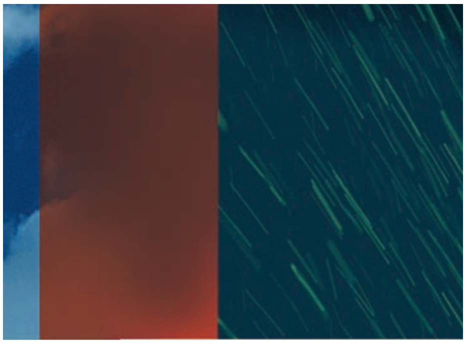
Chapter 16



HARVESTING AND TRANSPORT

Ross Ridge and Chris Norris

IN the early stages of the Australian sugar industry, cane was cut by hand and there was an on-going struggle to obtain labour for harvesting. Initially, Kanaka labourers were brought in from the Pacific islands to assist with harvesting, and, after World War II, European immigrants played a major role.

Hand cutters achieved daily outputs for cutting and loading of 9–12 tonnes in burnt cane and around 6 tonnes in green cane. The advent of mechanical loaders, such as the Toft grab loader, resulted in a significant improvement in output to about 12–18 tonnes per day in burnt cane. Approximately 30% of the crop was loaded mechanically in 1957, and 65% by 1962.

Wholestalk harvesters were used as early as 1944, but did not have a significant role until the 1960s. The pioneering chopped cane harvester was the MF515, side-mounted on a farm tractor. Development work began in 1956, and by 1964, chopper harvesters were well established. In the mid-1960s, the industry was poised between wholestalk and chopper harvesting, but the latter prevailed, due partly to the ability of choppers to handle lodged crops in north Queensland and the Burdekin. The combined cut-load operation of chopper harvesters also eliminated the extra loading step required with wholestalk machines.

The transition to chopper harvesters was not straightforward, with conflict over supply of special mesh bins for chopped cane and the more rapid deterioration of chopped cane between cutting and crushing. Once the deterioration problem had been overcome by better control of burning, improved mill transport scheduling, and the cessation of weekend storage of cane at the mill, chopper harvesting expanded rapidly and, by 1975, 98% of the crop was cut with chopper harvesters. Chopped cane proved easier and more compact to transport, tipped easily at the mill, and required less preparation for milling.

During the transition period to full mechanisation, the harvesting workforce was only slightly reduced, but there was a large increase in productivity. Average output per person in the harvest workforce increased from 750 tonnes per year in 1956 to 1500 tonnes in 1968, around 4000 tonnes in 1986, and 9800 tonnes in 1998. Although the number of mechanical harvesters has not changed greatly in the past 30 years, throughput per machine, approximately indicated by group size, has increased substantially (Table 1). In 1998, the range in average group size in different mill areas was 17 000–100 000 tonnes with predominantly green-cane areas in north Queensland having a range of 29 000–63 000 tonnes. These changes have been made possible by progressive refinement of the chopper harvesting and transport systems.

Table 1. Trends in harvester and group numbers and group sizes in Australia.

Year	Tonnes harvested (million)	Harvesting units		Average group size (t)
		Machines	Groups	
1972	17.6	1852	1810	8 900
1978	21.6	1800	1776	11 300
1982	24.9	1752	1649	15 100
1985	24.4	1692 *	1592	15 300
1989	27.6	1457 *	1371	20 100
1993	32.0	1303 *	1226	26 100
1997	40.7	1301 *	1225	33 200

* Estimated using 1982 survey data relating group and harvester numbers.

GREEN CANE HARVESTING

Until the 1940s, most of the Australian crop was cut green, with residual trash being burnt on the ground. Burning prior to harvest was allowed in some mill areas to control Weil's disease (spirochaetal jaundice or leptospirosis), a potentially fatal disease spread in rat urine. The shortage of labour, together with the increased output of manual cutters in burnt cane, led to burning becoming standard practice after World War II. Most mills retained a penalty for burnt cane.

Figure 1. *Green cane is harvested during trials using a weighing truck.*

Burning persisted as the standard practice until 1980 when north Queensland growers began to experiment with mechanical green-cane harvesting (Figure 1). Since that time, green-cane harvesting has expanded gradually (Figure 3) reaching 65% of the crop in 1998. While harvesters have improved markedly in their ability to cut green cane, there are still difficulties in high yielding, lodged crops (Figure 2). Capacity in green cane ranges from 50 to 80% of that in burnt cane, depending on crop size, variety, and the severity of lodging. Districts with high

Figure 2. *Cane is still harvested after burning in the Burdekin.*

yielding one- or two-year crops such as the Burdekin and northern New South Wales have largely avoided green-cane harvesting because of harvesting difficulties and agronomic constraints. These districts harvested 11% and 2%, respectively, green in 1998. In most districts, selective burning of large, lodged crops is carried out to make harvesting easier.

HARVESTER DEVELOPMENTS

The harvester fleet in Australia consists almost entirely of single, over-the-row harvesters with a swinging elevator capable of delivering cane to either side or to the rear of the harvester. The basic principles used in chopper harvesters have not changed significantly since they were first developed; the main changes are related to improved feeding and cleaning of green cane and increased capacity. Modern harvesters incorporate hydraulic drives and controls for all functions, and use extractor fans for primary and secondary cleaning of cane. Increased capacity has been achieved mainly by supplying extra power to critical areas such as the basecutters and chopper system, and engine size has more than doubled over time to approximately 240 kW in current Austoft and Cameco harvesters. Successive models of these harvesters have largely replaced the pioneering Toft, Massey Ferguson and Mizzi harvesters.

