MACHINERY SYSTEMS FOR SUGARCANE PRODUCTION IN SOUTH AFRICA

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Submitted in partial fulfilment of the requirements for the degree of
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November 2005

ABSTRACT

The objective of this document is to review the cultural practices, harvesting and transport systems which have been developed and used in the South African sugarcane industry. The focus of the review, which includes a comparison of costs, is on the more important and costly aspects of sugarcane production, especially harvesting, loading, transloading methods and systems, as well as the transportation of sugarcane, both infield and to the mill. Other major cost centres, excluding land, include cane stool eradication, replanting of poorly yielding fields, weed control and fertiliser application.

Many new techniques and farming systems have been developed and adopted by the South African sugarcane industry over the past four decades. These include the introduction of the minimum tillage concept and loose sugarcane loading and transport systems which have resulted in some significant improvements in terms of overall efficiencies and a reduction in production costs. However, there are still numerous challenges facing the South African sugarcane industry. Foremost of these challenges is the change from a burnt to a green cane harvesting regime and improving machine use and productivity, in particular the harvesting and transporting of sugarcane.

It is essential, that for the South African sugarcane industry to remain cost competitive on the global market, new machine technologies and farming systems are developed and or adopted that are not only profitable but also ensure soil sustainability, efficient use of water and protecting the environment for future farming generations.

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1. INTRODUCTION

The warm Mozambique current flowing along the eastern shore of South Africa allows sugarcane to be grown in KwaZulu-Natal coastal areas at latitudes further south from the equator than anywhere else in the world. Sugarcane is also grown in the hinterland at altitudes of over 500 metres as well as in Mpumalanga. The terrain varies from relatively flat in the northern regions to undulating in the hinterland to very steep along the coastal regions. The sugarcane producing areas and mill locations in South Africa are shown in Figure 1.

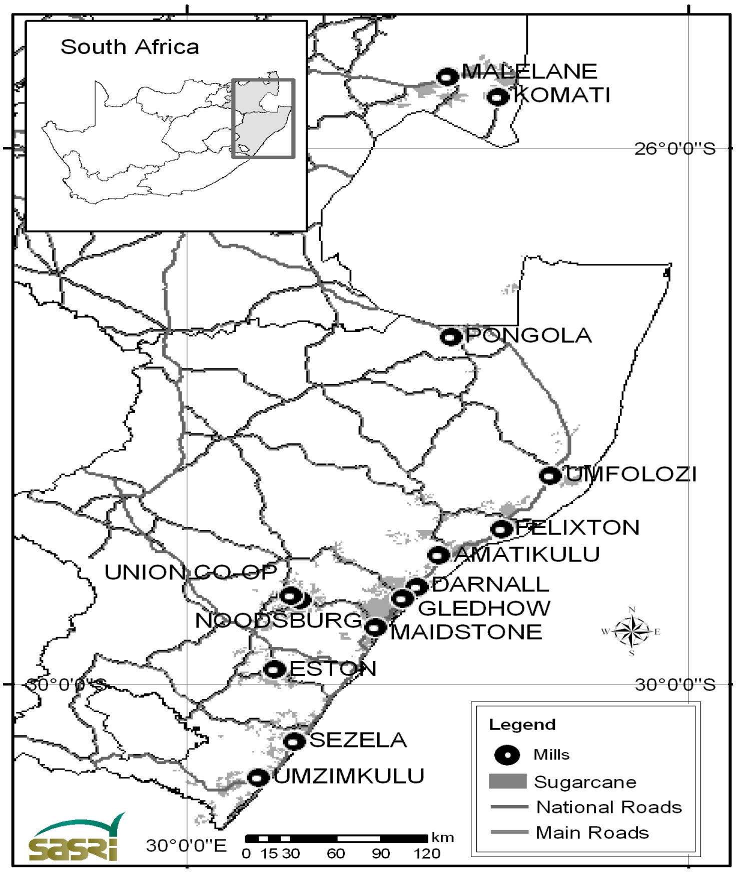

Figure 1. South African sugar industry

The total area under sugarcane production in South Africa is approximately 432 000 hectares, with about 20% grown under irrigation, mainly in the northern regions (Anon, 2005a). There are currently some 50 000 registered sugarcane growers, of whom about 48 000 are designated as 'small-scale' and 'medium-scale' growers. The average commercial farm produces between 8 000 and 10 000 tons of sugarcane per annum. In an average season the industry produces around 22 megatons of sugarcane, 75% of which comes from some 2 000 commercial growers and 13% from estates operated by six milling companies referred to as 'miller-cum-planters' (Anon, 2005a).

Sugarcane is a perennial crop which is usually harvested between six and eight times before it has to be re-established. Re-establishment consists of thoroughly eradicating the old crop using either mechanical or chemical methods. Seedbed preparation is effected by conventional ploughing/harrowing or by using specially designed minimum and reduced interrow tillage equipment. Creating furrows for planting is carried out mechanically, except on extremely steep slopes, where it is done manually. Although mechanical whole stalk sugarcane planting has been tried in the past, the planting and covering operations are currently still carried out manually.

Prior to the 1960s, weeds were controlled using hand labour and a range of mechanical cultivators. Although some herbicides are applied mechanically via boom sprayers, most private growers use manually operated knapsack sprayers. Fertiliser in the furrow and as a top dressing practised by much of the industry is applied manually using the 'tin and string' method, or using a range of manually operated 'wheelbarrow' and knapsack applicators. Mechanical fertiliser application, using both banding and broadcasting equipment, is carried out on much of the flatter terrain in the industry.

Sugarcane is predominantly harvested by hand between April and December, with between 85-90% of the sugarcane being burnt at harvest. It is estimated that at present 60% of the sugarcane is mechanically loaded.

Due to the wide range of topographical conditions under which sugarcane is grown in South Africa, numerous modes of transport are used to take the sugarcane from the field to a transloading siding or zone, or directly from the field to the mill. A large proportion of the crop is transported from the field to strategically located transloading zones on the farms. Mobile cranes or mechanical loaders are used to tranship the sugarcane onto 20-30 ton spiller road haulage vehicles, which transport the sugarcane to the mills.

Most of the rail system was phased out by the mid-1960s, because of a rapid rise in the cost of replacing rolling stock and tracks and extensive damage caused by floods. Today, only the Umfolozi mill is still being served by tramline.

The sugar industry is one of the major economic contributors in the South African agricultural sector. The sugar industry produces an average of 2.5 million tons of sugar per season, and contributes an estimated R2.38 billion to the country's foreign exchange earnings annually. Employment within the sugar industry is approximately 85 000 jobs. Direct and indirect employment is estimated at 350 000 people (Anon, 2005a).

For a typical South African dryland sugarcane enterprise, machinery related costs (including transport) account for between 30% to 40% of the total production costs (Figure 2), which highlights the importance of mechanised farming practices and management (Gillitt, 2005).

