern Africa.

Thanks are extended to those who conducted a scientific peer review of the report:

- Mr. P.J. Manohar Rao from India, one of the world's foremost experts on sugar cane, who has authored several books on sugar cane and its co-products;
- Mr Denis Tomlinson, ILLOVO Sugar, who has been active for many years in international initiatives on sugar cane as a renewable energy resource.

The scientific editor for this report was Bothwell Batidzirai (Chinhoyi University, Zimbabwe).

The technical editor and layout artist for this report were Kanika Pal and Jaison Jose respectively (Winrock International India).

Special thanks are extended to the University of Mauritius for hosting a workshop and stakeholders meeting in November 2004, which brought together academic, industry, and government representatives to present and debate the key issues on this topic, and which provided a solid foundation for completing the analysis in this report, as well as in the other reports in the CARENSA series.

The research programme that led to this report was supported under Contract A-4-2001-10103 in the European Commission Fifth Framework Research Programme, under which the Cane Resources Network for Southern Africa (CARENSA) operated as a Thematic Research Network. Additional funds were provided through the Swedish International Development Cooperation Agency (Sida) and Stockholm Environment Institute (SEI). The views expressed in the report are strictly those of the authors and do not necessarily represent those of their respective organisations nor do they represent the views of the European Commission, the SEI or Sida.

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ACRONYMS

BNT	Burnt, not topped (harvesting treatment)
BT	Burnt and topped (harvesting treatment)
D.R. Congo	Democratic Republic of Congo
EC	Electrical Conductivity
EROS	Earth Resources Observation Systems
FAO	Food and Agriculture Organisation
GIS	Geographic Information Systems
GPS	Geographical Positioning System
GT	Green cane, topped but not trashed (harvesting treatment)
IGBP/IHDP	International Geosphere-Biosphere Programme/ International Human Dimensions Programme
MAR	Mean Annual Rainfall
NIR	Near Infrared
RV	Recoverable Value
SA	South Africa(n)
SADC	southern African Development Community
SASEX	South African Sugar Association Experimental Station
SLIP	Sugar Logistics Improvement Programme
WDPA	World Database on Protected Areas
WP	Whole plant, i.e., Green cane, not topped nor trashed (harvesting treatment)
USAID	US Agency for International Development

UNITS AND SYMBOLS

dS/m	deci-Siemens per metre (measure of electrical conductivity)
GWh	Gigawatt Hour
Ha	Hectare
hilo	trailer used for transporting cane, often of a standard size
K ₂ O	Potassium Oxide
kg	kilogram
Km	Kilometre
kW	Kilowatt
MJ/kg	Megajoules per kilogram
Mm	Millimetre
MW	Megawatt
Na ₂ O	Sodium Oxide
Rs	Rupees (Indian currency)
t/ha	tonne per hectare
US\$	US dollar
ZAR	South African Rand

PREFACE

This report covers the agriculture phase within the CARENSA work programme. The CARENSA series of reports provide a critical assessment on the role of sugar cane resources in promoting sustainable development and global competitiveness in southern Africa. Among the many agricultural sources of biomass, sugar cane has special significance for the developing world, due to its high photosynthetic efficiency, its limitation to tropical and sub-tropical climates, and the long experience with its cultivation in developing countries. The CARENSA reports also briefly consider—within a similar context—the role of other highly productive energy crops such as Sweet Sorghum. The CARENSA series includes the following reports:

- Thematic Report 1: Agriculture
- Thematic Report 2: Industry
- Thematic Report 3: Markets
- Thematic Report 4: Impacts
- Thematic Report 5: International Experiences and Comparisons
- Thematic Report 6: Synthesis and Integration

Growing concerns worldwide about the impacts of climate change and the world's increasing dependence on fossil fuels have intensified interest in bioenergy and biofuels. The potential expansion of sugar cane and other highly productive energy crops in the developing world highlights important linkages among energy, environment and development goals across all scales—from local to global. As global markets develop and expand, it remains important that such crops be grown in the regions where they are most productive, so as to maximise their benefits and minimise negative impacts. The CARENSA reports address key issues across all relevant scales—local, national, regional, and global—based on the recognition that sugar cane has become a truly *global* resource for renewable energy and sustainable development. The reports draw on the many topics (work packages) within the CARENSA work programme, including:

- Agronomy & Land Resources
- Harvesting and Delivery
- Process Systems Analysis
- Fibre Resources
- Sugar Resources
- Policies and Regulations
- Trade, Financing, & Investment
- Implementation and Strategies
- Socio-economic Impacts
- Environmental Impacts
- Risk Analysis & Competitiveness
- Sustainable Development
- International Experiences & Comparisons
- Industry Perspectives
- Communications
- Dissemination

CARENSA brings together many different types of actors and stakeholders, representing government agencies, NGOs, industry, research institutes, university research groups, and international organisations:

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- 1) SEI, Stockholm Environment Institute, Sweden (Coordinator)
- 2) IC, Imperial College, London, UK (Principal Contractor)
- 3) UM, University of Mauritius, Chemical and Sugar Eng. Dept. (Principal Contractor)
- 4) UND, University of KwaZulu Natal, Durban, South Africa (Principal Contractor)
- 5) AUA, Agricultural University of Athens, Greece (Member)
- 6) CIRPS, Interuniversity Research Centre on Sustainable Development, Italy (Member)
- 7) BUN, Biomass Users Network, Zimbabwe (Member)
- 8) CEEEZ, Centre for Energy, Environment, and Engineering, Zambia (Member)
- 9) ISO, International Sugar Organisation (Member)
- 10) FAO, Food and Agricultural Organisation (FAO), United Nations (Member)
- 11) WII, Winrock International India (Member)
- 12) CENBIO, National Reference Centre for Biomass, Brazil (Member)
- 13) SADC, southern African Development Community (Member)
- 14) UNICAMP, University of Campinas, Brazil (Member)

In addition to the network members, representatives from many other organisations from both the public and private sectors were invited to CARENSA workshops and seminars.

Sugar cane has come to be associated with the production of bio-ethanol, particularly in Brazil, where bio-ethanol meets a significant share of the demand for transportation fuels. Sugar cane has also been associated with cogeneration of electricity from the significant amount of residues that remain after production of sugar, such as in Mauritius, where a significant share of the country's electricity generation now comes from the efficient systems installed at sugar factories. Many other countries have been encouraged by developments in Brazil, Mauritius, and elsewhere, and have established new programmes for expanded energy generation from sugar cane. Indeed, some future scenarios are based on using sugar cane predominantly or even solely for its energy production, as it provides an economically competitive and climate-neutral renewable energy resource.

Although the CARENSA reports focus on bio-ethanol and cogeneration because of their commercial significance, the reports also include some of the other “by-products” or “co-products” that can and have been produced from the sugar cane crop. Sugar cane is in fact also significant for its versatility as an economic resource; a wide variety of products have been developed from it to provide food, feed, and fibre as well as fuel. This versatility of sugar cane is valuable in economic terms, as it allows companies and investors to reduce the risk associated with relying mainly—or only—on one product, as has been the case with sugar markets, where rather complicated preferences and special arrangements have been used to protect certain segments of the market from competition. As these preferential markets are gradually removed, the discipline of market competition can help to unleash the potential of sugar cane as a global and sustainable resource.

1 Introduction

Energy crops represent the highest potential source of modern biomass energy apart from other sources such as harvesting residues and agro-industrial wastes. As a result, the agriculture sector will inevitably become intricately interconnected with the energy sector in a future where modern bioenergy plays a significant role.

The establishment, cultivation, nurturing up to harvesting of energy crops such as sugar cane represents a major cost in the biofuel production chain. Production of bioenergy feedstock can represent up to 20% of the final cost of fuel (Batidzirai, *et al*, 2006). Bioenergy feedstock production also requires substantial amounts of suitable land resources to maximise biomass production. Energy crop plantations are usually distributed over large areas as single continuous units or many separately managed plots. Processing of feedstock into usable energy forms usually requires large-scale centralised facilities to take advantage of economies of scale. Therefore transportation and logistics play an important role in the production of bioenergy. By their nature, bio-feedstocks are bulky and their transportation and handling to processing facilities is therefore costly. It is thus critical that the agronomic, harvesting and delivery practices for sugar cane (and other biomass energy feedstocks) are optimised to ensure that the final cost of biofuels is competitive. In addition, it is also important to optimise the biomass resource utilisation, so as to maximise the potential energy production from given biomass resources. For sugar cane, this includes the possibility of collecting trash and tops, in addition to harvesting the cane stalks, thereby increasing the amount of biomass which can be utilised in bioenergy production.

This Thematic Report on Agriculture is divided into two main sections: the first assesses “Agronomy and Land Resources” issues, and the second section examines “Harvesting and Delivery” systems with the ultimate objective of optimising the production and logistics of biofuel production. Although sugar cane is the crop of primary focus in this study, sweet sorghum is also examined as it has potential to play a complementary role.

The main objectives of the study include the following:

- Identification of key controllable agronomic parameters that affect productivity and yield of bioenergy crops.
- Assessment of agricultural performance and resource use in energy crop production.
- Exploring potential benefits from integrating complementary crops (with emphasis on sugar cane and sweet sorghum).
- Characterizing and comparing main land resource management scheme in the southern African region (with detailed assessment of land resources in Malawi, Mozambique and Zambia).
- Comparison of availability/scaling for key resources (such as water, land, labour).
- Development of benchmarks for agricultural productivity.
- Comparison of current harvesting, delivery, and transport methods, and their impact on costs, energy and mass balance of the biofuel chain.
- Evaluation of sugar cane burning vs. green cane harvesting options.
- Assessment of harvesting and delivery issues for co-cropping strategies.
- Identification of key collection, handling, and utilisation issues for cane transport.
- Development of system benchmarks for harvesting and delivery.

2 Agronomy and Land Resources

2.1 Background

In common with most other regions of the world, Southern Africa's demand for renewable energy is set to increase substantially. Sugar cane (*Saccharum officinarum*) and sweet sorghum (*Sorghum bicolor*) can potentially make a significant contribution to meeting this demand. Both plants are members of the *Gramineae* family; originated in the tropics; concentrate sucrose in their stalks and are currently widely grown in the region. Sugar cane is a perennial grass that re-emerges when cut, thus enabling several harvests to be obtained from one planting. It is grown on a large, medium and small scale, predominately as a long-term monoculture for commercial sugar production. Sweet sorghum is an annual grass mainly grown on a small scale as a short-term rotation crop for domestic consumption. Inherent differences in the growth habit and growth requirements of these plants suggest that spatial and temporal variations in their potential bioenergy production can compliment each other.

When assessing the agronomic, harvesting and delivery implications of these plants being more extensively and intensively used to produce bioenergy, the different requirements of the two most likely production scenarios need to be distinguished. These scenarios are (i) bioenergy and sugar and (ii) bioenergy. The first scenario involves use of:

- (a) bagasse as a boiler fuel to generate steam and electricity to run the mills and sugar crystallization processes,
- (b) juice to produce granulated raw sugar, and
- (c) molasses to produce ethanol.

Its principle objective is maximizing sucrose content and purity. In the second scenario, all the three by-products are used to produce ethanol. The bagasse may alternatively or additionally be used to generate steam and electricity to run the mills, and help fermentation and distillation of ethanol. Maximizing biomass is the principle objective.

2.2 Sugar Cane Agronomy

The agronomy of sugar cane in Southern Africa is examined in two parts. The first describes the plant's growth habit and the influence of a wide range of physiographic parameters on its growth and sucrose content. The second part highlights key cultivation practice considerations including those specifically aimed at maximizing sucrose content and purity.

2.2.1 Growth Habit and Habitat requirements

The geographical distribution of cane agriculture is largely confined to the lower latitudinal areas found on either side of the Equator, with the majority of cultivation occurring between 33° N and S of the Equator (Griffie, 2000; Qwabe, 2004). As one moves farther from the latitudes of 30°, the potential yield of cultivated cane drops rapidly (Griffie, 2000). Sugar cane is usually established by planting *setts* into the soil. The *setts* are obtained from cutting the shoots that emerge from the underground part of the stalk. Depending on where it is grown and the conditions under which it is

grown, the crop may take up to two years or more to complete growth, flower and die. Sugar cane is photoperiod sensitive with both ripening and flowering being triggered by a continuous reduction in day length. Sucrose levels peak for a relatively short period once the crop has attained full maturity. After harvesting, new shoots and roots develop from the underground part of the stalk. The emergent plant is known as a *ratoon*. Sucrose content and yield generally declines with successive *ratoons* principally because soil preparation for *ratoons* is less intensive than for plantings. Where harvesting is mechanised, soil compaction by heavy equipment accelerates this diminishing trend (Blume, 1985). In Southern Africa mechanical harvesting is not common.

2.2.1.1 Climatic Requirements

Sugar cane thrives in wet-dry tropical and subtropical climates where the wet season rainfall is sufficient to provide a soil water surplus capable of sustaining withdrawal by the crop during the shorter dry season, and where there is freedom from frost and cyclones. Even light frosts can damage cane (Griffiee, 2000). A summary of the climatic requirements for the optimal growth of sugar cane is presented in Table 1 below.

Table 1: Climatic requirements for optimal growth of sugar cane

Climatic Parameter	Requirement / Effect
Temperature	Germination occurs when temperatures > 8.5°C (Griffiee, 2000)
	Sprouting and rooting requires temperatures in excess of 20 °C (Blume, 1985)
	Mean annual temperatures range: 26 – 34 °C (Blume, 1985)
	Growth arrested below 15 °C and above 38°C (Blume, 1985)
	Ripening temperature range: 10 – 20 °C (Griffiee, 2000)
Sunshine	More than 1200 hours per annum (Blume, 1985)
Rainfall	Mean annual rainfall range: 1200mm – 1500mm (Blume, 1985)
Relative Humidity	Relative humidity of less than 70% during maturity and harvesting phases (Schulze <i>et al.</i> , 1997)

Temperature is the principal climatic determinant of sugar cane growth. While cane agriculture clearly requires high temperatures, the highest sucrose contents occur where there is a marked difference between day and night time temperatures (Blume, 1985), and sucrose accumulation with ripening is optimal with cooler temperatures (Griffiee, 2000). To achieve optimal growth, sugar cane requires more than 1200 hours of sunshine per annum. It requires high levels of solar radiation during its initial rapid growth phase and during ripening. The higher the intensity of insolation: (a) the higher the biomass production during the growth period, and (b) the higher the sucrose production during ripening. Optimal growth under rain fed conditions, occurs where the mean annual rainfall ranges between 1200 and 1500 mm. The crop requires a moist soil to germinate or to produce a *ratoon*. Its water requirement increases until it fully covers the ground, then stabilizes through the rest of the rapid growth phase. Drought during this period reduces biomass. However, water stress during the crop's ripening phase arrests vegetative growth and encourages sucrose accumulation in the stalks. Irrigation is essential where the mean annual rainfall is less than 800 mm. While the crop can tolerate precipitation in excess of 1500 mm per annum, occasional

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flooding and high water tables, both cane and sugar yields are reduced. While winds during the growth period reduce biomass production, during ripening they increase the sugar content. Excessive winds break the cane stalks rendering the crop susceptible to diseases and pests (Blume, 1985).