There has been limited experimentation with alternative concepts such as chop-throw systems, dual-row harvesting and blowers for cane cleaning. Of these, dual-row harvesters are used only rarely in Australia, with Cameco being the only manufacturer currently selling such machines in Australia.

The harvester fleet is predominantly rubber tyred in drier districts and steel tracked in wet districts. The adoption of full tracks for better flotation in wet conditions makes moving between farms more difficult and low loaders are used widely for moving these machines. Slow infield speed is usually not a disadvantage in crops of average size, but can restrict capacity in small crops or badly lodged crops where one-way cutting is necessary. Fulltrack harvesters have a compensating advantage of faster turning at the ends of rows. Rubber tracks overcome some of the mobility problems, but they have not proved sufficiently durable for use on cane harvesters.

FUNCTIONAL ELEMENTS OF CHOPPER HARVESTERS

The chopper harvester performs the basic functions of gathering and topping cane, severing stalks at ground level, feeding cane

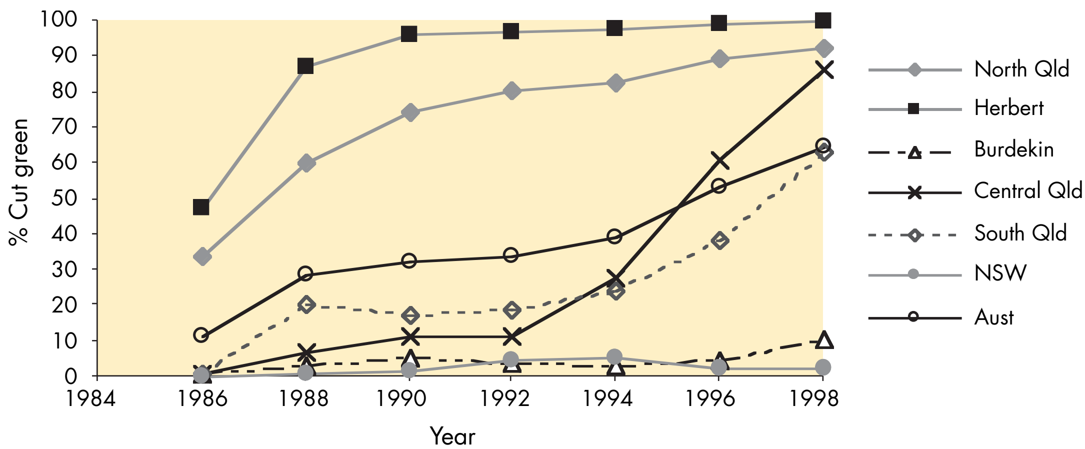


Figure 3. *Green cane harvesting trends in Australia from 1986.*

through a chopper system where it is cut into billets, removing as much adhering dirt, leaf and trash as possible, and delivering chopped cane directly into infield transporters.

Toppers

To cut tops and leaves into small pieces, chopper harvesters use either standard drum choppers with a single set of blades or shredder toppers with multiple banks of blades. Both types of toppers are fitted with a gathering system and have a reversible throwing mechanism to deliver tops to either side of the harvester away from standing cane.

Shredder toppers are generally less effective in gathering tops, but the chopping of tops improves ground cover and facilitates subsequent operations such as trash raking and the use of coulters in fertilising, insecticide application, or cultivation.

Gathering system

Cane is guided into the front of the harvester by tapered gathering spirals that rotate inwards. Current machines also have an outer spiral that rotates in reverse to separate sprawled cane in adjacent rows.

Gathering shoes on the bottom of the spirals follow the ground contour and help gather stalks that have fallen in the interspace between rows. The height of individual gathering spirals is controlled manually from the harvester cabin, but there is experimentation with automatic control and ground-following wheels to minimise gathering of soil by the shoes in wet conditions.

Forward feed

Feeding of cane into the front of the harvester is made easier by knocking cane forward so that it can be fed butt first into the harvester. The knockdown angle is typically between 42° and 60° when cane is cut by the basecutter, and this sometimes can cause stalk breakage and stool tipping.

A feed roller mounted just forward of the basecutter is used to assist cane flow into the front of the harvester.

Basecutters

Modern harvesters are fitted with twin basecutters driven from above through legs attached to a gearbox, or from a gearbox mounted under the basecutter discs. Basecutter discs are timed through the gearbox to allow cutting blades to pass under the adjacent disc. Non-timed discs driven independently from either side of the harvester were fitted to Massey Ferguson harvesters and these operated in different planes. The underslung basecutters give a wider flow of cane into the harvester, but are subject to stalling in wet conditions due to the friction between the discs and the gearbox.

Typically, each basecutter disc has five or six replaceable cutting blades and the disc may be dished to improve dirt rejection. The basecutter usually has a fixed rotational speed designed to maintain cutting by the blades at the expected average harvester forward speed. Ideally the speed should be adjustable for harvester forward speed to maintain optimal quality of cut. Blades require regular adjustment and replacement due to wear, and hardfaced blades are used in abrasive conditions to prolong life.