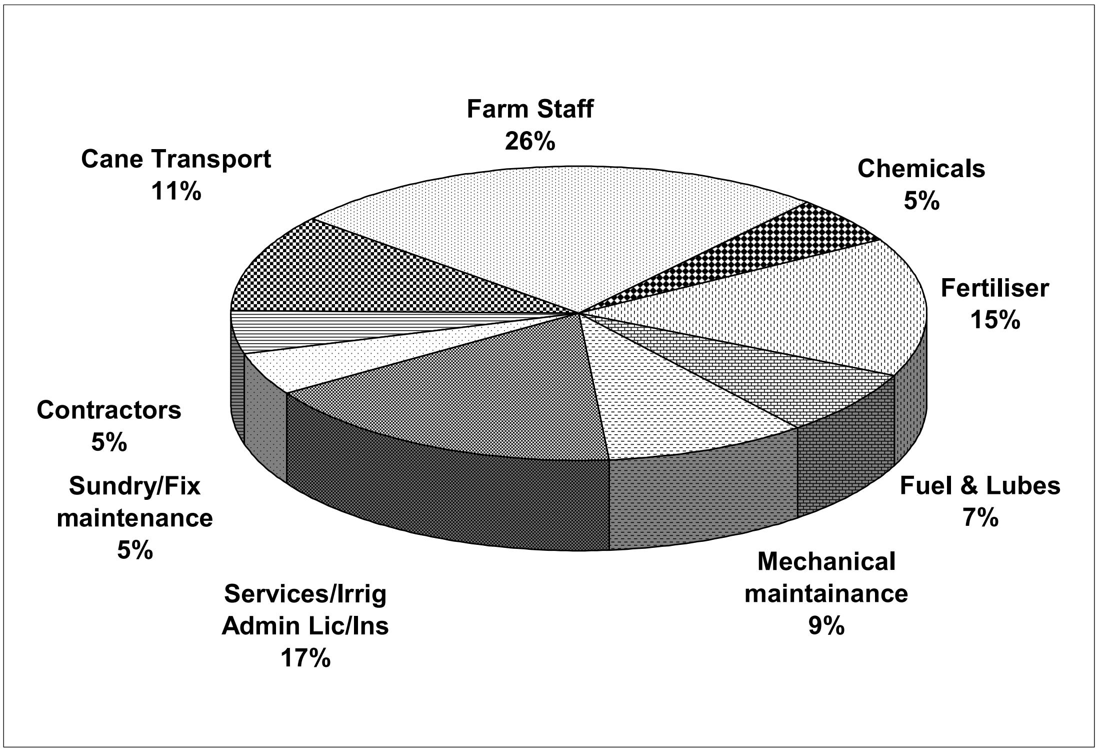

Figure 2. South African sugarcane production costs - 2003-2004 (Gillitt, 2005)

As can be seen in Figure 3, the major mechanisation costs are infield loading and transport, and the transportation of sugarcane by road haulage vehicles. More than 1 200 vehicles are used to transport the sugarcane, and Crickmay (2005) estimated that the average one-way distance is about 25 kilometres.

Apart from the road transport vehicles, many thousands of tractors are also used for infield transportation of sugarcane and other materials. There are also many hundreds of other types of machinery and equipment, such as land preparation implements, trailers, fertiliser and herbicide applicators, mechanical loaders and transloading cranes. With decreasing profit margins, often related to increases in vehicle and equipment costs, it has become important to develop more cost effective farming methods, and improve machine performance and utilisation if South African sugarcane enterprises are to remain viable and sustainable.

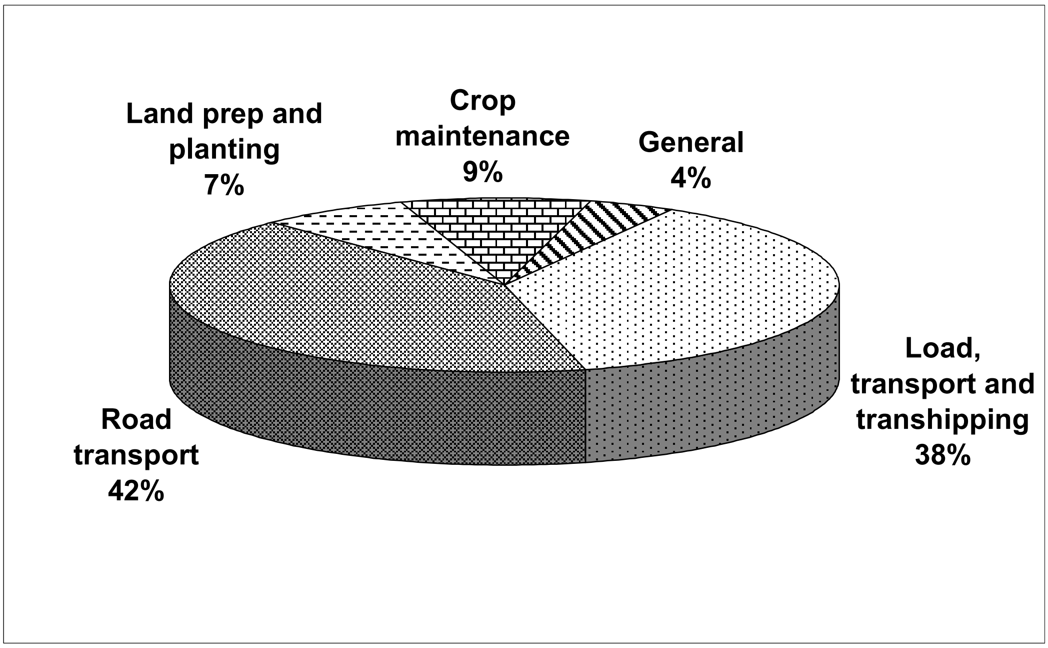

Figure 3. Estimated breakdown of mechanisation related costs on a typical dryland sugarcane farming enterprise

The objective of this document is to review the cultural practices, harvesting and transport systems presently in use in the South African sugarcane industry. Cost comparisons for the various operations are also presented. In addition, alternative economic farming systems and machinery, and equipment selection, are described and their implementation discussed in the following sections.

The review will focus only on the more important and costly aspects of sugarcane production. The major cost centres, excluding land, that are described and discussed in this document include stool eradication, replanting of poorly yielding fields, weed control and fertiliser application. Emphasis is placed on harvesting, loading and transportation of sugarcane, both infield and to the mill.

2. STOOL ERADICATION AND LAND PREPARATION

Sugarcane is a perennial crop with in excess of 30 ratoon crops having been reported under good management practices, and where soil and moisture conditions were not limiting. However, when yields decline due to diseases or drought, the affected fields are replanted. Most farmers re-establish approximately 10% of the area under sugarcane annually.

The importance of eradicating diseased sugarcane stools effectively and the need to ensure that plough-out fields are 'volunteer' free before planting a new sugarcane crop cannot be over-emphasised. Sugarcane fields infected with diseases such as Ratoon Stunting Disease (RSD) can have yield losses which exceed 40% in ratoon crops (Bailey and Bechet, 1986).