2.2.1.2 Terrain, Altitude and Soil Requirements

The requirements discussed below are needed for sugar cane to thrive.

Terrain

Although sugar cane can be cultivated on various terrains, the lowest input costs and the highest productivities are associated with gentle slopes. The steeper the slope, the more difficult it is to use machines for land preparation, planting and harvesting, and the greater becomes the need for soil erosion and drainage control structures. Sys *et al.* (1993) set the slope threshold above which commercial cultivation under rainfed conditions is constrained at 16%. Slopes steeper than this threshold are well represented in the commercial sugar cane producing areas. They are covered by a long established intricate pattern of conservation terraces, extraction roads and waterways. Intensive use of machinery was employed to create this pattern. Mechanical ploughing is becoming less common following SASEX's recommended general norm that compartmentalises between terraces steeper than 20%, being re-established using minimum tillage (SASEX, 1999). For erodible sandy soils the threshold is set at 10%.

While mechanical harvesting is not routine in the region, the implications of increased labour costs, more stringent labour regulations, and the HIV Aids pandemic are making it an increasing attractive option in Mauritius, South Africa and Swaziland. Sugar cane found on steep slopes elsewhere in Southern Africa can generally be attributed to peasant or small-scale farmers who use hand-held implements or animal-drawn ploughs to till the soil (Blume, 1985).

Altitude Requirements

Closer to the Equator, sugar cane is cultivated up to 1600 metres above sea level. Its growth cycle is lengthened at these higher altitudes (Griffie, 2000).

Texture/ Structure

Loams are the first choice for sugar cane production. Their equivalent amounts of sand and silt and clay particles yield a granular structure which allows for good aeration and easy cultivation and tillage (Sys *et al.*, 1993). Coarse-textured soils tend to impede root development while fine-textured soils often have poor drainage and are associated with water-logging problems (Schulze *et al.*, 1997).

Water-holding capacity

Ideal growth conditions for sugar cane require soils with a fair rate of drainage and an available water content of more than 150mm (Schulze *et al.*, 1997). Poorly drained and water-logged soils are susceptible to viruses, diseases and bacterial infections.

Soil Depth & pH

The optimal depth of a soil for sugar cane cultivation purposes should be in excess of one metre (Schulze *et al.*, 1997). Shallower soils pose tillage constraints, and soils with effective rooting depths of less than 400mm are non-arable or unsuitable for cane cultivation (Griffiee, 2000). Sugar cane can tolerate a pH range of 4.5 - 8.5 with the optimal pH range of 5.5 - 7.5 (Blume, 1985).

Nutrients

There are four key macronutrients that are required in large quantities: nitrogen, potassium, phosphorus and calcium. Deficiencies of these essential macronutrients can reduce vegetative growth, reduce resistance to diseases, cause root rot and even plant death (Sys *et al.*, 1993). Excessive aluminium concentrations are toxic (SASEX, 1999).

Salinity

In terms of the relative tolerance to salt, sugar cane is moderately sensitive. The electrical conductivity (EC) of a soil's solution should be less than 2.0 dS/m for there to be no impact upon cane yields (Griffiee, 2000). Sugar cane farming in Swaziland, Tanzania and Zambia has encouraged the development of saline soil conditions caused by improper drainage or the use of saline underground aquifers for irrigation purposes.

A suitable depth and texture is most important as it is easier to modify the other requirements listed by manipulating drainage and adding organic matter, lime and fertilizers (SASEX, 1999). According to the FAO (1978), the soils that are either suitable or marginally suitable for sugar cane cultivation include: Regosols, Andosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Cambisols, Luvisols, Planosols, Nitisols and Ferralsols.

2.2.2 Cultivation

Sustainable commercial sugar cane agriculture in Southern Africa involves a very wide range of practices that aim to optimize water use; ensure the safe and fair employment of labour; create enabling conditions for poor, small-scale growers; prevent soil erosion. A number of key aspects pertaining to cultivation are discussed below:

Cane Varieties

The specific cultivar chosen will depend on the climatic conditions of the area; desired yields; the required pest and disease resistances. The common cane varieties used in southern Africa include: NCo376, N12, N16, N17, N19, N21, N22, N23, N24, N25 and N31 (SASEX, 2003).

Land Preparation

Prior to planting, the land and the seedbed require preparation. Various phases constitute land preparation: clearing of the land; soil preparation (tillage and harrowing); levelling and grading of land; weed and insect control; ploughing and irrigation amongst others (Alexander, 1985; Blume, 1985). In the commercial context, the majority of land preparation is mechanised.

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Planting Season

In parts of Southern Africa where sugar cane production takes place under rain fed, as opposed to, irrigated conditions, the cane planting period is chiefly governed by the onset of the rainy season. Planting generally commences in late August or early September.

Irrigation

Irrigation is essential where the mean annual rainfall (MAR) is less than 800mm. Although most of the commercial cane production areas in Malawi, Mozambique, Swaziland, Tanzania and Zambia receive a MAR greater than this threshold, irrigation is routinely carried out. Furrow and drip methods are gaining favour over overhead irrigation because the latter is more susceptible to theft.

Fertilisation

As a plant's growth and development is largely influenced by the fertility of the soil in which it grows; the application of fertilisers can assist in improving crop yields. Sugar cane requires large quantities of nutrients and is often blamed for nutrient depletion in soils (Blume, 1985).

Pests and Diseases

Important diseases afflicting sugar cane include ratoon-stunting disease, rust, mosaic disease, leaf scald and smut (Blume, 1985). In Southern Africa, the Eldana borer (*Eldana saccharina*) is capable of infesting and rapidly affecting large tracts of sugar cane. Infestations are treated with pesticides and nematicides.

Weeds

Weeds compete with cane for water, sunlight, soil nutrients and may act as hosts for diseases and pests. Traditionally, weed removal is labour-intensive. In the commercial sector, this job has been overtaken by machinery. In addition to herbicides sprayed manually, by tractors or through aerial means, the advent of biological control has proved successful in weed control (Blume, 1985).

Energy Inputs

The proportion of energy inputs associated with irrigation, fertilisation and pesticide application for Zimbabwe are 24.0%, 1.6% and 28.0% respectively (Woods, 2000).

Maximising Sucrose Content and Purity

A fundamental aspect of southern African commercial sugar cane agriculture is maximising the sucrose content and purity. The cultivation practices specifically aimed at maximizing sucrose content and purity include:

- Not irrigating for two months prior to harvesting to increase sucrose production (Griffie, 2000);
- Spraying ripeners on irrigated cane and on rain fed cane during good rainfall years (Donaldson, 2000);
- Spraying both irrigated and rain fed cane with compounds to prevent flowering to improve sucrose purity. In southern Africa chemical regulation of crop

development is only widespread and common in Swaziland. Tomlinson (2005) is of the opinion that this situation is unlikely to change in the future;

- Burning prior to harvesting substantially improves the efficiency of harvesting, loading and transporting. Burnt cane is crushed at a better rate and the purity and colour of the juice is superior to green cane. Burning continues to be a very common and widespread practice in Southern Africa. Davis (2002) for example, reported that 90% of South Africa's cane was burnt in the 2001-2002 harvesting season.

2.3 Sugar Cane Land Resources

Smeets *et al.* (2004) revealed that compared to all the world's major regions, sub-Saharan Africa has the greatest bioenergy potential as a result of large areas of suitable cropland, large areas of unused pasture land and the low productivity of land under agriculture. Phillips (2002) estimated that a 50% increase over the 2000 production in Southern Africa would require expansion of 200,000 ha of land and create 100,000 jobs.

Knowing the habitat requirements for sugar cane, Geographic Information Systems (GIS) can be used to interrogate environmental data sets to identify suitable habitats. The larger the number of environmental parameters included, the higher the resolution and quality of the data, the more reliably these habitats can be identified. Using climate, terrain and soil data with a 10 km² resolution, FAO (2004) shows most of Southern Africa to be prohibitive and unsuitable for rain fed sugar cane production. Only the northern and eastern parts of Democratic Republic of Congo and the lower reaches of the Zambezi in Mozambique are identified as suitable to very suitable (see Figure 1).

Perusal of the yield statistics for the ten Southern African sugar cane producing countries shown in Table 2 below, suggests that environmental conditions for production are most conducive in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe.

Table 2: Sugar Cane Production in 2004

Country	Production (mt)	Area Harvested (ha)	Yield (t/ha)
Angola	360,000	9,500	37.89
Democratic Republic of Congo	1,787,300	43,000	41.57
Malawi	2,100,000	20,000	105.00
Mauritius	5,200,000	72,000	72.22
Mozambique	400,000	30,000	103.33
South Africa	19,094,760	305,000	62.61
Swaziland	4,500,000	48,307	93.15
Tanzania	1,800,000	17,000	105.88
Zambia	1,800,000	17,000	105.88
Zimbabwe	4,100,000	39,000	105.13

Source: FAO, 2005

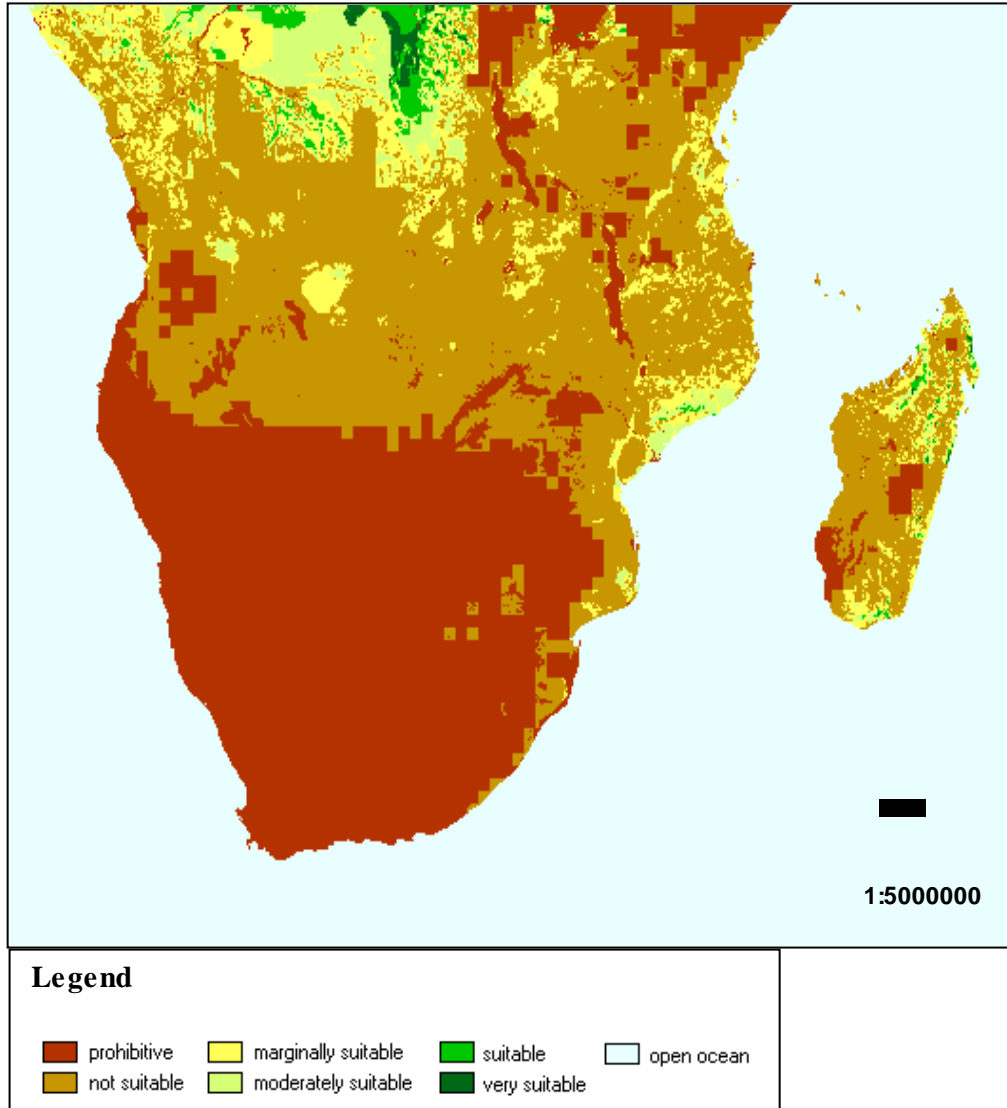


Figure 1: Land suitability for sugar cane production in southern Africa

Source: FAO, 2004.

The potential to increase the area under sugar cane in Southern Africa was assessed by Garland and Watson (2003) based on the proportion of arable land currently under the crop, the land reform and climatic change context, and the potential effect of such expansion on food crops, veld products and irrigation. They concluded that:

- the potential for any new plantings in Mauritius is very limited,
- the potential for medium to large scale and irrigated plantings in South Africa and Zimbabwe is limited, and
- elsewhere, the potential for small, medium and large scale, rain fed and irrigated plantings, is good.

With salinization becoming an increasing problem and its reliance on irrigation, it is becoming clear that the potential for expansion in Swaziland is limited. Potential investors are currently very optimistic about establishing new plantations in Angola but remain apprehensive about doing so in the Democratic Republic of Congo.

Table 3: Cane and sugar yields relative to areal intensity

Country	Cane Yield Area Harvested (t/ha)	Cane Yield Area Under Cane (t/ha/yr)	Sugar Yield Area Harvested (t/ha)	Sugar Yield Area Under Cane (t/ha/yr)	Sugar Recovery (%)	Vegetation Cycle (months)
D.R. Congo	64.83	42.99	6.05	4.01	10.15	11-13
Malawi	102.00	102.00	10.32	10.32	13.22	12
Mauritius	71.85	66.24	7.96	7.36	12.67	12-18
Mozambique	90.00	100.00	9.40	9.73	12.58	11-13
South Africa	90.35	52.15	9.78	5.67	12.77	12-24
Swaziland	96.00	96.61	13.72	12.68	13.12	11-13
Tanzania	80.00	69.05	6.98	6.20	12.29	12-15
Zambia	105.98	104.66	11.90	9.96	13.93	11-13
Zimbabwe	97.62			9.73	13.38	12-16

Source: adapted from Blume (1985) using 1970-2004 means from FAO

Another approach to determine the potential to expand sugar cane production in the region is to evaluate its comparative performance. The difference between yields of sugar cane per ha and yields per ha harvested shown in Table 3, are explained by the length of the vegetation cycle. As the length of this cycle increases, the areal intensity per ha under cane decreases. Blume (1985) notes “countries or regions with high areal intensity per ha under cane and sugar yields per ha under cane are the environments which offer optimum conditions for sugar cane agriculture”. Using these criteria, Malawi, Mozambique and Zambia are evidently the most suitable countries in Southern Africa for sugar cane production. Table 3 also reveals that the differences in yields between the countries are much larger than the differences in sugar content. The yield differences reflect environmental differences. Advances in and the careful selection of the most suitable varieties is responsible for the consistency in sugar content.

Schulze *et al.* (1997) used climate data, with a 2 km² resolution for South Africa, to produce maps showing areas climatically suitable for sugar cane cultivation. Bezuidenhout and Gers (2002) integrated South Africa’s contemporary sugar cane producing areas with 1 km² resolution climate and altitude data to produce maps. Both sets of maps revealed that the most suitable areas for rain fed sugar cane production in South Africa are areas where production of the crop is almost fully extended. Irrigation is used to enhance production within these areas and to expand production beyond them. Consequently, about 27% of the area under cane is dependent on irrigation.