The basecutters are tilted forward at an angle to facilitate flow of cane into the feed roller system and minimise dragging of the discs or gearbox on the cut stubble. Modern harvesters have variable basecutter angle settings in the range 11–18° to allow matching of the cutting profile to the hill shape.

The basecutter height setting is critical in gathering cane and minimising stubble shattering and also affects dirt intake by the harvester. Typically, the height is set indirectly by the harvester operator using a sight gauge in the cabin and there are obvious advantages in having an automatic system capable of adjusting for variable hill height. Effective automatic height control requires accurate sensing of the basecutter cutting height and the ability to adjust height quickly. Trials with ultrasonic and other height sensing and control systems have not been successful.

Feed train

The harvester feed train is responsible for delivering cane to the chopper system in a controlled way to maintain the desired billet length of chopped cane. Cane is guided into the feed train by a buttlifter roller mounted behind the basecutter. The buttlifter normally rotates slower than the feed train rollers, improving dirt rejection.

Typically, the buttlifter rotates at 70–90 r/min and the feed rollers at 125–145 r/min in the front to 160–180 r/min at the back adjacent to the chopper. Research has shown that a more even feed and billet length is obtained if feed rollers have the same nominal speed and this is matched to the chopper tip speed. This also reduces power requirements, losses during chopping, and billet damage in the rollers and chopper.

Design of the feed rollers is determined by the need for dirt rejection, wear considerations and minimal slippage and damage to cane. Usually the buttlifter and the next two bottom rollers are open slatted and the rear bottom and all top rollers are closed drums with rippled feeding bars. The slats and feeding bars are hardfaced to preserve their positive feeding action.

Choppers

The two main chopping devices in early billet type harvesters were the 'swinging-knife' and 'rotary-chop' systems. The MF515 was the first to incorporate the rotary-chop system successfully, and variations of this system are used in today's machines.

The swinging knife was used in early Toft harvesters and is still preferred by some operators in stony conditions. The blade is attached to a flywheel and cuts at right angles to the flow of cane. It has no feeding action and is not as effective in cutting green crops as the rotary chopper.

The rotary chopper consists of two parallel cylinders with cutting blades extending the full length of the cylinder and opposing blades timed to meet in a pinch-type cutting action. This system is self sharpening and has an aggressive self-feeding action. The replaceable blades last about 1000 tonnes in non-stony conditions without sharpening, compared to about 50 tonnes for the swinging knife.

There are several rotary chopper configurations including three drum sizes; 300 mm diameter, 375 mm diameter and differential drums with a large diameter over a small diameter. The blades meet in an 'over centre' arrangement in line with the centres of the drive shafts, or in an alternative 'off set' chopping arrangement (Figure 4) where the blades meet just before the centre line. This system gives less compression of cane during cutting. Current harvesters are also using wider blades than previously to minimise the compression of cane by the blade holders at high feed rates. The standard 300 mm system usually has two blades per drum and three or four blades are used on the 375 mm system. Some 375 mm choppers use a blade and anvil system with a single blade cutting into a notch between a pair of chopper blades on the opposing drum.

The billet length produced by harvesters is a compromise between shortening billets to improve cane packing in transporters and lengthening billets to reduce cane loss in chopping, splitting of billets and the risk of cane deterioration. The commonly accepted average billet length is 250 mm, but sugar mills may relax standards in green cane or cool or dry districts to obtain higher bin weights. In these cases, the risk of deterioration of chopped cane is less than in burnt cane or in hot, humid conditions.

Cleaning system

The main cleaning systems on current chopper harvesters are a primary extractor mounted in a cleaning chamber behind the chopper and a secondary extractor at the top of the side elevator that loads infield transporters. The extractor fans have three