2.1 Stool eradication

There are a wide range of systems, including manual (de Beer *et al*., 1996; Anon, 2002) and mechanical stool eradication methods that can be used. Chemical stool eradication can be extremely successful when used during a period of rapid sugarcane growth (Iggo, 1974). Combination tillage, which consists of the application of glyphosate and mechanical undercutting with a blade plough, can improve efficacy and/or reduce costs (Butler, 1992; Leibbrandt, 1993).

2.1.1 Mechanical stool eradication

Dicks *et al.,* (1981) showed that mechanical stool eradication is only successful when carried out at a shallow depth (100-150 mm) in heavy soil types and during the dry winter period. The aim is to invert the sugarcane stool, from which new shoots can develop, without burying these parts so deep that subsequent operations cannot reach them. This operation can be performed successfully using a mouldboard plough equipped with a depth control wheel or blade ploughs operating at a shallow depth.

2.1.2 Chemical stool eradication

Applying glyphosate to destroy old or diseased sugarcane crops was first done during the early seventies (Iggo, 1974). Research results as well as experience showed that the economic success and efficacy of this eradication method is dependent on application rate, quality of water used, growth stage and growth vigour of the crop, climatic conditions, sugarcane variety and soil type (Iggo and Moberly, 1976). Chemical stool eradication should be carried out when sugarcane is growing vigorously (Anon, 2002). Best results are obtained when between six and eight litres of glyphosate is sprayed in late summer when regrowth has reached a height of about 500 mm. Butler (1992) developed a combination tillage technique to reduce chemical costs and to improve the overall efficacy of using glyphosates, which enabled early season planting. In this system the spraying of glyphosate is followed by a mechanical 'on-the-row' undercutting operation, using a blade plough operating 100 mm below the soil surface, performed 3-7 days after spraying.

2.1.3 Manual stool eradication

Manual stool eradication, commonly referred to as chipping, comprises the use of purpose-built or modified hoes. Depending on labour availability and cost, this can be an alternative to the mechanical or chemical methods in terms of effectiveness and cost on lighter soils and on steep terrain. Between 30-40 man-days per hectare are required to perform this operation (Anon, 2002).

2.2 Land preparation

The primary objective of preparing a seedbed is to produce a tilth which will result in good bud germination and subsequent root development of the new crop. To achieve this, soil may have to be levelled or smoothed, flat low lying areas drained and steep slopes protected against erosion. Ripping may be necessary to break up 'hard pans' or limiting impervious layers, or to loosen up compacted soils.

2.2.1 Conventional tillage

The traditional method of seedbed preparation for sugarcane uses heavy machinery and implements, which are often not cost effective. Moberly (1972) showed that deep tillage, which entails ploughing to depths of 920 mm and subsoiling to depths of 750 mm, is not normally economically justified. Yields from rainfed plant and first ratoon crops have shown that, in general, there is little advantage in ploughing or subsoiling to depths greater than 200-250 mm (de Beer *et al.,* 1996).

The most common types of tillage equipment used for seedbed preparation in the sugar industry include traditional rippers, mouldboard or disc ploughs, and tandem and offset disc harrows. A disadvantage of conventional tillage is that one operation can be counteracted by a subsequent operation. For example, when a soil has been loosened during a ripping operation, repeated disc harrowing can cause the soil to become compacted again.

2.2.2 Minimum and reduced tillage

In these systems the old crop is sprayed with glyphosate, a seedbed is prepared and the sugarcane setts are planted in furrows drawn in the old interrow. The machinery commonly used to prepare a suitable planting tilth include split flange rotary hoes or split offset disc harrows, usually equipped with ripper tines (Anon, 1998). The timing of the operations plays an important role in determining the quality of the final seedbed. By 1977 minimum tillage had become widely accepted by the industry (Hadlow and Millard, 1977).

There is no reason why the above described minimum tillage equipment cannot also be used to prepare a seedbed following the mechanical stool eradication system described in Section 2.1.1. This option will reduce overall re-establishment costs. The comparative cost differences between conventional, reduced mechanical and chemical tillage systems on heavy soils are listed in Table 1 (Anon, 2005b).

Table 1. Comparative cost differences between conventional, reduced mechanical and chemical tillage systems on heavy soils (after Anon, 2005b)

Conventional mechanical tillage system		**Reduced mechanical tillage system**		**Chemical/mechanical tillage system**	
Operation	**R.ha^{-1}**	**Operation**	**R.ha^{-1}**	**Operation**	**R.ha^{-1}**
Shallow plough	326	Shallow plough	351	Manual spray	30
Heavy harrow	326	Light harrow	189	Chemical	184
Deep plough	326	Light harrow	189		
Heavy harrow	326				
Heavy harrow	326	Min. tiller/ridge*	485	Min. tiller/ridge*	485
Ridging	227				
Total	1857		1214		699

* Two-row rotary minimum tiller plus ridgers

The various planting methods used, as well as a cost comparison between the systems, are described in the following chapter. Plant and ratoon sugarcane operations such as weed control and fertiliser application are also described and discussed in the next chapter.

3. PLANTING, PLANT CROP AND RATOON SUGARCANE MANAGEMENT

3.1 Planting

Good quality, disease free seed cane is expensive to purchase and often difficult to obtain, particularly during a drought. The best seed is obtained from a registered nursery, where only the plant crop and first ratoon are used as seed. Under drought or flood conditions it may become necessary to plant sub-standard seed and it is therefore extremely important to prepare a good seedbed.

3.1.1 Hand planting

Traditionally the planting of sugarcane is done manually. The most common method of hand planting is where whole seedcane stalks are dumped in the field and then placed manually into pre-ridged planting furrows. The whole stalks are then cut into 300-400 mm setts to avoid any apical dominance. A hand hoe or tractor drawn covering implement is used to cover the setts with 30-40 mm of soil. The number of labourers required for this operation varies between 12 and 30 per hectare, depending on whether the seedcane is treated with fungicide or not, and whether filtercake is placed in the furrow. Another popular method of planting is that of using ‘hand droppers’ that follow a tractor/trailer combination operating in pre-ridged fields. Generally, the seeding rate is double stick, equating to between 6-10 tons of seedcane per hectare.

3.1.2 Mechanical planting

In the late seventies and early eighties, considerable interest was shown in single row planting aids such as the Australian cutter planters. Several of these planters were evaluated under local conditions (Anon, 1976a; Anon, 1976b; Anon, 1984). These semi-mounted tractor drawn planters are equipped with a ridger and covering device. Approximately 500 kg of whole stalk sugarcane is manually loaded onto the planters and the two-man crew then feed the stalks into a cutter box which cuts the stalks into predetermined sett lengths. The setts drop into the planting furrow below the machine, together with the planting fertiliser. The cutter box and fertiliser applicator chain are driven by two depth control wheels. Planting rates range between one and two hectares per day, using about 12 labourers for covering. This planting system is not widely used because of the relatively low output and because the method often results in irregular stands of sugarcane. The cost of various planting methods based on a 20 hectare planting operation under South African conditions is given in Table 2 (Anon, 2005b).