The Miombo Network (IGBP/IHDP, 1995) used an annual cycle of 1 km² Radiometer data to delineate land surfaces in Southern Africa which exhibited a distinctive phenology and common level of primary production. Surfaces with a spectral signature corresponding to sugar cane and sugar cane-like crops are shown in black in Figure 2. Focusing on South Africa, a GIS was used to overlay these areas on Schulze *et al.*’s (1997) map and Bezuidenhout and Gers’s (2002) map. There was

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88% correlation between the Miombo sugar cane surfaces and the sugar cane surfaces in the other two datasets. This suggests that surfaces shaded black elsewhere in the region are potentially suitable for the crop. In Malawi, Mozambique and Zambia, if these surfaces fell within protected areas, areas where the slopes were in excess of 16%, or cultivated or wetland areas, they were filtered out using the World Database on Protected Areas (WDPA, 2005), Africa Digital Elevation Model (EROS, 1996), and Global Land Cover 2000 (Global Vegetation Monitoring Unit, 2003), respectively. All areas already under sugar cane were filtered out. The areas smaller than 500 ha were then removed. The suitability of the areas left over for sugar cane production was then verified employing Sys *et al.*'s (1993) parametric ITC-Ghent land suitability assessment method and using Leemans and Cramer's (1991) and New *et al.*'s (2002) climatic data, and FAO (2003) soil data. A more detailed account of this methodology is found in Bajjnath (2005).

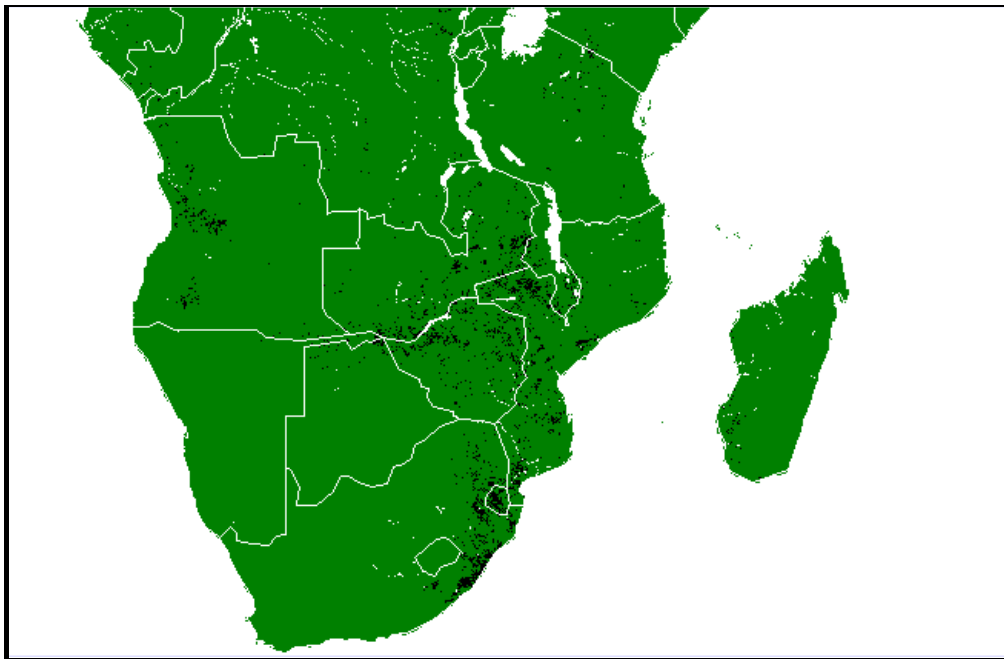


Figure 2: Areas in southern Africa potentially suitable for sugar cane production

Source: Derived from IGBP/IHDP (1995).

The findings of the GIS analysis described above are given in Table 4 below. Relative to the total area of the country, Malawi (7.9%) has the highest proportion of areas potentially suitable for sugar cane production, and Zambia (4.8%) the least. Once all the unsuitable and unavailable surfaces have been filtered out from these areas, Mozambique (1.6%) has the highest proportion of suitable/available areas, and Zambia (1.6%) retains its position of being the worst candidate among these three countries for expansion of sugar cane production. However, Malawi is a comparatively small country with Mozambique and Zambia being 8.3 and 7.9 times bigger than it, respectively. In terms of the area suitable and available for expanding sugar cane production, Mozambique (2.338 million ha) followed by Zambia (1.178 million ha) present the greatest prospects, with Malawi (206,000 ha) lagging behind at 11 and 6 orders of magnitude, respectively.

Table 4: Areas suitable for sugar cane production remaining after successive filtering out of data

	Malawi		Mozambique		Zambia	
	1000ha	% [‡]	1000ha	%	1000ha	%
Country area	9,408		78,409		74,339	
Potentially suitable for sugar cane	742	7.9	4,906	6.3	3,546	4.8
Protected areas filtered out	595	6.3	4,602	5.9	2,433	3.3
Slopes > 16% filtered out	580	6.2	4,530	5.8	2,427	3.3
Crops & wetlands filtered out	316	3.4	3,773	4.8	1,726	2.3
Existing sugar cane filtered out	314	3.3	3,771	4.8	1,726	2.3
Areas < 500 ha filtered out	256	2.7	3,470	4.4	1,485	2.0
Unsuitable soils & rainfall filtered out	206	2.2	2,338	3.0	1,178	1.6

[‡]as a percentage of country's area.

The area suitable and available for expanding sugar cane production in these three countries exceeds Phillips's (2002) threshold for creating a 100,000 jobs in SADC by a factor of 18.6. Clearly, 'land' is unlikely to be a limiting factor in harnessing sugar cane's bioenergy potential to create rural livelihoods and alleviate poverty, reduce dependence on imported energy sources, and offer new development pathways in the region. As Johnson *et al.* (2007) note, the potential of these countries alone is greater than the current production of cane in SADC. Furthermore, they draw attention to the fact that the areas identified in these countries are better suited for cane growing, than much of the land that is under cane in South Africa and Mauritius.

2.4 Sweet Sorghum Agronomy

The agronomy of sweet sorghum in Southern Africa was also examined in two parts. The first describes the plant's growth habit and the influence of a wide range of physiographic parameters on its growth and sucrose content. As it is not currently grown for commercial sugar, and/or electricity, and/or ethanol production in Southern Africa; the second part explores potential bioenergy production considerations by examining the implications of experimental plot work in Zimbabwe and production benchmarks in India.

2.4.1 Growth Habit and Habitat Requirements

A sweet sorghum crop is established from seed. The seed can be machine sown. Between 6 and 8 kg of seed is needed to establish a hectare of sweet sorghum (Dajue and Griffiee, 2005). Under optimal conditions they germinate and develop a root and canopy system completely covering the soil within a month. The crop is not photoperiod sensitive and reaches maturity in three to five months. During growth the plants accumulate sugars primarily in their stems. Towards maturity, the relative level of sucrose compared to total sugars increases. At maturity sucrose constitutes more than 70% of the sugars (Woods, 2000).

Sweet sorghum thrives in wet-dry tropical, subtropical, semi-arid and warm temperate regions, over a wider range of habitats than sugar cane, on account of its greater tolerance to both higher and lower temperatures, greater resistance to drought, and less particular soil requirements. Sweet sorghum achieves optimal growth where mean annual temperatures range from 27 to 35°C. Growth is arrested below 8°C and above 40°C. While the average rainfall in areas where the crop is grown ranges from 450 to

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1000mm per year, it achieves optimal growth where the mean annual rainfall is 800mm and is normally irrigated where the mean annual rainfall is less than 600mm. Sweet sorghum is more resistant to drought than most other crops on account of its superior water absorption and water loss regulation abilities (Dercas and Liakatas, 1999). According to Dajue and Griffiee (2005), sweet sorghum requires only a third of the quantity of water that sugar cane does. The crop grows successfully on a wide range of soils including heavy clays, calcareous and organic soils. It tolerates a pH from 5.5 to 8.5, as well as some degree of salinity (Dalianis *et al.*, 2004). Dajue and Griffiee (2005) note that sweet sorghum has a superior ability to tolerate waterlogged soils in comparison to sugar cane.

2.4.2 Cultivation

As noted above, sweet sorghum is not currently grown commercially for sugar or bioenergy production. Over the past three years there has been a rapid increase in interest in the bioenergy potential of the crop resulting in trials being established in South Africa, Botswana and Zambia.

Table 5: Comparative production inputs and outputs of sugar cane and sweet sorghum

Inputs and Outputs	Sugar cane	Sweet sorghum
Land preparation cost (Rs/ha)	1200	400
Seed cost (Rs/ha)	1000	300
Sowing cost (Rs/ha)	1200	200
Weeding cost (Rs/ha)	800	300
Fertilizer costs (Rs/ha)	2800	600
Miscellaneous labour costs (Rs/ha)	2800	400
Water & electricity costs (Rs/ha)	3500	1600
Harvesting & transport costs (Rs/ha)	2000	700
Yield (tons/ha)	62-70	75-97
Sugar content (%)	11-13	9-11
Bagasse (%)	30	28-30
Ethanol yield (l/ton)	68-74	45-55
Net income to farmer (Rs/ha/yr)	22 500	16 000

Source: Praj (2003)

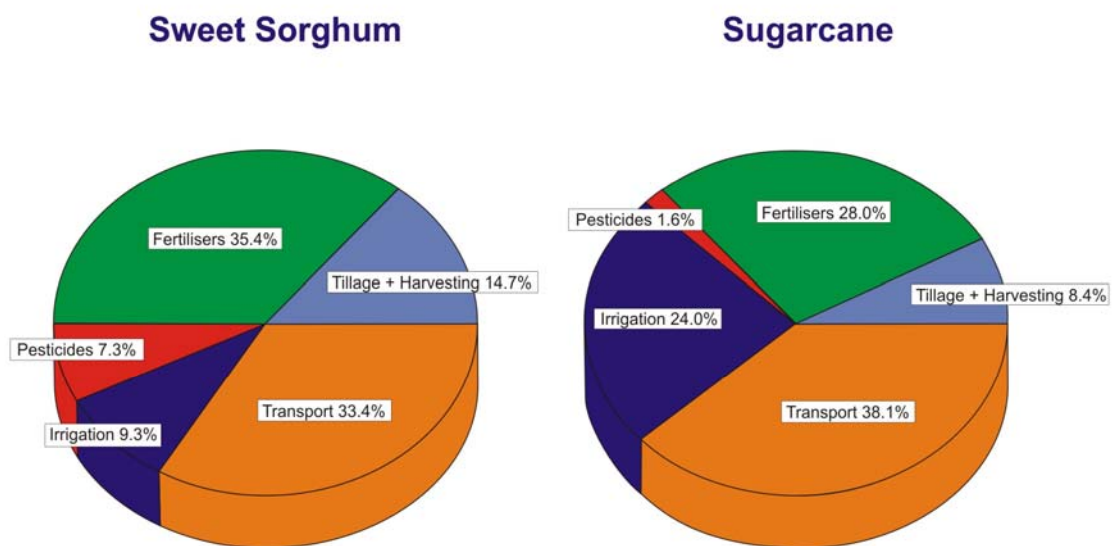
Table 5 summarizes the comparative production inputs and outputs of sugar cane and sweet sorghum in India. Praj (2003) argues that sweet sorghum represents a better option on the basis that (a) by growing two crops a year, the yield derived is 20 to 40% greater than that from sugar cane, (b) growing two crops a year leaves the land available for four to five months a year to grow another crop, (c) it is easier and cheaper to grow and handle than sugar cane, and (d) it is suitable as a fodder for cattle. Praj's (2003) maximum yield value of 49 t/ha for sweet sorghum appears to be conservative, suggesting that the yield to be gained from growing two crops of sweet sorghum in a year as compared to growing sugar cane may be even greater. According to Dajue and Griffiee (2005), sweet sorghum generally yields 45-120 t/ha of biomass and 38-90 t/ha of stems. Advances in biotechnology could potentially substantially increase yields. The superior yields and production efficiency of many sweet sorghum

cultivars has already been established (Dercas *et al.*, 1996; Dercas *et al.*, 2000) while the results of experimental trails on new hybrid cultivars are also promising (Dajue and Griffiee, 2005).

The differences between the bioenergy and sugar, and bioenergy production scenarios were described in section 1. According to Woods (2000) sweet sorghum is better suited to the latter because its relatively low levels of sucrose purity make it unsuitable for commercial crystalline sugar production. In addition, Dajue and Griffiee’s (2005) review of experimental findings in the USA, India and China suggest that the potential ethanol yield per hectare per year from sweet sorghum is 30% higher than from sugar cane.

Woods (2000) investigated sweet sorghum’s production potential using experimental plots at Triangle in Zimbabwe. His comparative estimates of production inputs in Zimbabwe, shown in Figure 3, indicate that while sweet sorghum has substantially lower energy related irrigation input needs than sugar cane, the pesticide, fertilizer, tillage and harvesting energy inputs are all significantly greater. He further cautions that sweet sorghum yields are inherently more variable than sugar cane yields arguing that unfavourable conditions during its shorter growth period have relatively larger effects on final yields.

Figure 3: Energy inputs for sweet sorghum and sugar cane production and delivery



Source: Woods (2000)

It would appear that in the Southern African context, sweet sorghum is a good bioenergy crop to consider in areas where the rainfall is insufficient for rain fed sugar cane production and where irrigation water is unavailable. Garland and Watson (2003) concluded that global climatic change is likely to result in the expansion of such areas.

Woods’ (2000) work suggests that sweet sorghum could also be grown in association with sugar cane. As noted above, sucrose accumulation in sugar cane is regulated by

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day length and is therefore seasonal. This seasonality defines the period during which it is economically feasible to harvest the cane and extract the sucrose. The period when the mill is not being used to process cane is known as the 'off-crop' period. Since sweet sorghum is not photoperiod sensitive, it can reach maturity during the sugar cane off-crop period and can potentially be used to extend the milling season for the production of bioenergy and sugar (Figure 4).