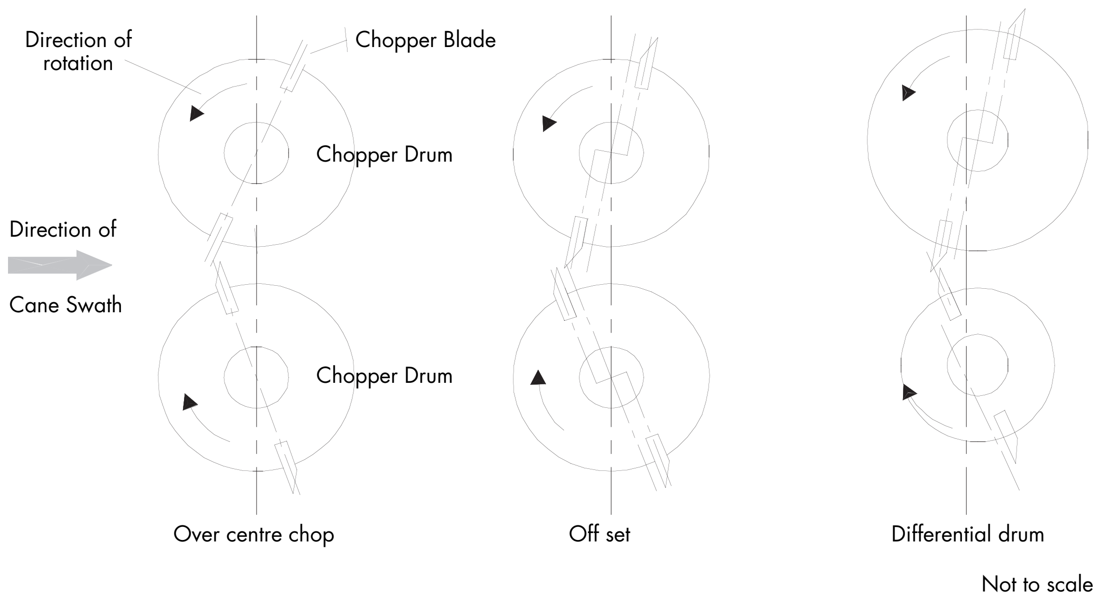


Figure 4. *Rotary chopper configurations.*

curved, tapered blades. These are designed as a compromise between efficiency and the cost of regular replacement of more complex blades operating in highly abrasive conditions.

The primary cleaning chamber has air intakes located to ensure flow of air through the mat of cane leaving the chopper to separate leaf and trash from billets. Smaller diameter chambers (900 mm) operating with high air velocities have been replaced with larger diameter chambers (1200–1350 mm) and lower air velocities. Average extractor air velocities have been reduced from about 20 m/s to 12–14 m/s by this change. This follows findings in research work on critical air velocities for removing trash and some tops without significant loss of cane. The trajectory of cane from the chopper relative to the primary extractor is controlled by a deflector plate or a roller to minimise cane loss during cleaning. Fan speed can also be varied from the cabin to adjust cleaning intensity. Cleaning efficiency is strongly dependent on the evenness of flow of cane through the harvester and overall flow rate or pour rate. Recent research shows benefits from directional, high-speed, air jets in separating cane and trash, and from counter-rotating fan blades designed to minimise swirl in the cleaning chamber.

Both extractor chambers are fitted with shrouds or hoods on the outlets to direct flow of leaf and trash onto the ground beside the harvester. The design of these hoods has been refined by smoothing the curves and increasing the area for discharge of trash to minimise the back pressure in the cleaning chamber.

Harvester instrumentation

Traditionally, harvesters have been fitted with minimal instrumentation for indicating hydraulic pressures in key areas, such as basecutter, chopper and extractor circuits, engine temperatures and oil pressures and basecutter position. Recent research has developed additional instrumentation to assist harvester operators.

The cane-loss monitor indicates cane loss through the primary extractor, extractor speed, harvester forward speed and basecutter speed during cutting. This allows the operator to adjust cutting speed, extractor speed and basecutter setting to reduce trash levels, cane loss and dirt intake. In addition, a simple device monitoring feed roller position can be fitted to indicate harvester pour rate. A yield monitoring device linked to a geographical positioning system (Yield Monitor) has also been developed for mapping cane yield during harvesting, and this is being used to a limited extent in the Burdekin area.

PERFORMANCE OF CANE HARVESTERS

The full mechanisation of cane harvesting in Australia has increased both extraneous matter levels, tops plus leaf and trash (Figure 5), and soil in the cane supply (Figure 6). However, current harvesters are operating in more adverse conditions with lodged, green crops, wetter field conditions, and at much higher throughput rates.

Topping

The efficiency of top removal by harvesters depends strongly on evenness of crop height and the degree of lodging of the crop. Extensive trials in Australia showed that 65–70% of tops could be removed by the topper and extractors in erect cane and 25–30% in lodged cane. There was little difference between green and burnt cane. Toppers also removed around 40–45% of leaf and trash in erect cane.

Shredder toppers are generally less effective in gathering and removing tops than standard toppers.

Gathering

The effectiveness of gathering by the harvester depends on the degree of lodging, varietal characteristics such as brittleness, and field conditions. Losses of cane during gathering are as high as 5 t/ha in adverse conditions.

Soil uptake and rejection

Many interacting factors affect dirt uptake and ejection by harvesters. Factors involved in initial intake of soil include potential ploughing of soil by the crop dividers, the knockdown angle of cane prior to basecutting, harvester forward speed, basecutter angle, and the basecutter height