Table 2. Comparative costs of various planting methods (Anon, 2005b)

Operation	Cost per hectare (R)		
	Mechanical planting	**Semi-mechanised planting**	**Manual planting**
Labour	300	600	600
Ridging	-	215	227
Covering	-	280	150
Mechanical planting	634	-	-
Total	934	1095	977

3.2 Plant and ratoon sugarcane management

When a good stand of sugarcane has been achieved, it is important to ensure that the new plant crop or ratoon has as little competition as possible from weeds in terms of moisture and nutrients. Some of the more important methods of applying granular fertilisers are described and discussed in this section.

3.2.1 Weed control

To ensure a high yielding sugarcane crop, it is vital that fields are kept as weed free as possible. There are numerous broadleaf weeds and grasses, including *Cynodon* spp. (kweek grass) which can have a significantly negative impact on sugarcane yields.

3.2.1.1 Mechanical weed control

Since the early 1960s, mechanical means of controlling weeds has declined rapidly because of the efficacy of chemical alternatives. Many types of mechanical cultivators were evaluated on different soil types and under different soil moisture conditions, with weeds of various types and at various stages of growth (Meyer and de Beer, 1975). Coiled and spring tine cultivators consistently gave the best results.

3.2.1.2 Chemical weed control

On small and medium sized farms, pre and post emergence herbicides are applied using manually operated knapsack sprayers, covering one row per pass. Tractor mounted boom sprayers are used on large estates and on flat terrain. Knapsack operators can spray between 1 and 1.5 hectares per day, while multi-row boom sprayers have the potential to achieve in excess of 15 hectares per day.

3.2.2 Fertiliser application

Several different methods of applying or incorporating gaseous, liquid and granular fertiliser are used in the sugar industry. The two popular methods of applying fertiliser are described and discussed below.

3.2.2.1 Manual application

In much of the industry, fertiliser is applied in the furrows and as a top-dressing using the 'tin and string' method, or by a range of manually operated 'wheelbarrow' and knapsack-type applicators. These application methods are usually very accurate and cost effective. Output per operator again varies between 1 and 1.5 hectares per day, depending on the method used, the row spacing and the terrain.

3.2.2.2 Mechanical application

Application of liquid and granular fertiliser, using mechanical banding and broadcasting equipment, is carried out on much of the flat terrain in the industry (Anon, 1981a; Anon, 1981b). The machines used are capable of treating up to 15 hectares per day, depending on the type and capacity of the machine as well as field layout and condition.

Meyer and Worlock (1983) evaluated several different methods of applying 500 kg bags of granular fertiliser. The main advantages of the evaluations included increased tractor and machinery productivity, as well as a reduction in labour requirements.

Harvesting is currently the most labour intensive and one of the most costly operations in the production of sugarcane. In the following chapter, various methods of harvesting sugarcane are described and discussed.

4. HARVESTING

The average sugarcane crop cycle varies between 12 and 24 months, depending on the bioclimatic region in which it is grown. Manual harvesting of sugarcane has dominated the South African sugarcane industry since 1848. During the early years, indentured Indians formed the major workforce in the fields, later supplemented with Tongas and Pondos. Mechanised harvesters could not compete with this cheap and abundant source of labour.

During the 2002/03 season, in a survey of all mill supply areas, Meyer (2003) showed that more than 97% of the sugarcane crop was harvested manually and that more than 90% was burnt before being cut. The methods used to harvest the crop during the 2003/04 season are shown in Table 3 where the bulk of the sugarcane was burnt and manually cut and windrowed.

Table 3. Harvesting systems in the South African sugar industry (Meyer, 2003)

System	Fraction of total crop (%)	Sugarcane yield 2003/04 (tons)
Manual cut and load	1.34	294 490
Manual cut and stack	30.04	6 596 073
Manual cut and windrow	66.43	14 588 430
Mechanical load	66.43	14 588 430
Mechanical harvest	2.19	481 419
Harvested burnt	93.86	20 611 138
Harvested green	6.14	1 349 274

4.1 Manual harvesting

In the majority of the sugar industry, sugarcane is harvested between April and December. Up to the 1960s, the most common ways of harvesting were to cut the sugarcane manually and load it into the transport vehicle, or to cut the sugarcane and stack it in bundles. However, over the past four decades there has been a significant move to manual cut and mechanical load system, especially on flat terrain. A survey was conducted throughout the southern African region to assess manual cutter performance for the various harvesting systems currently in use (Meyer and Fenwick, 2003). A summary of cutter performance is presented in Table 4, where it can be seen that productivity is higher in burnt than in green sugarcane in all cases. Furthermore, labour productivity for the cut and stack system is 56 and 91% lower than the cut and bundle and windrowing system respectively. It is anticipated that, for a host of political, social, health and economic reasons, labour is going to become more scarce and expensive (Langton *et al.*, 2005). Considering that much of the sugar industry is not ideally suitable for full mechanical harvesting operations, there is a real need to train and develop incentive schemes in order to improve cutter performance, as well as develop manual cutting aids (Meyer and Fenwick, 2003).

Table 4. Summary of manual sugarcane cutter performances in southern Africa (Meyer and Fenwick, 2003)

Harvesting system	Average cane yield (t/ha)	Cutter output (tons/day)	Cutters per 1000 tons
Cut and stack (green)	72.50	3.45	1.79
Cut and stack (burnt)	69.60	4.20	1.44
Cut and bundle (green)	73.94	5.58	1.07
Cut and bundle (burnt)	69.93	6.56	1.08
Cut and windrow (burnt)	92.87	8.01	0.99

4.2 Mechanical harvesting

Prior to 1973 a few mechanical harvesters were imported from Australia and the United States of America by the larger estates, and by growers who feared the consequences of sudden labour shortages. Several private growers were prompted to build their own harvesting machines, subsidised by funds made available by the South African Sugar Association. However, many of these machines were unsuccessful because they were limited to harvesting only erect burnt sugarcane, or they were suitable only for use on flat terrain, or they were too expensive when compared with the cost of harvesting sugarcane manually.

A wide range of machines are available internationally which can be used to harvest sugarcane (Meyer, 1996a; Meyer, 1997a; Meyer, 1999a). During the early seventies, the Agricultural Engineering Department at the South African Sugarcane Research Institute (SASRI) launched a harvesting development programme to investigate possible harvesting systems, and to develop equipment and machines which would be able to operate under local conditions. The burnt and green sugarcane harvesting systems, attachments and machines developed and tested by SASRI included burnt and green sugarcane whole-stalk linear windrowing machines, bundling machines and combine chopper harvesters (Meyer, 1996b). The various types of harvesting machines and associated sugarcane handling systems evaluated by SASRI are briefly described in the following sections.