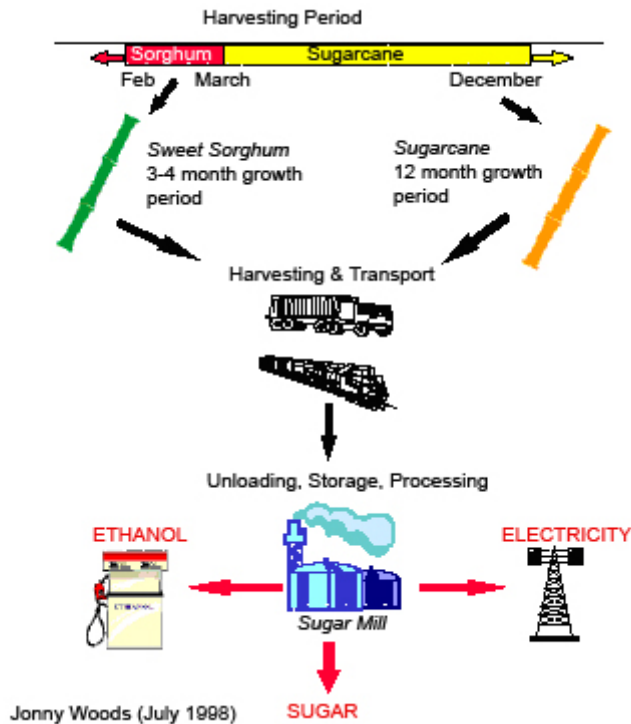


Figure 4: Integrating sweet sorghum with sugar cane

Source: Woods (2000)

Using the Triangle estates in South-eastern Zimbabwe as a case study, Woods (2000) evaluated this potential. The sugar cane harvesting period extends from March to November. The timing when and the duration for which sweet sorghum is available for processing depends on when it is planted, how much land is available from September to March, the season length of planted variety (short, medium or long-season), crop management etc. He found that by growing the Keller and Cowley varieties, the sweet sorghum would be ready for processing in February and March. He suggested that with further research into the management and selection of new varieties, the crop could be harvested from December to March completely closing the off-crop gap and allowing year round production. However, Tomlinson (2004) questions the practicality of closing this gap pointing out that it is routinely used for carrying out mill maintenance and sending staff on annual leave.

As with sugar cane, the sucrose content of sweet sorghum decreases rapidly as soon as it is cut, and hence needs to be transported to the mill as quickly as possible. The fact that transport to the mill comprises a substantial proportion of sweet sorghum, production costs is another reason why the crop needs to be grown in close proximity to existing sugar cane mills. In order not to disrupt the production of sugar cane as the principle crop, it needs to be integrated into the sugar cane agronomic schedules. Woods *et al.* (1996) suggested that fallow land within the sugar cane plantation

should be used for growing sweet sorghum. Typically about five percent of the plantation lies fallow after the old crop has been destroyed through until the beginning of the next season when the new crop is planted. However, Woods (2000) found that the yield from sweet sorghum planted on the fallow land in Triangle Estates was only capable of sustaining the mill for four days. Clearly, if sweet sorghum is to sustain mills for a significant proportion of the sugar cane off-crop period, additional land will need to be put under the crop. Advances in biotechnology indicate that in the not too distant future it may be possible to source this land at greater distances from the mill than is feasible at present. Dajue and Griffie (2005) describe a recently patented development that not only reduces the stalk volume by two thirds, but also enables them to be stored without spoiling for several years.

2.5 Sweet Sorghum Land Resources

Using climate, terrain and soil data with a 10 km² resolution, FAO (2004) identifies the areas shown in Figure 5 and Figure 6 as suitable for high and low input level of sweet sorghum production, respectively. In their analysis of these areas, Dalianis *et al.* (2004) compromised the 1 km² resolution of their climate and terrain data to match the 10 km² resolution of their soil data. They consequently produced maps virtually identical to those of FAO (2004). However, the quantification of the suitable areas in the different countries (see Table 6 and Table 7) provides additional insight. For both high and low input level production, Zambia clearly offers the best potential, followed by Mozambique and Malawi. The analysis of this coarse data indicates that South Africa is not at all suited to low input level production, and that high level input production is only viable in one percent of the country. It also indicates that Swaziland is not at all suited to either input level of production. Using climate data with a 2 km² resolution for South Africa, Schulze *et al.* (1997) produced the map shown in Figure 7. This map suggests that sweet sorghum production is viable in Northern Pondoland, over most of KwaZulu-Natal and in the lowveld of both Mpumalanga and Limpopo provinces. It also suggests that this production is viable in the western half of Swaziland.

Table 6: Percentage of Southern African countries in high input level land suitability categories for sweet sorghum production

Country	Prohibitive	Unsuitable	Slightly Suitable	Moderately Suitable	Suitable	Highly Suitable
Angola	14.2	46.1	15.3	14.4	9.4	0.5
Botswana	64.5	21.6	11.4	2.3	0.3	0.0
Congo	7.4	92.1	0.5	0.0	0.0	0.0
Lesotho	83.9	16.1	0.0	0.0	0.0	0.0
Malawi	25.1	16.3	18.6	14.4	15.1	10.6
Mozambique	1.3	24.5	23.5	23.0	17.1	10.6
South Africa	67.5	23.1	7.0	1.4	0.2	0.8
Tanzania	10.8	21.7	27.8	26.8	10.4	2.3
Swaziland	5.5	62.8	28.4	3.2	0.0	0.0
Zambia	2.2	14.3	23.3	26.7	23.1	10.4
Zimbabwe	9.7	30.7	38.4	17.8	3.3	0.1
Namibia	74.5	17.2	5.4	2.2	0.3	0.5

Source: Dalianis et al. (2004)

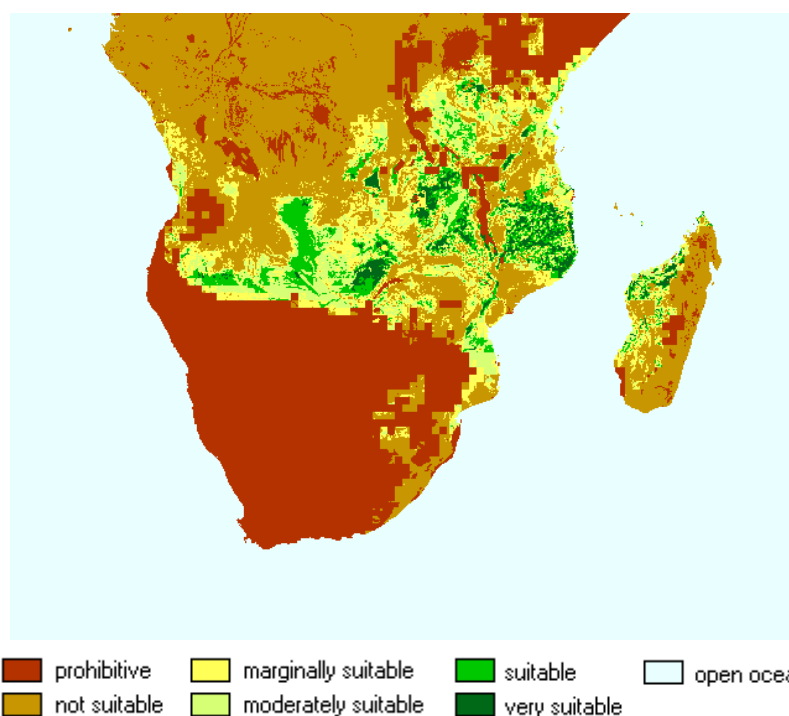


Figure 5: Land suitability for high input level sweet sorghum production in Africa

Source: FAO, 2004

Table 7: Percentage of Southern African countries in low input level land suitability categories for sweet sorghum production

Country	Prohibitive	Unsuitable	Slightly Suitable	Moderately Suitable	Suitable	Highly Suitable
Angola	20.7	55.0	19.3	4.5	0.5	0.0
Botswana	95.4	3.1	1.5	0.0	0.0	0.0
Congo	88.2	11.8	0.0	0.0	0.0	0.0
Lesotho	96.0	4.0	0.0	0.0	0.0	0.0
Malawi	25.5	24.7	20.5	18.1	10.4	0.8
Mozambique	11.9	30.8	25.0	15.8	13.8	2.6
South Africa	87.0	11.9	1.1	0.0	0.0	0.0
Tanzania	16.7	38.8	26.1	15.0	2.7	0.8
Swaziland	36.2	63.3	0.5	0.0	0.0	0.0
Zambia	3.1	29.5	39.7	20.1	6.4	1.2
Zimbabwe	40.9	38.5	17.3	3.1	0.2	0.0
Namibia	95.6	2.7	1.7	0.0	0.0	0.0

Source: Dalianis et al. (2004)

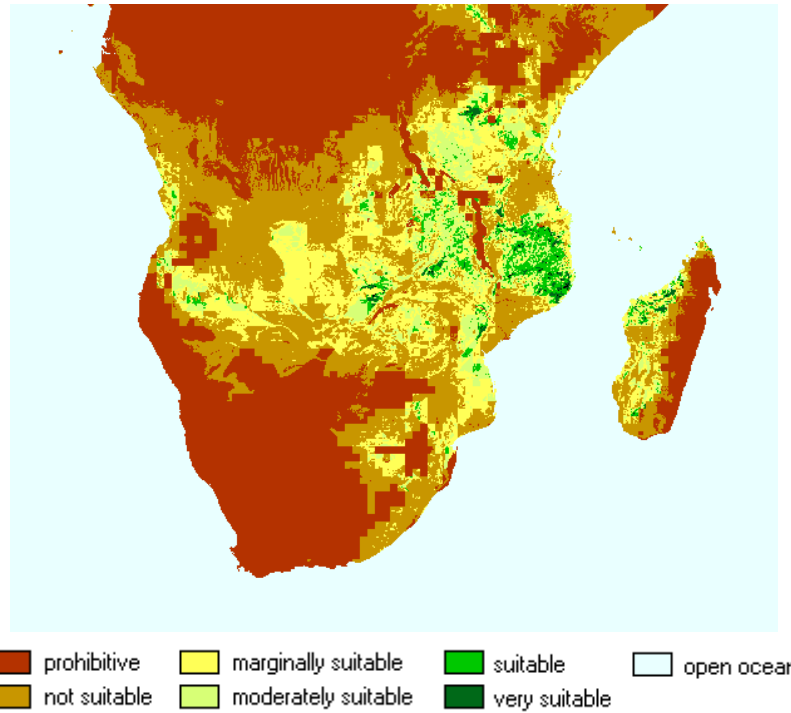


Figure 6: Land suitability, low input level sweet sorghum production in Africa

Source: FAO, 2004

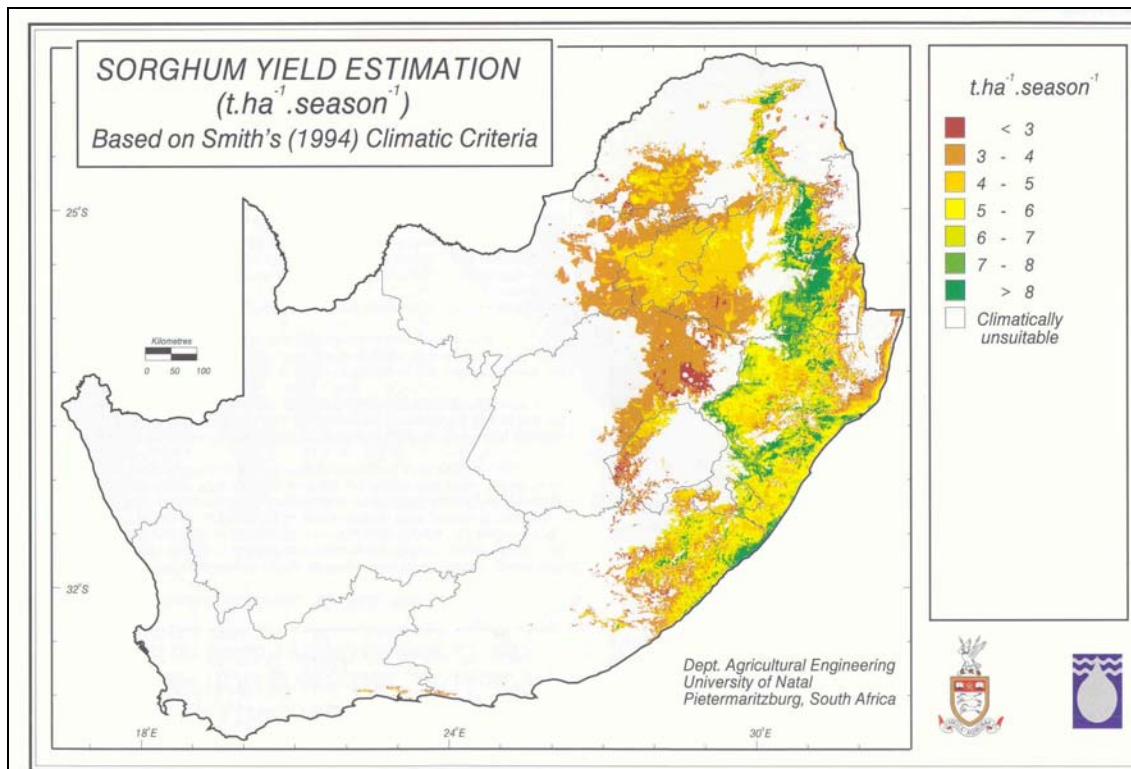


Figure 7: Areas in South Africa suitable for sweet sorghum production

Source: (Schulze et al. 1997)

3 Harvesting, Delivery and Transport

3.1 Background

3.1.1 Perspectives on cane and trash harvesting and delivery

The harvesting and delivery of sugar cane in southern Africa constitute approximately 30% of the cost of sugar production, with the transport component being 15-20% (Anon, 2007a). The processes involved usually include burning, cutting, loading, in-field transport, trans-loading, road transport, offloading and feeding to the mill. There has been a tendency for each process to be managed separately, but there is increasing realisation that these components of the supply chain need to be integrated and centrally co-ordinated for maximum efficiency. This need has attracted considerable effort in the past ten years.

For convenience, individual processes are described separately in the following sections but it is emphasised that there are considerable interactions and the whole supply chain can be affected by a change to any one process. For example, if cane is not burnt before harvest then the cutting rate changes, the characteristics of the material change such that loading is slower and payloads decrease. The transport fleet requirements then increase, as does the required capacity for milling. These effects need to be quantified for assessment of the costs and benefits of changing harvesting and delivery systems.

Most southern African countries have relatively inexpensive electricity generated from plentiful coal or hydropower. Sale of electricity from sugar factories is therefore generally not an economic proposition and, consequently, there are no incentives for harvesting and delivery of trash. Mauritius is exceptional in that, being an island with no coal; there is a profitable market for electricity generated from bagasse. There is therefore a distinct interest in trash harvesting in Mauritius (Deepchand, 2000).

In Swaziland, one factory (Ubombo) is practicing some trash harvesting (baling of field dried trash) for electricity generation; but elsewhere in southern Africa the harvesting and delivery systems still aim to minimise delivery of trash.

In South Africa, there were strong perceptions that extraneous matter in cane was the major factor affecting cane quality (Scott, 1977). Burning prior to harvest was seen as critical for reducing the extraneous matter (Lamusse and Munsamy, 1979). This requirement for burning precluded the harvesting of trash for industrial uses. Subsequent information has however changed these perceptions by illustrating that burning tends to be a major cause of delays (Barnes *et al.*, 1998) and burnt cane deteriorates faster than unburnt cane (Lionnet, 1996). In many circumstances the cane deterioration associated with burning may be more deleterious than is the residual trash on unburnt cane. There is therefore a fresh mindset open to the opportunities that could arise from not burning. New information has been generated to assist in decisions regarding trashing instead of burning, and new incentives for trash harvesting seem to be on the horizon. Nevertheless, more than 80% of cane is burnt before harvest in South Africa and the figure approaches 100% in most southern African countries.

Production of ethanol from hydrolysed bagasse was intensely researched in South Africa in the 1980s (Paterson-Jones, 1989; Purchase, 1983). This prompted some research on trash harvesting and processing (de Beer *et al.*, 1989; Reid and Lionnet, 1989; Purchase *et al.*, 1990) but commercial experience under southern African conditions is very limited. The harvesting and delivery of sugar cane has however been a focus of recent studies and these have provided some useful basic information relevant to trash harvesting.