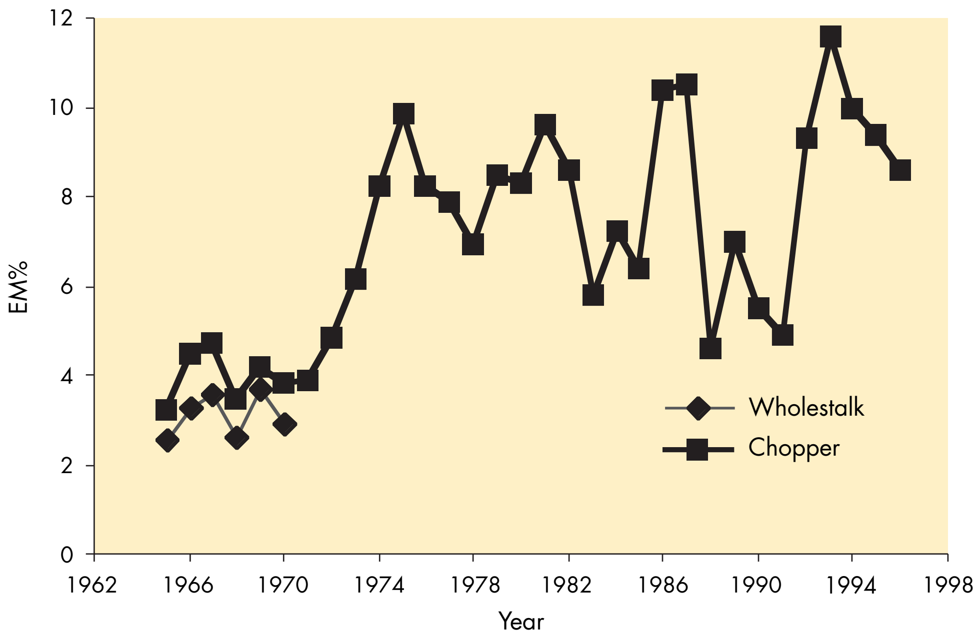


Figure 5. *Mill area extraneous matter trends in north Queensland.*

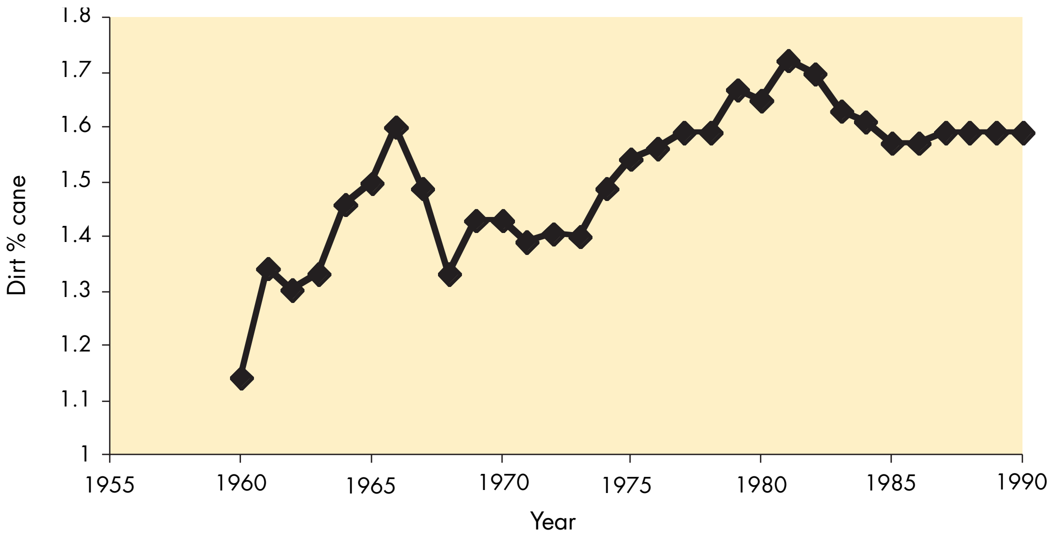


Figure 6. *Queensland trends in dirt levels in the cane supply based on mud in filter cake.*

setting. Subsequent ejection of soil is affected by cutting speed, basecutter design (degree of dishing or scalloping), buttlifter design and rotational speed, roller design and evenness of feeding, and extractor speed setting.

The flow of soil over harvester basecutters can be as high as 50–100 t/ha when cutting below ground level, and results from test rigs indicate that about 98% of this loose soil is rejected by the buttlifter and feed rollers. Less soil is ejected in wet conditions and where soil is attached to cane or mixed in the mat of cane flowing through the harvester. Up to 95% ejection of loose moist soil and as low as 60% ejection of soil attached to cane roots can be achieved.

Chopper performance

The performance of the chopper system is usually rated according to billet length, billet size distribution and billet damage. A general index of performance is the percentage of sound billets greater than 250 mm long. Typical seasonal average figures range from 30–74% between harvesters.

The billet quality index is particularly important where harvesters are used to cut billet-planting material; where it is desirable to have an index higher than 70%. Chopper performance is closely related to evenness of feed through the roller system, and specially modified harvesters with rubber-coated rollers and synchronisation of roller and chopper speed are now being used to cut planting material.

Cleaning and cane loss

There has been intensive monitoring of harvester cleaning performance and cane loss in the Australian industry during the 1980s and 1990s. Standing burnt cane typically has extraneous matter levels of 10–14%, made up of 64% tops and 36% leaf and trash. In green cane, the extraneous matter levels vary between 16 and 30%, made up of 35% tops and 65% leaf and trash. In standing cane, the harvester can remove about 70% of tops and 82–94% of leaf and trash; in lodged cane, 25–30% of tops and 72–92% of leaf and trash can be removed.

Other research identified typical cane losses through the extractors and extraneous matter levels in different districts. Average district cane losses varied from 2.5–10.5% in green cane and 1.5–2.0% in burnt cane. Extraneous matter levels were in the range 7–10% in green cane and 6–8% in burnt cane. Cane losses are strongly influenced by extractor speed (Figure 7) and extraneous matter by harvester pour rates (Figure 8). As harvester pour rates increase, the cleaning system becomes overloaded and is unable to separate trash from cane as effectively as is the case at low pour rates. Increasing extractor speed to improve cleaning has only a small effect on trash removal, but increases cane loss substantially. Extraneous matter levels have increased in most mill areas with recent increases in harvester pour rate capacity.

FIELD FACTORS AFFECTING CANE HARVESTER PERFORMANCE

Presentation of the crop has a significant effect on harvester performance and quality of cane delivered to the mill.