4.2.1 Whole stalk transverse windrowing machines

This type of machine harvests a single row of sugarcane per pass. The sugarcane stalks are placed in a windrow at right angles to the row direction, either mechanically or manually. Stalks are topped by the machine, or by hand in a subsequent manual operation (Anon, 1974; Anon, 1979; Anon, 1981c). The windrowed sugarcane is then manually piled into 3-5 ton stacks, winched onto tractor drawn self-loading trailers or mechanically loaded into tractor drawn basket trailers, and transported to a transloading zone.

4.2.2 Whole stalk linear windrowing machines

This type of machine cuts and lays one or two rows of sugarcane into linear windrows ('sauages') parallel to the row direction. This type of machine included the SASEX cutter (Pilcher and van der Merwe, 1976), the Edgecombe cutter (van der Merwe *et al.*, 1978), the Midway cutter (Meyer, 1984) and the front mounted cutter (Boast, 1989). The sugarcane was then manually turned 90° to the row direction and placed in small bundles forming a windrow, or it was piled into 3-5 ton stacks. Tractor drawn basket or self-loading trailer combinations were used to transport the sugarcane to on-farm transloading zones.

The option of using linear windrowing machines has the potential of reducing labour requirements by 33% when sugarcane is manually stacked, and 67% when sugarcane is manually windrows and mechanically loaded compared with manual cutting and stacking (de Beer *et al.*, 1991). Meyer and Worlock (1982) showed that, by using a linear tractor mounted cutter and a grab loader a total of 22 men can easily handle a daily sugarcane allocation of 150 tons per day. This number of people required in this system can be considerably lower, depending on labour performance, than the two traditional manual cut and stack or cut and windrow harvesting systems.

4.2.3 Whole stalk bundling machines

This category of machine tops, base cuts and collects whole stalk sugarcane in a bin at the rear of the machine. The sugarcane in the bin is dumped at intervals along the sugarcane row and subsequently reloaded into tractor drawn basket trailers or transloaded into following basket trailers. The machines developed and/or evaluated by SASRI included the 'Gobbler' (Anon, 1976c), the McConnel Stage II (Boast, 1977), the Toft J150 (Anon, 1978a), the Sasaby 1 and 2 (Pilcher and Boast, 1980), the Sasaby (Boast, 1985) and the Ngwenya (Boast, 1994). Apart from the Gobbler and Toft J150, the machines in this category were designed to harvest green sugarcane, and achieved harvesting rates of between 10 and 25 $t.h^{-1}$.

4.2.4 Chopper harvesters

Chopper harvesters are the only type of machine capable of harvesting both green and burnt, erect and lodged sugarcane. However, there are many factors to consider when implementing a fully mechanised harvesting system (Meyer, 1997b; Meyer, 1999b). The issues that must be considered include terrain, field layout and condition, sugarcane variety, transport system and harvest-to-crush delays.

Figure 4. A chopper harvester operating in green sugarcane on a KwaZulu-Natal estate

Extensive evaluations were conducted on chopper harvester operations in Swaziland between 1975 and 1978 (de Beer and Boevey, 1977; Boevey and de Beer, 1977; de Beer and Boevey, 1979). Modern chopper harvester and mechanical loader performances were again evaluated between 1999 and 2002 both in South Africa and Swaziland (Meyer, 1999c; Meyer, 2001a; Meyer *et al.*, 2002). A summary of time and motion studies conducted in various parts of the sugar industry on several types of chopper harvesters by Meyer (1999a) are compared in Table 5. The results presented in Table 5 are ranked according to the potential harvesting rate under the particular operating conditions.

Table 5. Summary of chopper harvester performances (Meyer, 1999a)

Study No.	**Speed (km h^{-1})**	**Av.turn time (min)**	**Pour rate (t.h^{-1})**	**Field efficiency (%)**	**Harvest rate (t.h^{-1})**	**Potential harvest rate (t.h^{-1})**
10*	2.75	2.03	43.7	57.6	25.1	39.9
6*	4.41	1.70	61.1	60.5	37.0	40.2
2	4.38	2.38	77.9	40.9	31.9	43.4
11	3.59	2.27	80.3	39.5	31.7	53.0
4	5.89	1.31	80.2	52.8	42.3	54.0
13	2.63	0.98	63.2	41.4	26.2	58.3
12	2.79	1.38	62.7	79.3	49.7	58.5
5	7.15	1.34	99.2	36.6	36.4	59.6
8	6.44	1.08	92.2	56.2	51.8	60.1
3	4.14	1.67	81.2	48.4	39.3	60.3
7	6.68	1.08	92.6	49.9	46.2	61.8
1	5.72	1.88	98.0	40.6	39.7	67.4
9	4.12	1.93	95.9	31.0	29.7	68.1

*Green sugarcane

Based on the results and experience gained during the above studies, a computer based model was developed to assess the viability of using a fully mechanised chopper harvesting system (Meyer, 1998a; Meyer *et al.*, 2000). This work showed that a fully mechanised harvesting system can be economically competitive compared with a semi-mechanised harvesting system, provided a minimum harvesting rate of around 40 t.h^{-1} is maintained in burnt sugarcane, and approximately 60-80 thousand tons of sugarcane is harvested by a single machine in a season. This implies that the harvester must be well maintained, fields must be well laid out and there must be sufficient transport to service the harvester.

The harvesting of sugarcane is only the first step in delivery of the sugarcane crop to the various sugarcane mills. Different loading and transloading systems are used depending on individual grower crop size, terrain and labour availability. In the next chapter the various manual and mechanical sugarcane loading and transloading machinery and systems used in the sugar industry are described and discussed.

5. INFIELD LOADING AND TRANSLOADING

It is estimated that at present about 60% of the industry's annual sugarcane crop is mechanically loaded (Meyer, 2003). The remaining tonnage is manually cut and stacked and transported to transloading zones using tractor drawn self-loading trailers.

5.1 Loading systems

5.1.1 Manual loading

Manual loading of sugarcane is usually carried out when field conditions are poor and where the annual tonnage handled does not justify other forms of mechanised systems. The main advantages of manual loading relate to low extraneous matter levels. The main disadvantage of manual loading is that it is often expensive and time consuming, resulting in poor vehicle utilisation and therefore increased transport costs.

5.1.2 Mechanical loading

In most instances the first step in mechanising the harvesting operation is the acquisition of a mechanical loader. However, any cost savings made during the manual harvesting operation and/or increase in transport payload must justify and cover the cost of owning and operating the loader. In a mechanical loading operation cutter performance is significantly improved, as the manual cutter can now concentrate on putting all his effort into the cutting operation. Time and motion studies have shown that cutters spend about 30% of their time carrying sugarcane and building stacks in a cut and stacking system (Meyer and Fenwick, 2003).

5.1.2.1 Self-propelled grab loaders

In South Africa the most popular grab loader is the locally developed hydraulically operated three-wheel non-slewing loader. Its popularity is based on the fact that it is relatively inexpensive, highly productive (20-30 $t.h^{-1}$), cheap to operate and extremely versatile (de Beer, 1982).