A practical point that must be remembered is that most varieties of cane currently grown in southern Africa are varieties that produce a high number of thin stalks with tightly bound leaf sheaths. Trash separation from stalks is therefore more difficult than with many of the varieties grown in other countries.

3.1.2 The Sugar Logistics Improvement Plan (SLIP)

The Sugar Logistics Improvement Plan is a major initiative in analysing and benchmarking harvesting and delivery systems in South Africa and Swaziland. It involved the collecting and analysis of information gathered from cane logistics chains. The information provides a basis for decisions involving changes towards greater efficiency. Measurements started in 2002 and involved seven mills with 356 logistics chains, based on groups of growers. This ongoing initiative has highlighted major differences between average efficiencies and best practice efficiencies (Perry and Wynne, 2004). SLIP is an important source of appropriate information for this report.

3.1.3 Types of supply chains

In South Africa there are two basic types of supply chains, influenced mainly by topography. Where the topography is unsuitable for large vehicles to enter the fields, the cane is loaded onto small in-field trailers, and subsequently transferred to road vehicles at a loading zone. This ‘indirect delivery’ adds costs compared to ‘direct delivery’ with in-field loading of road vehicles. The topography must therefore be taken into account while benchmarking supply chains in southern Africa. The major part of the industry has topography unsuitable for direct delivery.

Where the topography is suitable for direct deliveries, the soil type and conditions may preclude heavy vehicles from entering the field. This applies in Zimbabwe and explains why indirect deliveries predominate there.

A small amount of cane is harvested mechanically but at least 90% is hand harvested and delivered in whole stick form. Approximately 88% is burnt before harvest. Some is delivered in chained bundles, but most is delivered loose with grab loading and spiller offloading. In 2005, 6.2% was delivered by train or tram with the remainder being delivered by road (Davis & Archary, 2006).

3.1.4 A typical supply chain

The following description, from Guilleman *et al.* (2003) and Giles *et al.* (2005), gives perspectives on the issues involved in a typical supply chain at a South African factory (Sezela). This situation applies at most factories in southern Africa except that, in countries outside South Africa, the miller-cum-planter usually provides more than 50% of the cane supply.

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In 2000-01, the mill crushed 2.38 million tons of cane. Of this, 22% was produced by the miller-cum-planter estate, 65% by 180 large-scale farmers and 13% by 5000 small-scale farmers. The supply management involves up to four operators: growers, harvest contractors, hauliers and the mill. The Mill Group Board is responsible for planning and co-ordination between these operators.

Approximately 120 independently operated vehicles serve the mill area. The 2005 cost of transport (fixed and running costs) was ZAR58 million (approximately US\$ 7.9 million). The ton-weighted-average distance is 30 km.

Harvesting is done by the growers themselves or by harvest contractors. Cutting is by hand and it is the responsibility of the harvesters to transport the cane to loading zones and load it onto large road vehicles. The cane is in bundles that are weighed (for cutter payment) as they are transferred to road vehicles. Many different modes of transport are used for hauling the cane from the field to the loading zones.

Hauliers control the transport from loading zones to the mill. The hauliers may be individual contractors, large companies or the growers themselves. It is the individual grower's responsibility to arrange haulage via contracts that extend throughout the season.

On arrival at the mill, payloads are weighed and offloaded either onto a feeder table or onto a stockpile. Sampling for analysis takes place only after the cane has been fed to the mill and shredded.

The length of the milling season is decided by the Mill Group Board, based on estimates of crop size provided by the Local Grower Council. Daily rateable deliveries are then assigned to individual growers. For operational purposes, these individual rateable deliveries are aggregated and allocated to the hauliers in accordance with their contracts. The hauliers are then responsible for making regular deliveries, and must source the cane by arrangement with their contracted growers.

Many growers have insufficient cane for supply throughout the season. To prevent pressure for oversupply at mid-season (when sucrose content is highest), a relative payment system is applied. This adjusts the measured quality to a 'relative quality' (RQ) for each week according to the following formula:

$$\text{Grower's relative \% RQ} = \text{Grower's \% RQ} - \text{mill week average \% RQ} + \text{mill season average \% RQ}$$

3.1.5 Comparison with Australia

From the above, it is evident that the South African system has various complexities and deficiencies that affect costs. Giles *et al.* (2006) report on efforts to introduce an Australian scheduling system to a mill in South Africa. The system helped to improve efficiencies but highlighted the following requirements for major cost savings:

- Co-operation between growers, hauliers and millers, with central co-ordination of the supply chain.
- Formation of large consortia of growers and hauliers with uniform equipment and minimal cutting fronts.

- Rationalisation of vehicles, roads and loading zones.
- Twenty-four hour operation by all participants.
- Improved communication systems, including GPS on all vehicles and radio information regarding stock levels at loading zones.
- Synchronization of delivery rate with mill crushing rate.

3.1.6 Length of milling season

The length of milling season in 2005-06 ranged from 186 days in Mozambique to 251 days in South Africa, with individual South African mills ranging between 213 and 286 days (Davis & Archary, 2006). These season lengths are longer than in most cane producing countries. Long seasons are a definite benefit for reducing capital costs and minimising storage costs for the downstream products. A disadvantage of long seasons is the low cane quality at the beginning and end of season.

3.2 Harvesting and Loading of Cane

3.2.1 Overview of harvesting

More than 90% of cane in southern Africa is harvested manually, and more than 80% is burnt before harvesting. Two main systems are used: (a) cut and stack, and (b) cut and windrow. The stacks and windrows are then loaded mechanically (see section 3.2.2.4). Productivity of the cane cutters is higher where they can windrow rather than stack the cane. The cutters are responsible for topping the cane and for removing trash from unburnt cane. Their remuneration is based on quantity cut but rates vary according to requirements for trashing and stacking, and rates per tonne often increase after a base tonnage has been exceeded.

Only about 10-15% of South Africa's cane is produced by small-scale growers but these growers constitute about 50,000 of the 53,000 registered growers. Attempts are being made to improve harvesting and delivery efficiencies among these growers but there are severe difficulties of co-ordination (Le Gal and Requis, 2002).

Prolonged efforts to develop simple mechanical harvesting machines suitable for hill slopes have not been economically successful. A few chopper harvesters are operating but for most situations, manual harvesting appears to be appreciably more economical than mechanical harvesting (Stutterheim *et al.*, 2006).

3.2.2 Harvesting equipment

3.2.2.1 Burning

Public aversion to the pollution caused by burning means that burning has to be carefully controlled to minimise pollution of sensitive areas. In South Africa, daily weather reports predicting suitable or unsuitable conditions for burning are sent as text messages to farmers' mobile phones in sensitive areas. A set of "Guidelines for cane burning" has been drawn up by the South Africa Cane Growers' Association in an attempt to minimise conflict with local communities. The restriction of burning to periods when weather conditions are favourable causes farmers to burn excessively large areas when the opportunity for burning arises.

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Most large-scale farmers have a tractor-drawn water tanker and pump on standby during burning operations. Burning usually takes place in the late afternoon or early morning. Cane on the edge of the block to be burnt is either cleared or pushed inwards to create a firebreak. Blowtorches or handfuls of trash are used as firelighters along the edge of the block and against the wind. A small team of fire fighters equipped with beaters ensure that the fire does not spread to adjacent cane.

When arson or accidental runaway fires cause large areas to be burnt, these areas are generally given preference for harvesting. Normal scheduled deliveries are then disrupted and harvesting teams from adjacent farms assist in the burnt area.

3.2.2.2 Cane knives

Two types of knives are used. The long handled version is preferred for burnt cane and the short handled for green cane (Table 8).

Table 8: Type of cane knife used for various harvesting methods (% of farms)

Cane knife	Cut & stack		Cut & windrow		Cut & bundle	
	Burnt	Green	Burnt	Green	Burnt	Green
Long handled curved	64	22	89	0	84	67
Short handled curved	18	33	11	0	13	33
Mixed	18	45	0	0	3	0

Source: Meyer and Fenwick (2003)

3.2.2.3 Chains

Stacked cane is chained into bundles (two chains per bundle). In some systems the bundles are unchained when they are trans-loaded into long distance road transport. In such cases the chains are readily recovered for immediate return to the fields. Where bundled cane is delivered to the mill, the recycling of chains can present a logistics problem. Such chains are generally owned and controlled by the mill.

3.2.2.4 In-field loading and transport

No manual loading of cane takes place – a variety of mechanical loaders operate under the different conditions.

Stacked cane is chained and winched onto self-loading, low-level field trailers. These tractor-drawn trailers carry approximately 5 tonnes and are used mainly in fields where topography or soil conditions prevent larger units from operating.

Grab loaders are used where cane is cut and placed in small stacks (bundles). The loaders operate in conjunction with road transport trailers that are able to go in-field. Some such trailers may be pulled into the fields by tractors. After loading, two trailers may be linked and hauled to the mill by a specialised haulage unit.

Push-pile-grab loaders operate where cane is laid in windrows. They push the cane into a bundle and then grab it for loading.

In Swaziland, some continuous loaders operate by pushing a conveyer system under the windrows. The conveyer lifts the cane and passes it through a biler before loading into an accompanying vehicle for direct transport to the mill.

In Zimbabwe, one system involves self-loading trailers carrying 5 tonne bundles from the field and tipping them onto low-level road trailers (“Muscanes”) that take three bundles to the mill. This system is suited only for intermediate distances. It has the advantage of not requiring special equipment for trans-loading.

Trans-loading may involve a mobile crane or gantry (for bundles) or a grab loader if bundles are “spilt” at the zone.

3.2.2.5 *Mechanical harvesters*

A variety of whole-stick mechanical harvesters have been developed for South African conditions (e.g. Boast (1985); de Beer and Adey (1985)) or imported for trials but none enjoy widespread use. The interest in whole-stick machines arises from the need to operate on slopes and irregular shaped fields unsuitable for large chopper harvesters with their accompanying cane transport vehicles.

A small number of chopper harvesters operate where field conditions permit but the economics is generally not attractive especially because of comparatively high losses of cane (Meyer *et al.*, 2002). The availability of labour for manual harvesting and the need to preserve such employment opportunities is another reason for not converting to mechanical harvesting. If the need arises then designs for tractor-mounted whole-stick harvesters, that have been developed and tested under local conditions, are available (de Beer and Adey, 1985).

A hand-held motorised brush-cutter has been modified and tested as a potential replacement for the cane knife. Further development is necessary to reduce the high downtime and maintenance costs but the peak cutting rate of 4.4 t/h is encouraging (Langton *et al.*, 2006).

3.2.3 *Harvesting efficiency*

Meyer and Fenwick (2003) surveyed the performance of cane cutters in South Africa and Swaziland and found considerable variation, summarised in Table 9.

Table 9: Summary of cutter performances for various harvesting systems

Harvesting system	Cane yield (t/ha)	Cutter output (t/day)	Cutters per 1000 t
Cut & stack (green)	72	3.4	1.8
Cut & stack (burnt)	70	4.2	1.4
Cut & bundle (green)	74	5.6	1.1
Cut & bundle (burnt)	70	6.6	1.1
Cut & windrow (burnt)	93	8.0	1.0

Source: Meyer and Fenwick (2003)

From Table 9 it is evident that cutter performance is enhanced less by burning than by conversion from stacking to bundling or windrowing. Time and motion studies showed that stacking involved 30-35% of the total time.

Nyati (1998) reported that the benchmark for cutting and stacking in Zimbabwe was 5 t/day/cutter where the yield is 85-150 t/ha; de Beer (1998) noted that some cutters in Swaziland average 14 t/d throughout a 220 day season, and attributed this to no

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stacking, correct cane knives, good nutrition, good field conditions with high yields and cash bonuses. At the other extreme, he mentioned that productivity in Uganda may be as low as 1 t/day.

Meyer and Fenwick (2003) sought to correlate productivity with various factors and found that provision of drinking water in the field and supervision by an “induna” (rather than manager) were particularly important.

If efficiency is measured in terms of revenue minus cost then mechanical harvesting is not as efficient as manual harvesting under southern African conditions. Meyer *et al.* (2002) give extensive results of comparative trials with different harvesting systems in Swaziland. Abbreviated results are presented in Table 10.

Table 10: Abbreviated results of comparative harvesting trials

TRIAL 1 System (all with burnt cane)	Recoveries (t/ha) & (% of “control”)		
	Cane	Sucrose	Fibre
Hand cut, push-pile grab loader into bins	103.4 (100)	15.07 (100)	13.33 (100)
Hand cut, continuous loader into bins	105.6 (102)	15.77 (105)	12.95 (97)
Austoft 7000 chopper harvester into bins	99.2 (96)	14.16 (94)	12.19 (91)
TRIAL 3			
Hand cut, push-pile grab loaded	140.8 (100)	19.22 (100)	18.69 (100)
Cameco CHW2500 chopping burnt cane	141.5 (100)	19.19 (100)	16.66 (89)
Cameco CHW2500 chopping GREEN cane	133.7 (95)	18.36 (95)	16.82 (90)

Source: Meyer et al. (2002)

Separate measurements of cane pieces left in the field (expressed as % of harvested yield) gave 1.53 to 3.89% for hand cut and 3.69 to 5.56% for chopper harvesters, confirming the relatively low recoveries for chopper harvesters. The grab loaders gave better yields than the continuous loaders.

Instantaneous loading rates for the various machines varied with field conditions and are summarised in Table 11.

3.2.4 Crop damage – replanting requirements

In southern Africa, if disease management and in-field vehicle management are good, it is normal to harvest 8-10 crops (up to 15) before replanting is necessary. Harvesting operations may damage cane stools, from which the next crop emerges, and if the damage is severe it brings forward the need for replanting.

The cost of replanting is high because it involves ploughing and harrowing to kill the old crop, furrowing for the new seed cane, buying specially grown and treated seed cane, weed control and an extended period between harvests. The cost of ploughing can be reduced by ‘minimum tillage’ which involves soil disturbance only along the lines where the new crop is to be established. Herbicides and manual ‘chipping’ are used to kill the old crop.

To avoid harvesting damage, it is important that wheel spacing of in-field vehicles match the inter-row distances and that vehicles are driven carefully. The plant crop

(i.e. the first crop) is particularly prone to stool damage because the stools have not developed fully. For this reason, chopper harvesting of plant crops is avoided in Swaziland.

Meyer *et al.* (2002) attempted to assess crop damage by measuring the numbers and lengths of stalks that grew after harvesting. There was no apparent difference between the damage caused by the chopper harvesters and mechanical loaders used in the trial.

Table 11: Instantaneous loading rates of loaders and chopper harvesters

Machine and conditions	Instantaneous rate (t/h)
<i>Chopper harvesters</i>	
Case Austoft 7000 - burnt cane	68-80
- green cane	64
Cameco CHW2500 - burnt cane	104
- green cane	71
<i>Mechanical loaders</i>	
Tamhe tractor-mounted, push-pile grab	62
Cameco SP2254 push-pile grab	85-115
J & L continuous	211

Source: Meyer et al. (2002)

3.2.5 Collection of residues

3.2.5.1 Extensive Brazilian studies

Comprehensive Brazilian studies, partly funded by the United Nations Development Fund, give substantial information on trash harvesting under Brazilian conditions and on gasification trials (Hassuani et al., 2005). Some findings are summarised in Table 12 to Table 14.