Crop size/harvesting speed

Crop size has a significant effect on potential harvesting rates with the rates being lower in both small crops and large, lodged cane. In high-yielding, erect cane, modern harvesters have instantaneous pour rates as high as 200 tonnes per hour.

Levels of trash and dirt in the cane supply are closely dependent on pour rate (Figure 8). Similarly, damage to cane stubble by the harvester basecutters increases at high harvester forward speeds, due to cane being sheared by the basecutter discs rather than cut by the blades.

Pour rates for single-row machines should be restricted to 80–100 tonnes per hour to minimise stubble damage and extraneous matter levels. However, in practice, average pour rates in green cane can be as high as 120 tonnes per hour and instantaneous flow rates as high as 400 tonnes per hour are possible, due to uneven feeding.

Lodged cane presents particular harvesting problems in feeding tangled material into the harvester. It is often necessary to cut one way to improve feeding and reduce loss of cane on the ground. Throughput is severely reduced in lodged green crops, and cane is burnt in extreme cases to improve feed and reduce the bulk of material processed by the harvester. Amounts of leaf, trash, tops and suckers are generally higher in lodged cane, due to lack of topping and the higher level of

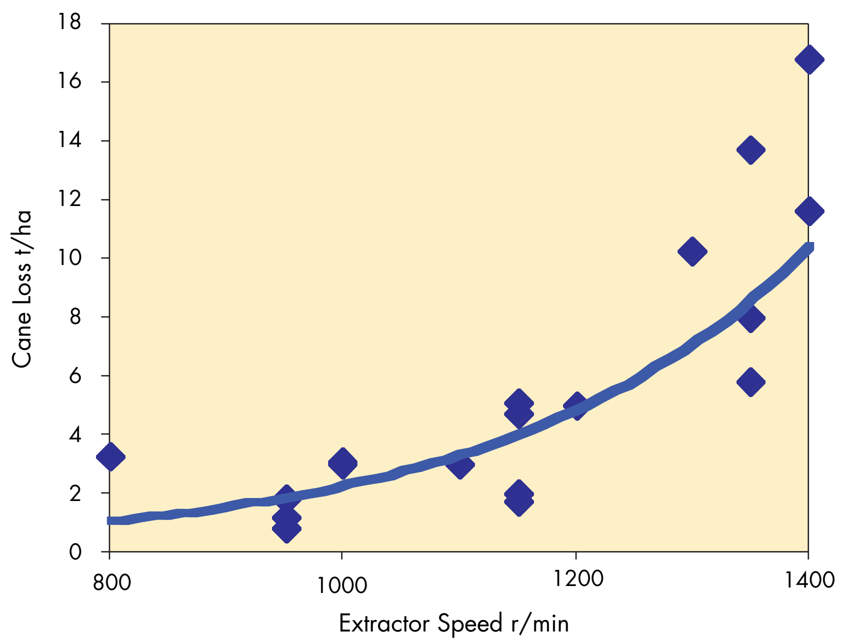


Figure 7. *Increase in cane loss with extractor speed.*

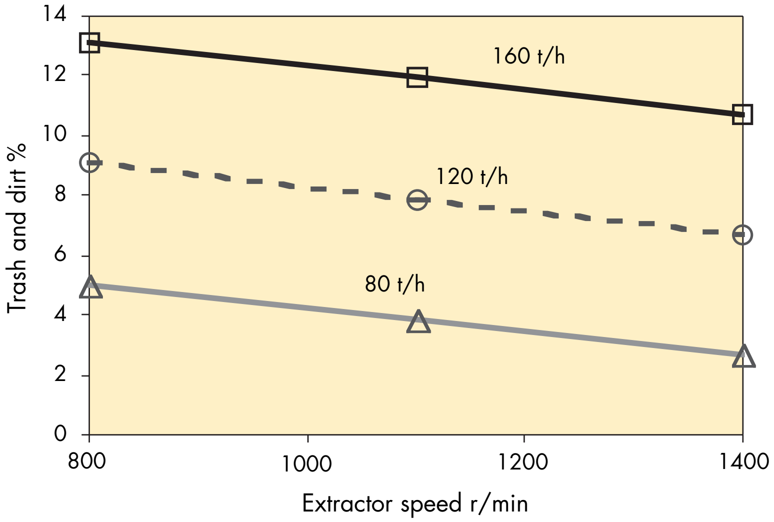


Figure 8. *Effect of pour rate and extractor speed on trash and dirt levels.*

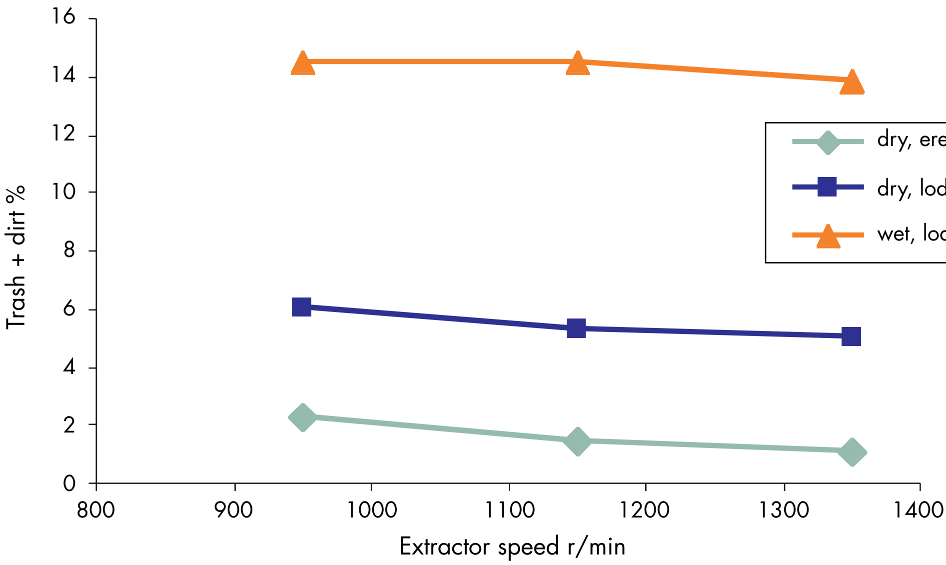


Figure 9. *Effect of harvesting conditions on extraneous matter levels.*

suckers (Figure 9). Soil levels also increase, due to partially tipped cane stools being taken into the harvester by the basecutter.

Cane variety

Cane varieties vary significantly in levels of leaf, trash, tops and suckers in the field and, therefore, extraneous matter levels in the cane supply. Pre-harvest extraneous matter levels (excluding suckers) in a range of Australian varieties vary between 16–30%, with cane supply extraneous matter levels of 4–13% in untopped green cane.

Fibre characteristics of varieties also affect harvestability. High leaf fibres lead to wrapping during harvesting and difficulty chopping and extracting leaf material. Erect, free-trashing varieties are the most suitable for green-cane harvesting.

Limited information is available on suckering behaviour of varieties, but suckering is generally variety specific and is enhanced by lodging. Suckers have similar aerodynamic properties to cane billets and are not removed by the harvester cleaning system. Immature suckers can have a significant negative impact on CCS levels.

Some cane varieties are associated with higher soil levels in the cane supply. This is linked with a tendency to lodge and also in some cases to stool tip when lodged. In bad cases, roots with attached dirt are tipped from the ground, with both cane and roots being gathered by the harvester. Tall, strong-stalked varieties with a sprawled habit and/or shallow root system appear most susceptible to stool tipping.

Weather and crop conditions

The weather has a significant impact on harvester performance, with removal of trash and dirt becoming more difficult (Figure 9) and intake of dirt increasing in wet conditions. In many districts, harvesting equipment can operate in wet conditions, due to improved flotation, and local policy on harvesting in wet weather determines its impact on cane quality. Harvesting at night or early in the morning also reduces cane quality due to the effect of dew on trash and dirt removal.