5.1.2.2 Self-propelled and tractor mounted slewing push-pile loaders

On some larger estates, especially in the northern irrigated areas, high capacity self-propelled push-pile loaders are used by growers and contractors to load windrowed sugarcane into both infield and road transport vehicles. Several loaders have been evaluated and the results indicated that some of the machines are capable of loading rates in excess of 60 $t.h^{-1}$ (Anon, 1978b; Meyer and Worlock, 1982; Meyer, 2001a). Mechanical grab and push-pile loading systems are prone to include extraneous matter (earth and rocks) and several ways to reduce the amount of extraneous matter have been studied and systems developed (Gordon, 1978; Neethling, 1982).

5.1.2.3 Winch loaders

In the past, hydraulically operated heavy duty winches mounted on a two-wheel drive tractor were used to retrieve manually built, chained sugarcane stacks from distances of up to 80 m on steep slopes (de Beer, 1982). The winch system is an extremely efficient and cost effective system, capable of handling up to 200 $t.d^{-1}$ on steep terrain. However, due to high maintenance costs, this system has largely been replaced by self-loading trailer systems.

5.2 Transloading systems

A large proportion of the industry's crop is transported from the field to strategically located transloading zones on sugarcane farms. A wide range of equipment is used to transload bundled and loose sugarcane on transloading sites into both rail and road transport. These include Scotch derricks, self-propelled and tractor mounted or drawn mobile cranes, push-pile and grab loaders, and overhead gantry systems (Anon, 1982).

At present the most popular transloading systems include mobile cranes and grab loaders. Mobile cranes are capable of transloading bundled sugarcane at a rate of around 30 $t.h^{-1}$. Grab and push-pile loaders are capable of loading rates of around 30-40 $t.h^{-1}$. The relatively high labour costs associated with using the chained bundled/mobile crane system can be reduced significantly by using the 'no-chain' grab loading system (Carter-Brown, 1980).

An innovative container sugarcane transport system has recently been developed, which uses 5-10 ton containers fitted with 'golovan' rail wheels. The containers are mechanically loaded infield and stored on a rail structure before being rolled onto the road haulage vehicles (Meyer, 2001b). This system has the potential to reduce sugarcane spillage, labour requirements and transloading costs, as well as improve vehicle turn-around times.

6. SUGARCANE TRANSPORT

One of the major cost components of sugarcane production that has not changed over the years is the transportation of sugarcane from the field to the mill. As milling capacities increased, so have distances over which the sugarcane had to be transported, in some cases to over 100 kilometres. Sugarcane transport has undergone many changes and has been streamlined to reduce costs as well as to accommodate the wide range of topographical conditions under which sugarcane is grown in South Africa.

The transport of sugarcane by road haulage vehicles really came into its own as the tramline systems were phased out. Although the use of large capacity truck/trailer combinations has increased significantly, especially for transporting sugarcane directly from field to mill, the use of tractor-drawn self-loading trailers is still popular and cost effective in many areas in the industry.

Prior to 1984, growers delivered a large proportion of their sugarcane to communal transloading zones, to be taken to the mills by commercial hauliers or miller-owned transport. With this system, growers all received a standard rate of payment for their sugarcane, irrespective of the distance over which it was hauled to the mill. During this period there were no real incentives to improve sugarcane transport efficiencies and sugarcane was grown at uneconomical distances from the mill.

A major change in sugarcane transport occurred in 1981/82, when the Rörich Commission of Enquiry into the Sugar Industry was appointed to investigate the sugar industry's sugarcane transport structure (Rörich *et al.*, 1982). After much deliberation, the Commission's recommendations to make growers responsible for transport were finally accepted by the industry and were implemented in 1984. This meant that commercial hauliers had to compete not only against each other, but also against major sugar companies, farmer co-operatives and the many private growers who transported their own sugarcane. It was estimated that within the first three years of the adoption of the Rörich Commission recommendations, more than R100 million was saved in sugar industry sugarcane transport costs (Hudson, 2005). Unfortunately since then there has been a proliferation of vehicles, which has resulted in the mills being over-fleeted (Giles *et al.*,

2005) for various reasons including queuing at the mill because vehicle delivery times have not been scheduled correctly.

6.1. Infield transport

A wide range of infield transport systems are currently in use in the South African sugar industry. Sugarcane is transported either in a loose form or in bundles from infield to one or more strategically located transloading zones on farms. The distance that sugarcane is transported is dependent on the grower's annual tonnage, the terrain and the type of transport used, but usually varies between 0.5 and 1.5 km. However, in some small-scale grower regions this distance can be greater than 3 km. The transport of sugarcane from field to transloading zone is expensive (R6-R9 t^{-1}. $km^{-1)}$ compared with road transport (R0.80-R1.00 t^{-1}. km^{-1}). It is therefore extremely important that the siting of transloading zones and quality of extraction roads be thoroughly investigated to minimise these costs (Meyer, 1998b; Bezuidenhout *et al.*, 2004).

6.1.1 Bundled sugarcane

A wide range of winch operated self-loading trailers coupled to standard agricultural tractors are used to transport mainly sugarcane to on-farm transloading zones. Trailer types used include single, double and even triple bundle side and rear loading pto winch operated configurations (Anon, 1986). This method of sugarcane transport is not only extremely flexible, but usually delivers the cleanest sugarcane to the mill, with low field losses at a relatively low capital investment.

It is possible for one single bundle tractor/trailer combination to deliver in excess of 100 $t.d^{-1}$ to a transloading zone (Braithwaite, 1984). Worrall and Meyer (1991) showed that an articulated double bundle tractor/self-loading trailer combination was more effective under poor infield operating conditions, and was more comfortable and easily steered than a similar standard front steer haulage unit.

6.1.2 Windrowed sugarcane

Again there are a wide range of trailer types which are used to transport sugarcane, either in a loose or chained bundle form. The trailers used include the standard basket trailer, rear tipping basket trailers and spiller trailers which transport loose sugarcane directly from infield to the mill. During the loading operation the tractor/basket trailer combinations follow the mechanical loader along the manually made sugarcane windrows until fully loaded. Another cost efficient method of loading is that of the shuttle system, whereby a single tractor and two basket trailers transport the sugarcane using the shuttle method. With this method, while one stationary trailer is being loaded infield, the tractor is pulling the other loaded trailer to the transloading zone. Using this method it has been shown that a single tractor's hauling rate can be increased from 16 to 23 $t.h^{-1}$ (Meyer and Worlock, 1982).

6.1.3 Chopped sugarcane

There are currently only two types of infield transport vehicles being used in the industry. These are the tractor drawn high lift trailer and the single or double piggyback golovan (4-6 ton narrow gauge rail truck) trailer. Both of these vehicles types follow the harvester in the field until fully loaded. The high lift trailer will transfer the sugarcane into a high speed road haulage vehicle while the loaded golovan trucks are rolled off the trailer onto the tramline network.