The relatively high K (Potassium) and Na (Sodium) content of residue compared to bagasse raises concerns about possible ‘glass’ formation during burning of residues. But one mill (Cruangi) experimented with 100% trash (tops included) as boiler fuel for more than a month and found no deleterious effects in terms of erosion or molten ash deposits in the boiler. The fuel had been cleaned to remove soil prior to baling in a specially modified baler (Leal, 1995).

The Brazilian trials involved various approaches to residue harvesting. Whole stick harvesting (by machine) was abandoned because the machines could not operate effectively on green cane where yields exceeded 70 t/ha. Chopper harvester trials involved three levels of trash separation (controlled by fan speed) in conjunction with baling of trash deposited in field or recovery of the trash from the partially cleaned cane by dry cleaning at the mill. Table 13 shows summarised results.

Table 12: Summary of residue quantity and composition from Brazilian trash study

Item	Quantity	Units
Residue ratio (average)	140	kg(dry residue)/t stalks (wet)
Residue ratio (range)	110-170	kg(dry residue)/t stalks (wet)
Residue composition		
Components		
- dry leaves	1	Ratios relative to dry leaves (wet basis)
- green leaves	2.28	
- tops	1.05	
Water		
- dry leaves	13	% at harvest
- green leaves	65	% at harvest
- tops	80	% at harvest
K ₂ O		
- dry leaves	2.7	g/kg (dry basis)
- green leaves	13.3	g/kg (dry basis)
- tops	29.5	g/kg (dry basis)
- bagasse	1.7	g/kg (dry basis)
Na ₂ O		
- dry leaves	123	g/kg (dry basis)
- green leaves	128	g/kg (dry basis)
- tops	119	g/kg (dry basis)
- bagasse	45	g/kg (dry basis)
High heat value		
- dry leaves	17.4	MJ/kg (dry basis)
- green leaves	17.4	MJ/kg (dry basis)
- tops	16.4	MJ/kg (dry basis)
- bagasse	18.1	MJ/kg (dry basis)

Source: Hassuani et al. (2005)

Table 13: Summary of harvest and dry cleaner performances in Brazilian trash study

Harvester fan setting	Normal	Slow	Off
Harvester cleaning efficiency (%)	75.5	29.2	5.5
Load per infield transport unit (ton)	6.0	3.6	2.8
Truck load density (kg/m ³)	410	270	240
Prototype dry cleaner performance (t/h)	210	150	111
Extraneous matter prior to cleaning (% wet)	7.1	12.8	23.0
Separation efficiency (% dry basis)	46	45	60
Pol losses (% of pol prior to dry cleaning)	1.12	2.56	4.90

Source: Hassuani et al. (2005)

These results emphasized the high cost of transporting trash-laden material because of its high bulk density. The option of separating the trash in field and then baling it (after partial drying) reduces the transport costs. Various baling and bale-breaking systems were tested. Machines that produce rectangular bales (as opposed to cylindrical) proved best because they produce higher densities and a shape that is

more amenable to transport and storage. Performances of the best machines are indicated in Table 14.

Table 14: Performances of selected baler and bale breaker in Brazilian studies

Baling	
Tractor power requirement (kW)	67
Fuel consumption (L/t dry trash)	1.6
Baling rate (t/h at 13% moisture)	9.1 – 9.8
Bale density (kg/m ³ dry)	175
Bale size (m)	0.8 x 0.9 x 1.9
Trash recovery efficiency (%)	56 – 84
Bale breaking and shredding	
Power per unit (kW)	82
Rate per unit (kg/h)	1000
Number of operators per unit	3

Source: Hassuani *et al.* (2005)

Bale breaking and shredding is necessary to enable existing fuel feeders to handle the trash. The power requirement would be reduced if it was not necessary to match the particle sizing of bagasse.

Although extensive research has been done in Brazil to develop best methods for collection of trash, very little collection for commercial operations is being practiced (J Felix Silva, 2007).

3.2.5.2 Colombian studies

An assessment of potential for deriving energy from cane trash in Colombia (Cock, *et al.*, 2000) generated the following information:

- Residues constitute more than 30% of the total biomass at harvest.
- The moisture content decreases by 3-5% per day when left in the field.
- Density of loose residues is less than 100 kg/m³, but this can be increased to 600 kg/m³ by compaction.
- The energy value is 10 MJ/kg at 35% moisture.
- The estimated cost for collection and delivery was US\$7.4-11.7 /t.
- To compete with coal this cost must be US\$8 /t at 35% moisture or US\$4.3 /t at 65% moisture.

3.2.5.3 Indian trials

Paull and Krishnamurthy (2007) reported on baling trials on small farms in India. The trials involved the development of custom designed mechanical rakes and the eventual use of tractors with “creeper” gears to enable the required slow speed. Commercial balers were not robust enough to withstand the extreme abrasive conditions. Square bales proved more suitable than round ones and a baling rate of 3.14 t/h (wet basis) was achieved.

3.2.5.4 southern Africa

In South Africa, no trash is intentionally harvested but some full-scale trials were done in the late 1980s to assess the impact of bringing in various amounts of trash

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with the cane so as to increase bagasse supply (de Beer *et al.*, 1989; Reid and Lionnet, 1989 and Purchase *et al.*, 1990). Four harvesting treatments were compared (all hand harvested):

- Green cane, topped but not trashed (GT)
- Burnt and topped (BT)
- Green cane, not topped nor trashed, i.e., whole plant (WP)
- Burnt, not topped (BNT).

Extensive measurements of cutting, loading and transporting were made and enough cane was harvested for each treatment to run a factory for three hours so that the impact on the factory could be measured. Results are summarised in Table 15- Table 18.

Table 15: Productivity of men and equipment working with different harvesting techniques

Total mass basis	Treatment			
	GT	BT	WP	BNT
t/man hr (cut & bundle)	1.03	1.06	1.51	1.33
t/trailer (in-field)	4.16	5.17	3.60	4.99
t/hilo	20.8	26.0	18.2	24.9
Loading rate (t/hr)	35.8	43.2	33.6	45.7
On clean stalk basis				
t/man hr (cut & bundle)	0.93	1.03	1.17	1.21
t/trailer (in-field)	3.76	5.00	2.80	4.55
t/hilo	18.8	25.2	14.1	22.7
Loading rate (t/hr)	32.3	41.8	26.1	41.7

Source: Purchase et al. (1990) based on de Beer et al. (1989)

On a cost basis, the influence of the harvesting method on cutting was small compared with the influence on loading and transport. On a clean stalk basis, payloads with whole cane (WP) were 44% less than those with burnt, topped (BT) cane, and loading rates were 49% lower. This problem of high transport costs for trashy cane was also encountered in the Brazilian studies (Hassuani *et al.*, 2005).

The fibre content of the WP treatment was 50% higher than the BT (Table 16) but when the different tonnages harvested were taken into account the fibre yield (t/ha) was almost 100% higher, illustrating that bagasse supplies can be almost doubled by harvesting the entire plant.

Whereas fibre throughputs were almost equivalent across all treatments; the pol throughput was almost halved when the whole plant (WP) was processed (Table 17). This represents a considerable increase in the cost of sugar production. In addition, the colour and turbidity of juice increased substantially.

Table 16: Composition of cane harvested by different methods

	Treatment			
	GT	BT	WP	BNT
Component	Composition (% wet basis)			
Stalk	90.3	96.8	77.8	91.2
Tops	2.8	2.7	14.3	8.3
Trash	6.9	0.5	7.9	0.5
	Composition (% dry basis)			
Stalk	80.5	96.1	66.2	88.8
Tops	1.8	2.4	13.0	9.8
Trash	17.6	1.4	20.8	1.4
	Cane analysis (% wet basis)			
Pol	11.5	13.6	10.6	13.4
Purity	84.6	88.4	80.4	86.4
Fibre	21.2	14.4	21.6	14.7
Ash	2.5	1.1	2.8	2.1

Source: Purchase et al. (1990) based on de Beer et al., (1989)

Table 17: Factory throughputs associated with different harvesting techniques

	Treatment			
	GT	BT	WP	BNT
Component	Throughput (t/h)			
Cane	140	181	127	190
Fibre	30	26	27	28
Pol	16	24	13	25

Source: Purchase et al. (1990) based on Reid & Lionnet (1989)

A computer model was developed to integrate the various costs and revenues associated with the different harvesting techniques. This showed that as long as bagasse is valued at its coal replacement value, then highest profits are associated with the cleanest cane. By simulating different bagasse values it appeared that the economics depicted in Table 18 might operate.

Table 18: Bagasse values required to justify extra fibre collection through different harvesting techniques

Treatment	Required bagasse value (multiple of coal equivalent value)**
BT	1 (existing situation)
GT	1.5
WP	1.8
BNT	2.5

Source: Purchase et al. (1990)

** Based on 1989 figures. The calculations assume that the BT treatment is standard. To justify the BNT harvest system the value of bagasse would have to increase 250%.

Investment in cogeneration at three mills in Swaziland was the subject of an analysis (USAID, 1990) that indicated potential positive returns at one of the three mills

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(Ubombo). The analysis also indicated that supplementary fuel was necessary to achieve energy self-sufficiency (which included 8–10 MW for irrigation). Some trash is now baled for power generation at Ubombo.

3.2.6 *Inter-row cropping and co-cropping*

- Harvesting operations may be affected by the existence of other crops growing between the cane rows. Sugar cane offers unique opportunities for inter-row cropping because the plant crop takes two to three months to canopy, thus enabling a quick-growing crop to be grown in the inter-rows prior to canopy formation. Such inter-cropping is particularly suited to Africa where it provides a greater diversity of food and allows more even distribution of labour through the season (Parsons, 1999). Despite these apparent attractions the practice is not common in mainland Africa. It is only in Mauritius that extensive intercropping takes place, with considerable production of groundnuts, potatoes (80% of national requirements), maize and vegetables. In South Africa, Parsons (1999) conducted trials and concluded that crops such as cabbage and green mealies (maize) can be produced economically in the plant crop inter-rows, thereby providing additional food or cash within 120 days of planting. The practice should improve the viability of many small-scale growers.
- The growing of sweet sorghum in the inter-row is precluded because the harvesting would probably cause severe damage to the cane. Sorghum could be grown as a co-crop (i.e. as fields alongside cane, not within it) but there is little incentive for this, because if the area is suitable for cane, then cane is the better crop as it *ratoons* (i.e. re-grows) 8-10 times, and it does not require the short harvesting window that is necessary for sweet sorghum. In areas where irrigation water is restricted but land is plentiful, sorghum might be a viable co-crop because it requires less water than most varieties of cane (however the production of biomass per unit of water is higher for cane than for sorghum).
- Some co-cropping is practiced in regions where there are low-lying frost-prone patches. Trials of co-cropping and co-processing of sugar beet with cane have proved reasonably successful under such conditions in the South African midlands; however maize tends to be the chosen co-crop.
- Many cane farms in South Africa grow timber as a co-crop. Natural forests have also become more extensive on cane farms as cane is withdrawn from riverine zones and indigenous trees are encouraged to grow.
- The co-cropping of sugar beet with sweet sorghum for ethanol production is an interesting possibility being investigated for the Eastern Cape region of South Africa. (The area is too far south for sugar cane).

3.2.7 *Key issues to be addressed*

Key issues being addressed, or that need attention are:

- The advantages and disadvantages of burning prior to harvest (see section 3.6.1 for more discussions on burning).
- The need to reduce the number of harvesting fronts so that the entire harvesting and delivery system can be better co-ordinated. This involves the formation of

effective harvesting groups- a challenging issue particularly among small-scale growers.

- The training and financing of harvesting contractors to improve their performance and viability.
- The reduction of indirect delivery (i.e. transloading) by increased use of road trailers that can be loaded in-field.
- Control of the spread of HI virus that affects the wellbeing of cane cutters.
- Optimisation of harvesting procedures (including loading and transport) for possible future trash collection.
- Testing of self-trashing varieties.

3.3 Delivery Arrangements

3.3.1 Overview

The delivery arrangements described under section 3.1.4 (“A typical supply chain”) apply throughout much of southern Africa. Individual mills are however free to negotiate different arrangements with their growers according to circumstances.

3.3.2 Scheduling

There is no uniform scheduling system for deliveries and at one mill certain growers have the right to deliver only during daylight. The daily rateable delivery allocation for each grower does not generally have an associated time slot. Some mills (e.g. Malelane) do not have cane yards and must therefore accept cane at a rate determined by the crush rate. Most mills however accumulate cane in a cane yard that provides some on-site buffer for cane supply.

It is emphasised that, in South Africa, the harvesting and delivery of cane is the responsibility of the growers, not the mill. This tends to result in a wide diversity of systems and equipment. In Swaziland, Zimbabwe, Malawi and Zambia the mills have more control over harvesting and transport than in South Africa. This reduces the number of cutting fronts and the diversity of transport vehicles.

In South Africa, growers who fall behind with their daily delivery allocations may be penalised by disallowing any catch-up later in the season. Arrangements exist for compensation of millers by growers if ‘no cane’ stops cause excessive downtime. Similarly, growers are compensated if mill breakdowns cause excessive extension of the milling season.

Computer modelling (Giles *et al.*, 2005) has highlighted opportunities to increase efficiency through better scheduling and central control of the supply operations. At many mills the transport fleet could be reduced substantially, thus enabling reduction of capital costs and queue time. The Sugar Logistics Improvement Programme aims to address these inefficiencies by comparing different systems and providing best practice benchmarks for stages in the supply chain.

3.3.3 Offloading

Most mills operate an overhead gantry for offloading bundled cane, and spillers for loose cane. The spillers rely on Hilo trailers having chains under the cane load with one end attached to a side bar. Spilling involves lifting the bar with a special crane so

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that the chains eject the load. Spilling is mainly direct onto a feeder table, but some is onto the floor of a cane yard. Gantry-mounted or tractor-mounted grabs move the cane in the cane yard.

3.3.4 Quality assurance and payment

In South Africa, measurements of cane quality are performed by the Cane Testing Service which is an independent organisation financed by the Sugar Association. The methods used by this service are also used by most non-South African mills in the region.

Cane is sampled after it has entered the factory and has been shredded. The sample of shredded cane is macerated in a 'cold digester' and the resulting liquid is analysed for pol (sucrose) and brix (total soluble matter). Residual fibre (including soil) is washed, dried and weighed.

Individual consignments are paid for on the basis of the 'Recoverable Value' (RV) formula. In essence this formula uses historical industrial average performance data to estimate how much sugar and molasses will be made from the cane, according to its quality. This estimate is based on the fact that each unit of non-pol (i.e. brix – pol) will divert a known amount of sugar to molasses, and each unit of fibre will retain a known amount of sugar. The market values of molasses and sugar are then used to convert the recoveries to a value index (RV).

No value is attributed to fibre for cane payment purposes – any revenue derived from this source is retained by the miller in South Africa. In Swaziland, any revenue derived from fibre that is used for anything other than factory energy is subject to a sharing agreement with growers.

3.3.5 Other aspects

The use of Near Infrared (NIR) spectrometers for analysing cane has been the subject of extensive research in South Africa. An online trial system is installed at one mill, but NIR is not yet used for quality assurance or payment purposes.