Cyclones and flooding reduce cane harvestability significantly in some years, particularly in north Queensland, due to stalk breakage, deposition of silt on cane and erosion channels in fields.

Poor weed control in fields also impacts negatively on harvesting, increasing extraneous matter levels and causing wrapping on the gathering spirals and feed rollers. Similarly, bad infestations of canegrubs, root pathogens or other pests that weaken cane root systems reduce pick up of cane and increase soil levels in the cane supply.

Row spacing

Row spacing affects harvester performance in several ways. In narrow row spacings, cane may need to be cut with the basecutter off-centre from the cane row to minimise stalk breakage in the adjacent row of standing cane. This can lead to increased intake of soil, because the basecutter needs to be set deeper to gather all the cane. Alternatively, if the harvester runs on adjacent rows, cane may be broken off and/or the hill pushed out of shape for subsequent harvests.

The second problem noted in Australia is uneven row spacings. This has similar effects to narrow row spacings and may also lead to variable row-profile shape and height where multi-row cultivation equipment is used. The minimum desirable row spacing for single-row harvesting is 1.5 m, and a wider spacing is desirable to minimise compaction effects. Spacings can be as high as 1.65 m in south Queensland, and 1.55 m in north Queensland without a loss in yield with most cane varieties.

Mound shape

The shape of the row profile determines whether cane can be cut at ground level without taking in soil. The most suitable shape at harvesting is a low hill 50–100 mm high with gradually sloping sides. In furrow-irrigated fields, hills may need to be higher to prevent overtopping during irrigation, but gradually sloping sides should be retained.

The most common problem is poor filling in of rows in plant cane leaving a depression in the centre of the row and/or a ridge of soil on either side of the row. This results in either high cutting with damage to stubble and poor gathering of sprawled stalks, or high dirt intake if the basecutter is set below ground to gather all the cane.

These problems can be minimised by progressive filling in of the planting furrow during cultivation, or the use of well-designed hiller boards to form a low mound. These operations need to be well timed, so that they are completed before the cane stool is well developed and impedes the forming of the hill.

Cultivation practices

The type of cultivation system adopted has both direct and indirect effects on harvesting operations. Normal tillage operations in ratoons can result in large clods being left in cane rows or tine marks adjacent to the cane row. This may increase soil intake and pick up loss of cane during harvesting.

Minimum or zero tillage limits reshaping of row profiles in ratoons and cane often grows from the side of the row in old ratoon crops. This again affects both soil levels and pick-up losses. There is also limited opportunity to remove ruts left after wet-weather harvesting. On the positive side, reduced tillage allows controlled compaction of the interspace and reduces bogging of equipment in wet weather.