6.2. Road transport

Sugarcane is transported by tractor/trailer combinations and by trucks. Although most tractors used to transport sugarcane are of the standard agricultural type, two local manufacturers have successfully developed specialised 'haulage tractors' with payloads of around 24 tons. Trucks that carry both chained bundles and loose 'spiller' or chopped sugarcane, range from single to double drive axle rigid trucks to articulated truck tractor/trailer combinations which have up to a total of seven axles and payloads exceeding 32 tons. The various transport modes used to deliver sugarcane to the factories throughout the industry are shown in Figure 5 (Davis, 2003). As can be seen in Figure 5 the majority of the sugarcane is transported to the mills using high speed articulated trucks (see Figure 6) because these are efficient systems over longer haulage distances.

A wide range of tractors and trucks have been evaluated to assess their fuel consumption and haulage productivity (Anon, 1977; Anon, 1981d; Boevey and Meyer, 1984; Murray and Meyer, 1984). It has been shown that, in terms of fuel consumption and haulage productivity, trucks out-perform tractors (Murray and Boevey, 1981). However, tractor/trailer haulage vehicles can compete economically with larger capacity truck combinations where lead distances are less than 15-20 km, mainly because of their lower capital cost and because speed is less critical over shorter distances.

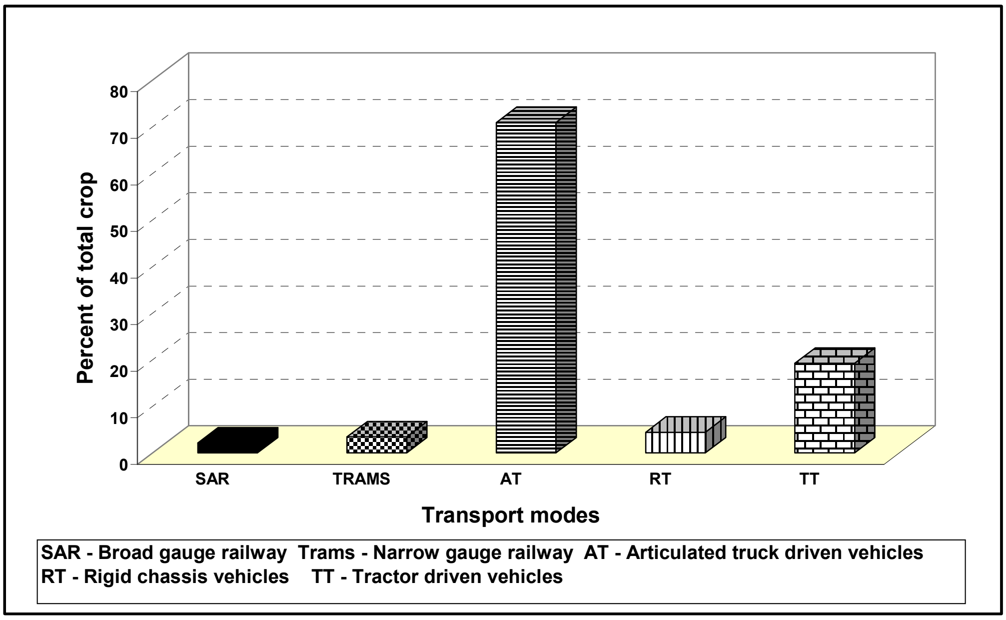

Figure 5. South African sugarcane transport modes (Davis, 2003)

Figure 6. Typical road transport vehicle used in the South African sugarcane industry

Significant cost savings are possible where it is feasible to use road transport vehicles to deliver sugarcane directly from infield to the factory. The direct transport systems are popular in the Mpumalanga and KwaZulu-Natal Midlands regions where the terrain is flat. However, there are disadvantages associated with direct haulage systems which include increased risk of sugarcane stool damage and soil compaction. As can be seen in the example given in Figure 7, the cost of infield transport and transloading is eliminated when using the direct haulage system (Meyer, 2005).

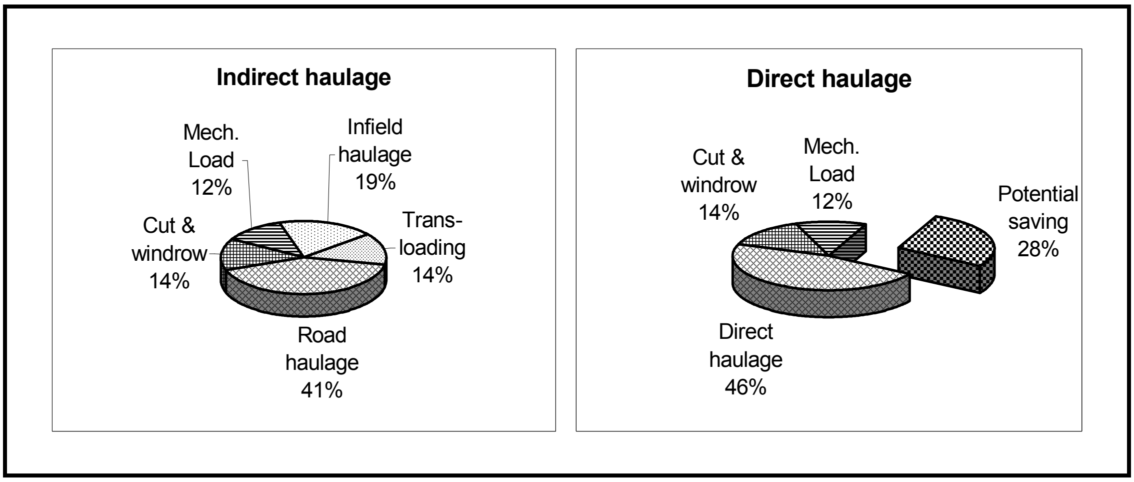

Figure 7. Indirect versus direct harvesting, loading and transport costs (Meyer, 2005)

6.3 Sugarcane stool damage and soil compaction

Increasing economic pressures are leading to larger capacity vehicles being used to extract sugarcane from fields. This is particularly true where sugarcane is transported directly from infield to the factory. Measures to reduce the negative impacts of sugarcane stool damage and soil compaction must include laying out machine friendly fields, avoiding operating in wet field conditions and ensuring that wheel spacing and row spacing are compatible. Furthermore, special attention should be paid to vehicle design in order to reduce tare masses to a minimum, and vehicles should be equipped with walking beam axles where possible and fitted with high floatation tyres. Trials conducted by Swinford and Boevey (1984) at the SASRI La Mercy farm showed that sugarcane yields can be significantly reduced on Longlands form soils (see Figure 8). Sugarcane yield reduction is greater when vehicle tyres are driven directly on and along the rows compared to when the vehicle tyres were restricted to the interrows. Furthermore, as can be seen in Figure 8, the effect on sugarcane yield also decreases as the total mass of the trailer and payload is increased in both first and second ratoon crops.