At least one mill has a penalty for ash, which is an indicator of soil in cane and is largely a reflection of loading operations. Push piling and grab loading can result in high ash levels.

The fact that cane is sampled only after it has entered the mill creates complications, if delivered cane is to be subjected to dry cleaning after being weighed and offloaded. For such purposes the sampling point will need to be at the weighing point.

3.4 Transport

3.4.1 Vehicles

The transport fleet in South Africa consists of a variety of vehicles (see Table 19). Where the delivery distance is short, tractor-drawn field trailers carrying bundled cane may go direct to the mill with payloads of 15-30 t. For intermediate distances, a variety of trucks with 15-20 t payloads are common. For long distances, high-sided

trailers carrying loose cane are used with payloads around 30 t. The maximum size of vehicles is limited by law to 22 m length and 56 t gross mass.

Table 19: Modes of cane delivery used in South Africa in 2005-06

Transport mode	%
Rail	2.3
Tram	3.9
Articulated trucks	
- interlink	44.5
- tri-axle	3.0
- Hilo	4.5
Rigid chassis	
- truck	20.2
- lorry	1.0
Tractor driven	
- Hilo	6.5
- rig	5.3
- interlink	8.9

Source: Davis and Archary (2006)

Rail transport accounts for only 2.3% of South African cane and a small amount of Zimbabwe cane. Trams are used at only one mill in South Africa, contributing 3.9% of total transport in 2005 (Davis and Archary, 2006).

In surrounding countries the fleets are generally less diverse and more centrally coordinated because most of the cane is produced by the miller-cum-planter.

Trials with on-board weighing equipment (Cole *et al.*, 2006) suggest that such equipment assists in increasing the payloads without overloading, and it would pay for itself in 1-2 years.

3.4.2 Efficiency benchmarks

The Sugar Logistics Improvement Programme (SLIP) has provided useful information in setting benchmarks. Measurements of the various efficiency parameters needs to continue for many years before the benchmarks become reasonably stable because, in the early stages, the publication of these measurements usually results in “today’s record becoming tomorrow’s average”.

Comparative information on vehicle utilization is shown in Table 20 and highlights a large range in efficiencies.

When all South African mills are considered, the vehicle utilisation efficiency varies even more than that shown in Table 20. At one extreme, a mill crushes two million tons of cane with a delivery fleet of only 75 vehicles while another mill has 250 vehicles delivering 1.7 million tons (Meyer, 2005).

A breakdown of some of the factors affecting overall efficiency is shown in Table 21 in the form that is presented to participants in the benchmarking exercise. This table

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also gives information on best practice achievements for various supply conditions in South Africa.

Table 20: Vehicle utilisation efficiency

		Vehicle utilization					
		General			Payload Distribution (%)		
Mill	Average lead distance (km)	No. of vehicles used	Total tonnes per vehicle per annum	Average payload (t)	0 to 15 tonnes	15 to 30 tonnes	30 to 45 tonnes
AK	25.11	304	5308	21.91	41.59	22.36	35.89
DL	14.08	213	6354	21.62	35.94	40.19	23.85
GH	23.74	120	9870	27.72	7.87	52.02	40.11
MH	15.93	122	11107	22.99	12.10	65.12	22.76
ML	39.75	108	14986	27.74	1.15	67.25	31.59
MS	17.38	116	11289	26.47	13.66	42.38	43.96
SM	20.90	186	10138	32.02	10.55	27.73	52.51
SZ	30.60	115	18823	30.23	0.94	40.44	58.62
UB	19.74	119	18055	27.11	1.55	68.14	30.30

Data is from those mills participating in the Logistics Improvement Programme in 2005.

MH, SM and UB are in Swaziland; all others are in South Africa.

The full forms of the Mills are: AK- Amatikulu; DL- Darnall; GH- Gledhow; MH- Mhlume; ML- Malelane; MS- Maidstone; SM- Simunye; SZ- Sezela; UB- Ubombo

Source: Data provided by Crickmay & Associates, logistics consultants

Table 21: Extracts from a haulier report showing individual performance and best practice achievements for various conditions and factors

Lead distance category: 10-20km				Factors affecting t/h moved			
Allocation group	Haulier code	Destination	t/hr per vehicle	Average payload (t)	Average speed loaded (km/h)	Average cycle time (h)	Average fuel consumption (L/100km)
ML20	180	Malelane	6.77	22.5	20.6	3.9	80.0
Best practice (Malelane)			6.96	25.5	27.4	3.7	73.6
Best practice (all mills)			9.59	22.5	24.0	2.3	60.0
Best practice (from loading zone)			8.38	30.8	11.1	3.7	73.2
Best practice (from in-field)			7.92	20.9	32.8	2.6	62.0
Best practice (burnt cane)			9.59	22.5	24.0	2.3	60.0
Best practice (trashed cane)			6.77	25.8	19.5	3.8	67.0
Best practice (spiller)			9.59	22.5	24.0	2.3	60.0
Best practice (bundle)			7.92	20.9	32.8	2.6	62.0
Industry average			5.77	23.4	22.1	4.4	64.1

Source: Perry and Wynne (2004)

The detailed measurements arising from SLIP have helped to eliminate some serious misconceptions. For example, the queuing time for offloading was perceived as a major problem in delaying the delivery of cane to the mill, but Figure 8 shows that the queuing time is insignificantly relative to the time between burning and loading.

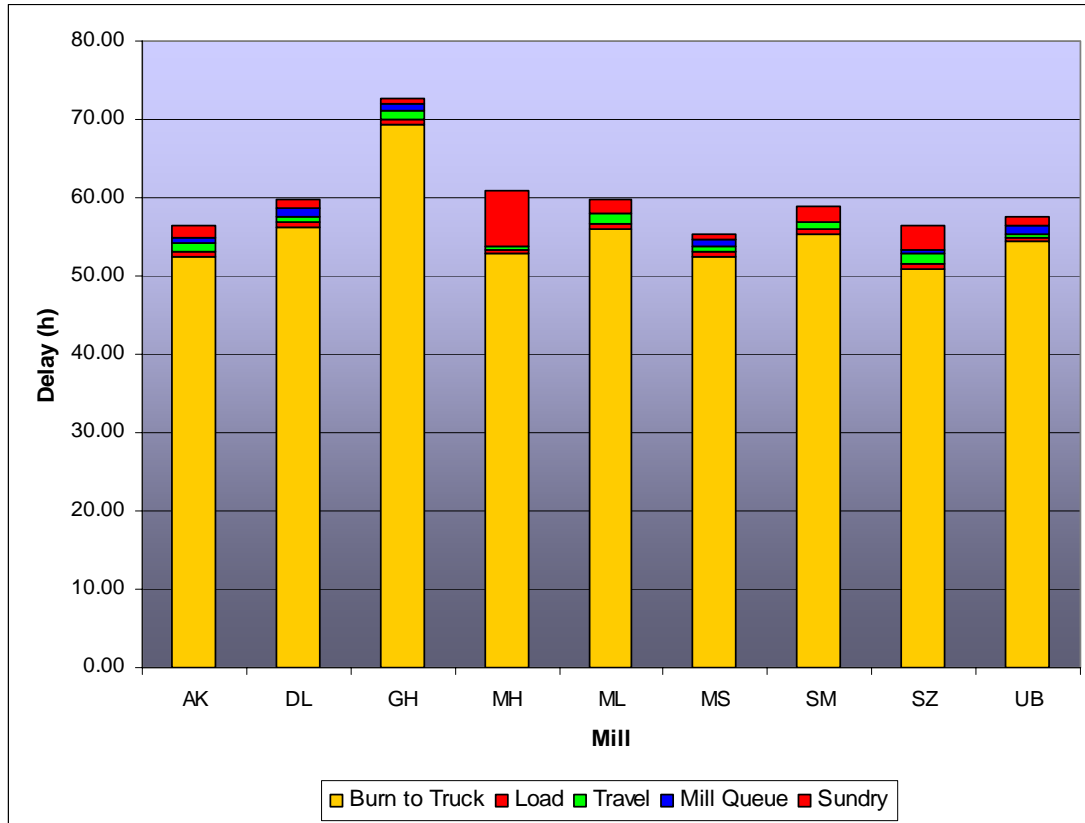


Figure 8: Components of delay between burn and crush at different mills.

Source: Data provided by Crickmay & Associates

This does not imply that queuing time has an insignificant impact on transport costs but it highlights the delay, and consequent pol losses, associated with burning.

The delays impacting on the transport system are compared in Figure 9. Mills showing no apparent queuing time generally involve a system that allows the haulage vehicle to unhitch a full trailer and immediately hitch an empty trailer.

3.4.3 Key issues to be addressed

The key issues to be addressed in South Africa include:

- Reduction of the transport fleet through better co-ordination and scheduling (this involves the entire supply chain), and quicker loading.
- Optimisation of vehicle design so as to enable more in-field direct loading, e.g., by increased use of inter-linking, high floatation trailers that can be pulled individually into fields by tractor but inter-linked for road transport.
- Optimisation of trailer and hauler ratio so that hauler units can exchange empty trailers for full ones without waiting.

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- Optimisation of designs to maximise payloads, i.e. improve the payload: tare weight ratio, and include on-board weighing systems.
- Improvement to roads servicing remote areas.
- Improvement of cost awareness among small-scale transport contractors.

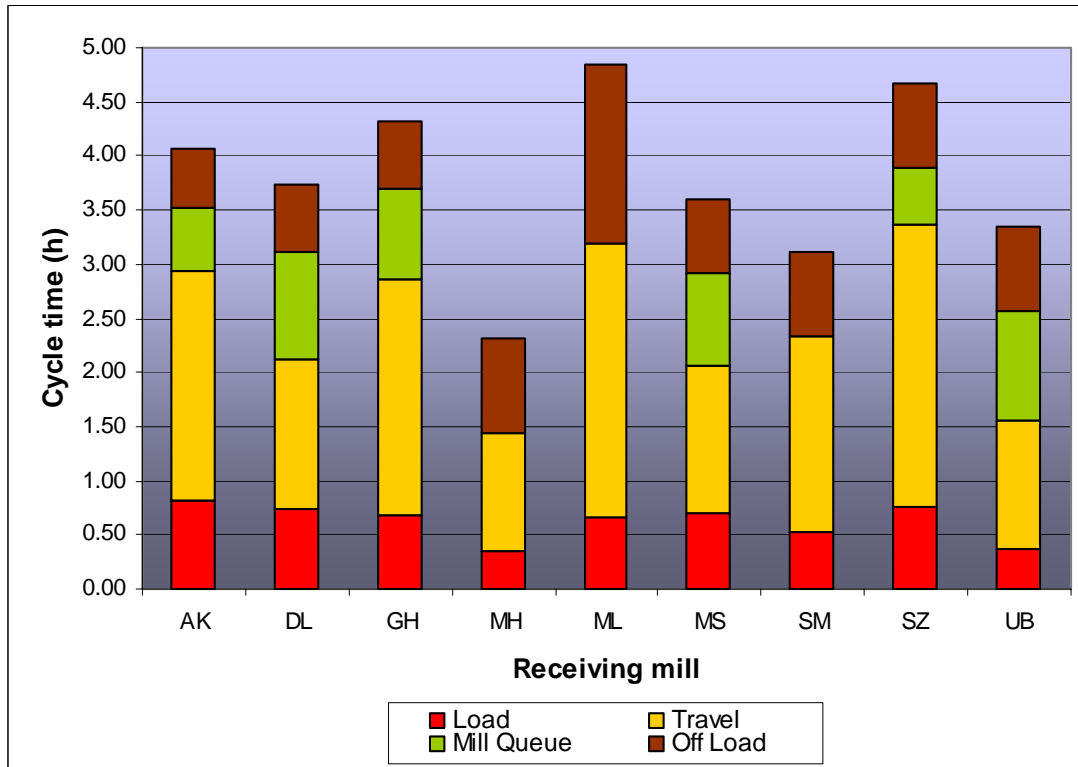


Figure 9: Delays affecting the transport fleets at different mills.

Source: Data provided by Crickmay & Associates

3.5 A Prize-Winning Example

The Sugar Logistics Improvement Plan has identified a prize-winning harvesting and delivery chain (Thomson and Turvey, 2004). Features of this efficient system are:

- Formation of a harvesting group involving nine farmers jointly delivering 225,000 t cane/yr with an average lead distance of 11 km.
- Location on a flat area conducive to direct deliveries.
- Joint ownership of six 160 kW haulage rigs and three grab loaders with a combined loading and delivery capacity of 250,000 t/yr.
- Cut cane is windrowed (high cutter productivity) but there is no push-piling by the grab loaders (minimal soil in cane).
- Soil compaction is minimised through use of low pressure, high floatation tyres on loaders and haulage vehicles, and use of tandem trailers that can be used individually under difficult field conditions.
- Use of specially designed walking axles with low pivot points such that the haulage vector ‘lifts’ rather than ‘buries’ wheels, and weight is evenly distributed to wheels. This enables operation under difficult field conditions and it minimises stool damage.

- Special co-operation during wet weather – all participating farmers assist at the harvesting front by bringing their small tipper trailers in-field to carry cane to a loading zone without charge to the farm being harvested.
- Operations continue 24 hr/day and 7 days/week.

3.6 Cross-Cutting Issues

3.6.1 Green cane vs. burnt cane harvesting

(Manual harvesting of green cane is often referred to as “trashing”.)

This topic is critical to trash harvesting because such harvesting requires green cane. It is a topic with a long history and intense focus in recent years, culminating in an economic model (Wynne and van Antwerpen, 2004) that attempts to assess the multitude of factors influencing the decision of whether to burn before harvest. Another model (Van der Berg *et al.*, 2006) is reasonably successful in explaining the mechanism whereby trashing has given higher yields than burning in a comparative (trashing vs. burning) field experiment, extending over more than 60 years. Under the conditions of the experiment (no irrigation), the trash layer improved yield mainly by increasing availability of water. It is probable that this mechanism operates in most areas where trash has a positive impact on yield, and it explains why trashing is of limited benefit for irrigated cane.

To illustrate the complexity of the issue, the economic model has 249 variables. Some of the factors that need to be taken into account are listed in Table 22. The model suggests that, under average South African conditions (no irrigation), burning results in greater loss of revenue (due to sugar degradation) than the additional cost involved in harvesting and processing trashed cane (offset by additional yield due to positive impacts on moisture retention).

Table 22: Major factors affecting the economics of trashing vs. burning

Trashing compared to burning	
Advantages of trashing	Disadvantages of trashing
Slower yield decline – higher long-term average yield	Higher cutting, loading and transport costs (because not all trash is removed)
Slower post-harvest deterioration	Higher milling costs
No delay due to burning	Slower re-growth in cold conditions
Lower herbicide costs	Increased chances of insect damage
Lower fertilizer costs	Interference with flood irrigation
Improved moisture availability	Interference with fertilizer application
Reduced soil erosion on slopes	Exposure of cutters to snakes and “itch”
No air pollution	

Source: Wynne and van Antwerpen (2004)

It is emphasised that the economics of trashing vary with different circumstances. For example, under irrigated conditions in Zimbabwe, a trash blanket is considered to be more nuisance than it is worth, but when water was restricted by drought then trashing had a worthwhile impact on yields (Murombo *et al.*, 1997). In Malawi, where some fields are infested with a certain weed (buffalo bean) that causes skin irritation, cutters refuse to harvest without prior burning.