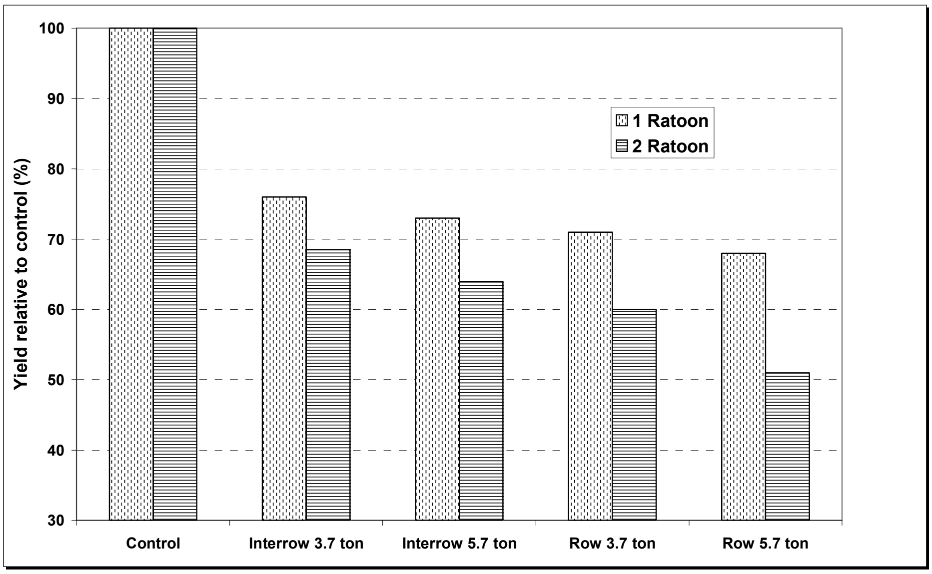

Figure 8. Effect of compaction on sugarcane yield (after Swinford and Boevey, 1984)

6.4 Sugarcane and transport vehicle scheduling

Sugarcane transport can be defined as moving sugarcane in an organised manner from field to mill in the shortest possible time to ensure a continuous and steady supply of fresh, clean sugarcane to the mill using the least and most cost effective transport. Transport management requires an understanding of the interaction between the various factors affecting equipment utilisation such as weather, harvesting policies, harvesting rate, delivery rate, service, queuing, loading, unloading and travelling time.

In the majority of mill supply areas there is an over-supply of transport vehicles, resulting in under-utilised vehicles operating at sub-economic levels. Despite the under-utilisation of vehicles, Davis (2003) reported that ‘no-cane’ stops at South African mills were as high as 10% and were attributed to poor vehicle scheduling. There are a host of tools ranging from simple manual procedures (Dent, 1973) to complex computerised techniques involving linear programming and scheduling algorithms, queuing theory and simulation modelling (Barnes *et al.*, 1998), which can assist transport managers to optimise sugarcane transport. Giles *et al.,* (2005) showed the potential to save up to R20 million per annum by scheduling vehicles in the Sezela Mill area.

Research conducted recently has shown that by modifying sugarcane supplies in a mill supply area in which sugarcane is grown under different climatic conditions can result in increased revenue for both growers and millers (Guilleman *et al.*, 2003; Le Gal *et al.*, 2004). However, in order to achieve an increase in revenue, harvesting and transport schedules will have to be modified. Re-scheduling should result in improved vehicle utilisation, reduced harvest-to-crush delays and an increase in the total amount of sugar produced.

6.5 Vehicle design and configuration

In the past decade, new loading and transloading machinery and systems have been developed to minimise vehicle down-time. Optimal payloads are being achieved by the use of electronic onboard mass monitors (Cole *et al*., 2006). Improved vehicle designs have resulted in lower tare masses, higher payloads and greater manoeuvrability. New operational systems have been developed to increase vehicle utilisation and reduce harvest-to-crush delays, including vehicles that are equipped with microprocessor controlled engine management systems (EMS). These EMS improve engine performance and fuel efficiency, and reduce harmful emissions. They also make the vehicle easier to drive. The modern transport operator has at his disposal the Global Positioning System to monitor vehicle movements, and sophisticated computer software to assist him not only in scheduling deliveries, but also in optimising his fleet capacity and size.

7. DISCUSSION AND CONCLUSIONS

Many new techniques and farming systems have been developed and adopted by the South African sugarcane industry in the past four decades such as the introduction of the minimum tillage concept and loose sugarcane loading and transport systems that have resulted in significant improvements in terms of overall efficiencies and a reduction in production costs. However, for the South African sugarcane industry to remain globally competitive there is still room for much more innovation to further reduce production costs.

In many areas of the South African sugar industry where sugarcane is grown under marginal climatic and soil conditions, there is a dire need to develop and implement new farming systems. These systems will not only maintain, but improve soil health, increase yields and at the same time minimising sugarcane stool damage and soil compaction.

The principle of separating mechanical stool eradication and seedbed preparation operations enables the use of relatively small equipment to eradicate sugarcane stools, which results in a reduction in overall re-establishment costs. The system of eradicating sugarcane stools using glyphosates, and the introduction of the minimum and reduced tillage concepts, have gained widespread adoption throughout the South African sugar industry. These systems have not only improved the efficacy of destroying the old crop, but have also resulted in reductions in re-establishment costs.

The re-establishment of sugarcane is currently a labour intensive and expensive operation. This problem is not only confined to the South African sugarcane industry but is a factor in most other industries around the world. More research is required in order to develop a more efficient and cost effective planting system. The answer may lie in outsourcing this operation with well defined work quality standards. This option would enable contractors to use relatively expensive high capacity machinery, but yet be able to provide a cost effective service to farmers as a result of improved economies of scale.

It is expected that sugarcane will be manually harvested in the short to medium term in the South African sugarcane industry. The current apparent shortage or unwillingness of labour to harvest sugarcane can be ascribed to several reasons. While high capacity sugarcane harvesters are commercially available from overseas, these are expensive to operate and in many instances not suited to large areas of South Africa. It is therefore vital that alternative sugarcane harvesting aids be developed to improve manual cutter productivity. On the other hand sugarcane growers should ensure that infield conditions and their field layouts are such that these are more acceptable to using harvesting machinery than is currently the case.

In order for sugarcane growers to maximise machinery efficiency and performance, reduce maintenance costs and minimise overall production costs, more attention will have to be paid to improving field layout and field surface conditions. For the South African sugar industry to continue to compete internationally as one of the world's low cost producers, the transport sector must strive to reduce sugarcane transport costs wherever possible by means of lower trailer tare mass, and implementing efficient harvesting and vehicle scheduling systems. Furthermore, there is potential for substantial economic gains to be made in terms of streamlining the sugarcane logistics supply chain. The formation of well structured harvesting and transport groups will ease logistical bottlenecks, and further benefits should derive from improved economies of scale.

One of the major challenges facing the South African sugarcane industry is that of moving to green cane harvesting regime. Green sugarcane cane harvesting presents the opportunity to develop new technologies and make significant advances in productivity and profitability while at the same time ensuring soil sustainability and protecting the environment.

For South African sugarcane enterprises to remain viable and sustainable will require a 'whole industry' approach involving researchers, millers, growers, hauliers and transport operators. An integrated approach is essential for seeking innovations that will improve overall efficiencies and overcome current challenges facing the South African sugar industry.

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