Measurements involving cane cutters cutting burnt or green cane showed that the energy expenditure and oxygen uptake per unit of cane cut was 29.1% and 10.7% respectively more for green cane, than for burnt cane (Smit *et al.*, 2001).

The accumulated knowledge on trashing is now sufficient to enable reasonably accurate assessments of various scenarios associated with trash harvesting. It must be remembered that the in-field benefits of a trashing will not exist if the trash is removed. Partial harvesting of residues might be the best solution under circumstances where the agronomic benefits can be realised without leaving all the residues. Under irrigated conditions, trash is of little benefit (or negative benefit) so it could best be harvested under such conditions.

3.6.2 Alternative uses of residues

Cane residues can be used to supplement bagasse in whatever uses there are for bagasse. These include energy for sugar refining (distinct from raw sugar production), cogeneration and manufacture of paper, boards, furfural and animal feeds. Such uses already consume nearly all surplus bagasse in South Africa, but there are surpluses in surrounding countries.

Interest in trash harvesting has been heightened in South Africa by the government's commitment (Anon, 2002) to produce 10,000 GWh of renewable energy by 2013, with cogeneration from bagasse seen as a logical development for this purpose. To-date, however, no economic incentives for cogeneration with trash harvesting exist. The development of an economical process for making fuel ethanol from lignocellulose would create a distinct demand for cane residues.

3.6.3 In-field juice extraction

Where cane is grown for fuel ethanol production there is often the thought of not investing in a sugar factory but, instead, expressing the cane juice in the field and transporting it to a distillery. No such systems have been installed. The problem is that high sugar extraction must be achieved to ensure profitability. Such extraction needs the equipment of a factory, not a mobile field unit. In a factory, the cost of extracting the juice from the cane is approximately 66% of the total factory cost because it involves the heavy (costly) machinery and the boilers for energy. Small-scale factories making panela in Colombia achieve only about 65% extraction, suggesting that similar low extractions would be achieved by decentralised small units. Furthermore, the distillery would not have a supply of bagasse for fuel.

3.7 Cost Structure

Cost details are not in the public domain but Table 23 gives an overview of average cost proportions for South African large-scale cane farmers. These costs include harvesting and delivery, which comprise most of the staff costs, all cane transport costs, and a portion of mechanical maintenance and fuel costs (for in-field transport). Harvesting and delivery therefore constitutes at least 33% of the direct costs of delivered cane. These direct costs averaged ZAR126 /t cane for the season.

Determining the cost of trash harvesting is complex because of the multitude of interactions relating to agronomic effects of not burning. A computer model suitable for use under various soil and climatic conditions is under development.

Table 23: Cost proportions for cane delivered by large-scale South African farmers in 2004 (excluding capital cost of farm).

Item	Cost – rainfed (% of total)	Cost – irrigated (% of total)
Farm staff	28.5	19.8
Cane transport	14.8	20.0
Fertilizer	14.1	14.5
Sundry fixtures & maintenance	10.5	6.4
Administration, licences & insurance	9.4	10.0
Mechanical maintenance	8.0	6.5
Fuel & lubricants	6.5	5.3
Chemicals	5.6	3.0
Services / Irrigation	2.6	14.4

Source: South African Cane Growers' Association (2007)

3.7.1 Harvesting equipment

Less than 10% of the cane is harvested mechanically and therefore, there are no meaningful cost figures for mechanical harvesting.

3.7.2 Labour

In South Africa, labour productivity in terms of units per 1,000 tonnes of cane produced, averages between three and four units depending on the annual yields. This translates to 14 to 18 units per 100 ha. (South African Cane Growers' Association, 2007). Judging from Meyer and Fenwick's (2003) survey results (1.4 cutters per 1,000 tonnes of burnt stacked cane), approximately half of the labour input involves cutting cane. The approximate cost of cane cutters is ZAR39 (about US\$5.5) per day.

3.7.3 In-field loading and transport

Based on 2007 figures (Anon, 2007b) and a typical set of working conditions (200 days @ 8 hr/day, 1.5 km haul-out distance, 55 kW tractor with self-loading trailer), the cost of in-field loading and transport is R7.99/t cane. If a grab loader is used in conjunction with 6 t haul-out units then the cost increases to R14.48 /t.

3.7.4 Transloading

A representative cost (2007) of transloading, using a tractor mounted crane, is ZAR8 /t (Anon, 2007b).

3.7.5 Transport

3.7.5.1 Short distance with farm truck

Where the distance from zone to mill is only 5 km, an 8 t truck will operate with an estimated cost of ZAR16.73 /t of cane (Anon, 2007b).

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3.7.5.2 Long distance with big rigs

Guideline transport cost for June 2005 (Meyer, 2005) can be represented by the equation for costs expressed in South African Rand (ZAR):

$$\text{Cost (ZAR) per ton} = 13 + \text{distance} * 0.466$$

with an adjustment of ± 7 ZAR/t depending on terrain (1US\$ \approx 7 ZAR, 2007).

The components of this cost are indicated in Table 24.

3.7.5.3 Transport cost breakdown

Table 24: Vehicle cost breakdown

Item	% of total
Staff	24
Insurance & licence	11
Interest	10
Depreciation	13
Fuel and oil	28
Repairs & maint.	10
Tyres	4

Source: Meyer (2005)

3.7.5.4 Fixed and variable costs as affected by usage

Obviously transport costs increase if the equipment is not fully used during the season. For example, the 2005 costs for a rig doing 30,000 km/yr was ZAR19/km and this decreased to ZAR12 /km if the annual distance travelled was doubled (Meyer, 2005).

3.7.5.5 Other factors affecting costs

Direct vs. Indirect haulage

The potential savings of direct vs. indirect delivery are illustrated in Table 25.

Table 25: Relative costs of indirect and direct delivery

Item	Indirect (% total)	Direct (% total)
Cut and windrow	19	19
Mechanical load	11	11
In-field haulage	14	-
Trans-load	10	-
Road haulage	46	50
Potential saving		20

Source: Meyer (2005)

Lead distances

Haulage distances obviously affect vehicle productivity. A summary of some measurements is shown in Table 26.

Table 26: Delivery rates as influenced by lead distances

Lead distance (km)	0-10	10-20	20-30	30-40	40-50
Delivery rate (t/hr/vehicle)	10 (max.18)	8.5	7.5	6.5	6.0

Source: Summary of data provided by Crickmay & Associates

3.7.5.6 Comparison with Brazil

In South Africa, average payloads are about 28 t/vehicle. Much higher payloads are permitted in Brazil. A sample of Brazilian transport figures is shown in Table 27.

Table 27: Some Brazilian transport figures

Parameter	Figure [‡]
Annual tonnage/yr	82 000
Payload (tons)	57.4
Trips/yr	1400
Annual distance (km)	70 000
Fuel usage (l/100 km)	83
Fuel usage (l/t cane)	0.71

[‡]These figures are rounded averages per vehicle, derived from 10 vehicles supplying San Martino mill
Source: Meyer (2005)

3.8 Cane Trash Collection and Processing Costs

Estimates of costs of trash collection are misleading if they do not cover indirect costs such as the cost of soil fertility decline, soil erosion and weed control. Fortunately, the state of knowledge of sugar cane agronomy has reached a point where such costs can begin to be quantified, based on some long-term measurements of soil fertility trends under different burning/trashing regimes. Models of the impact of trashing (or green cane harvesting) compared to burning are beginning to appear (e.g. Wynne and van Antwerpen, 2004). Such models need to be extended so as to assess the impacts of removing different amounts of trash from the field for industrial use. In South Africa, a start has been made in this direction by adding a module to the Wynne & van Antwerpen model. The preliminary, unpublished results suggest that trash collection may have become an attractive option as a replacement for coal at those factories that purchase coal for their normal operations. This does not imply that new electricity generating facilities, based on trash, have become economically attractive. Where coal is being used in existing facilities, its price has increased so much that there is a relatively small market for dry, shredded trash as a coal replacement. Development of this trash supply will provide valuable experience for later circumstances where large-scale cogeneration or lignocellulose processing may become attractive.

In developing a 'trade in trash' regime, it is important that quality parameters be defined, including moisture content (for safe storage), energy value (for pricing against coal), ash content (for avoidance of boiler tube erosion and glass formation), and particle sizing (to ensure trouble free feeding with existing bagasse feeders).

3.9 Key Issues for Future Research / Analysis

Most of these issues have been covered in the preceding discussion. The following are some additional issues worthy of attention:

- Development of an ‘integration index’ for benchmarking the degree of co-ordination and co-operation in supply chains.
- Further development of cane varieties suited to dry conditions.
- Development of local varieties and knowledge relating to growing and processing of sorghum as an energy crop.
- Development of a holistic computer model for assessing the impacts of green cane harvesting and trash collection under various agronomic conditions.
- Further development of equipment and procedures for stripping trash from green cane during manual harvesting.
- Further development of dry cleaning systems and other systems (e.g., special balers) for trash recovery.
- Investigation of claims that trash can be converted to diesel in relatively small factories operated in cane-growing areas.
- Further development of bagasse gasification processes to increase energy recovery and, possibly, to provide hydrogen for fuel cells or gases for conversion to liquid fuels.
- Continuing analysis of the economics of converting trash to fuel ethanol via hydrolysis of cellulose.
- Technical, economic and market investigations of the potential for steaming bagasse/trash to make it more digestible for sale as an animal feed in Africa, as is done in Brazil.

4 Conclusions

Sugar cane and sweet sorghum can potentially make a significant contribution to meeting the future energy demand in southern Africa. Both crops thrive in wet-dry tropical and subtropical climates, although sweet sorghum tolerates a wider range of habitats. The inherent differences in the growth habit and growth requirements of these plants result in spatial and temporal variations in their potential bioenergy production, which can be exploited so that they can compliment each other.

Sugar cane thrives in tropical climates where there is freedom from frost and cyclones. Irrigation is essential where the mean annual rainfall is less than 800 mm. Temperature is the principal climatic determinant of sugar cane growth, and a high diurnal range promotes higher sucrose levels. Sweet sorghum on the other hand thrives over a wider range of habitats than sugar cane due to its greater tolerance to temperatures variations, greater resistance to drought, and less particular soil requirements. Sweet sorghum is more resistant to drought due to its superior water regulation abilities, and requires less than half of the quantity of water that sugar cane does. As water resources become more constrained in the region, sweet sorghum should therefore be an increasingly advantageous bioenergy crop in the region.

To achieve optimal growth, sugar cane requires high levels of solar radiation during its initial rapid growth phase and during ripening to maximize biomass and sucrose. In contrast, sweet sorghum is not photoperiod sensitive, hence it can reach maturity during the sugar cane off-crop period, and can potentially be used to extend the milling season for the production of bioenergy and sugar. Hence the two energy crops can be grown so as to complement each other, ensuring year-round supply of biofuel feedstock.

FAO analysis shows most of southern Africa to be prohibitive and unsuitable for rain fed sugar cane production. Only parts of DRC and Mozambique are identified as being very suitable. However, on a regional comparative basis, conditions are quite conducive in Malawi, Mozambique, Tanzania, and Zambia. GIS analysis performed in this study shows potentially suitable and available land for expanding sugar cane production in Mozambique (2.3 million ha), Zambia (1.2 million ha) and Malawi (206,000 ha). The potential of these three countries alone is greater than the *entire* current production of cane in SADC. This result is in general agreement with other independent studies conducted in the region. Clearly, land is unlikely to be a limiting factor in harnessing sugar cane's bioenergy potential in the region of southern Africa.

Although sweet sorghum is not yet grown commercially in the region, research suggests that its yields can be just as high (based on two crop cycles per year). Sweet sorghum is an annual crop that it is easier and cheaper to grow and handle: initial investment costs will generally be much lower than for sugar cane. Sweet sorghum is better suited to bioenergy production because its relatively low levels of sucrose purity make it unsuitable for commercial crystalline sugar production; with two crop cycles per year, it can achieve higher annual yields of ethanol per hectare. Although sweet sorghum has substantially lower irrigation input needs than sugar cane; its pesticide, fertilizer, tillage and harvesting energy inputs can be significantly greater.

Harvesting and delivery of sugar cane in southern Africa account for 30% of the cost of sugar production, with transport about 15-20%. The logistic chain steps such as

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burning, cutting, loading and transport have generally been managed separately, but maximum efficiency can be realized by integration and central coordination.

At least 90% of sugar cane in the region is hand harvested and delivered in whole stick form. A small number of chopper harvesters operate where field conditions permit but the economics is generally not attractive due to comparatively high losses of cane. Generally, mechanical harvesting is not as cost efficient as manual harvesting under southern African conditions. The availability of labour for manual harvesting and the need to preserve such employment opportunities is another reason for not using mechanical harvesting. Of the two main harvesting systems used, productivity of the cane cutters is higher where they can windrow rather than stack the cane.

About 88% of sugar cane is burnt before harvest in the region. In South Africa, burning is carefully controlled to minimise pollution and conflict with local communities. Research shows that cutter performance is enhanced less by burning than by conversion from stacking to bundling or windrowing. Time and motion studies show that stacking involved 30-35% of the total time.

There are no incentives for harvesting and delivery of trash in most countries due to lack of incentives. Studies conducted in Brazil and South Africa indicate that it is costly to transport trash-laden material because of its high bulk density. Separating the trash in field and then baling it (after partial drying) could reduce transport costs.

The economics of trashing vary with different circumstances. A trash blanket is considered a nuisance under irrigated conditions, but significantly improves yields during a drought. Where fields are infested with irritating weeds or snakes, cutters may refuse to harvest without prior burning. Partial harvesting of residues could be the best solution under circumstances where the agronomic benefits can be realised without leaving all the residues. Under rain fed conditions (such as in South Africa), burning results in greater loss of revenue (due to sugar degradation) than the additional cost involved in harvesting and processing trashed cane (offset by additional yield due to positive impacts on moisture retention).

Efficiency improvement has become an important issue in the sugar industry; the development of the Sugar Logistics Improvement Plan (a tool for analysing and benchmarking harvesting and delivery systems) has highlighted major differences between average efficiencies and best practice efficiencies in the region. Detailed measurements arising from SLIP have helped to eliminate some serious misconceptions such as the impact of offloading queuing time on transport costs and the correlation between burning delays and pol losses. Further refinement of SLIP will go a long way in improving efficiency in the sector.

- Sugar cane offers unique opportunities for production of food, fuel, feed and fibre. There are opportunities for inter-row cropping which is particularly suited to southern Africa where it provides a greater diversity of food and allows more even distribution of labour throughout the season. Such models have been successfully proven in Mauritius where 80% of national requirements of potatoes are grown using inter-cropping. This practice should improve the viability of many small-scale growers, promoting development of rural economies.

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Partners



The Cane Resources Network for Southern Africa (CARENESA) was a Thematic Research Network supported by the European Commission's Directorate General for Research (DG-RES). The primary objective of the CARENESA work programme was to evaluate the potential for renewable energy from sugar cane and similar crops to support sustainable development and improve global competitiveness within the southern African Development Community (SADC) region.



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