CANE TRANSPORT

Field to mill

The cane transport system in the Australian sugar industry is usually a combination of infield transporters delivering to mesh mill bins at local sidings, and a dedicated narrow-gauge rail network for delivery of bins to the mill by locomotives. About 90% of cane is delivered to mills by rail. The most common size for rail bins is 6 t, and older bins of 3–5 t capacity are gradually being replaced. Several mills are moving to bins of 8–12 t capacity to improve loading efficiency in the field and tipping rates at the mill.

In some mills, there is a combined system of mill tramlines and road transport delivering directly to the mill, and several mills have a full road transport system. Road transport includes a multilift system with nominal 24 t containers picked up from farm delivery pads, a system of similar capacity with detachable trailers left beside the fields, and detachable B-double trailers carrying three, 14 t containers. Most road transport systems tip directly into the mill carrier, but some mills transload cane onto the rail system to allow cane storage prior to crushing.

Infield transport

Roll-on roll-off systems

The major infield transport system historically is a roll-on roll-off system where rail bins are carried into the field on trucks or tractor-drawn trailers. The infield transporters are fitted with drop-down points to allow winching on of empty bins at the rail sidings and drop off of full bins. The most modern systems have radio control of winches to speed up loading of empty bins.

This is an inexpensive system, but is poorly suited to wet weather harvesting because relatively small diameter, narrow, high-pressure tyres must be used. Unloading at the mill siding is relatively slow compared to alternative transloading systems. However, bin weights are generally higher than in other transport systems because the mill bins are loaded directly beside the harvester.

High-flotation transport systems

The introduction of high-flotation tipper and elevator bin systems in a number of mill areas has been brought about by several factors: the need for improved mobility in wet weather; adaptability of self unloading systems to different bin sizes; faster unloading; and the increased load carrying capacity of the large tyres that can be fitted to custom-built transporters. However, they are expensive to buy and maintain.

Typically, high-flotation systems are rubber tyred, but both steel- and rubber-tracked equipment is used in wet districts. The steel-tracked transporters are less mobile and are used in short-haul situations.

Design of rubber-tyred transporters is constrained by axle load limits set by Queensland Transport to minimise road pavement damage. Concessional loadings of up to 11 t for single axles and 20 t for tandem axles are allowed for low-pressure tyres operated mainly off-road at low speeds. The single axle loading is reduced to 10 t for driven axles. These loadings are subject to tyre size and tyre manufacturers' load specifications at the projected maximum transporter speed. Tyres rated for speeds of up to 50 km/h at maximum allowable axle loadings are now available.

The majority of high-flotation transporters are drawn by tractors, with articulated and four-wheel-drive tractors being most common. Several self-propelled transporters are also available. Modern high-flotation equipment is fitted with improved suspension systems, such as airbags to improve stability and high-speed performance. Many of these units use weight transfer principles, transferring some of the load to the tractor axles, but there is scope for improvement in design to maximise productive load-carrying capacity.

Tipper transporters are generally matched to mill bin capacity and use fold-out hoppers to minimise cane spillage during tipping (Figure 10). An alternative option is to use split compartments in the bin and a metering roller to control tipping from one compartment. This system allows topping up of bins and can be adapted to a wider range of bin sizes. Capacity is 4–12 t. The larger units may have two separate bins matched to mill bin size or a single bin for filling road-transport container systems. Tippers are a durable, high-flotation option with low maintenance costs and unloading times between 30 seconds and 1 minute.

Figure 10. *Tipper bin unloading cane.*

Tipper-elevator bins incorporate a dual action with cane being tipped forward onto side or front feeding elevators which load the mill bins. They are more flexible than a standard tipper and can load into a range of mill bin sizes. Capacity is 8–9 t in single-axle units, up to 12–14 t in tandem-axle units, with some weight transfer to the prime mover in both cases. Unloading times are 2–3 minutes and maintenance costs are higher than for tipper bins. There have been problems in maintaining mill bin weights in green cane with tipper-elevator transporters due to the loose packing of billets and problems in obtaining adequate clearance to fill mill bins completely.

HARVEST ORGANISATION

The harvest in Australia is carried out under a grouping system with individual farms within a group rostered for several cuts spread throughout the season. This assists farmers in managing their crop rotation, limits their exposure to adverse harvesting conditions, and helps in optimising cane CCS levels. Groups generally include nearby farms within a mill area and may be run by contractors, individual farmers, or as a co-operative between farmers.

The scheduling of road transport and delivery of mill bins to harvesting groups is a complex operation and sophisticated queuing or scheduling programs are available for optimising the system. Some mills use geographical positioning systems (GPS) for tracking locomotives and road transporters to improve flexibility in transport scheduling. Similar GPS systems on harvesters, combined with infield weighing systems, offer potential for further refinement of transport scheduling.

Delivery and pick up of bins are also designed to minimise cut to crush delays. Typically, there are two deliveries of mill bins each day. Start-up times for harvesters are also offset in some mill areas to provide fresh cane for the early morning changeover of cane supply to the new day's cutting. Mills employ cane inspectors to help co-ordinate harvest-related field and mill operations.

As harvesting group sizes have increased, infield storage capacity has expanded to keep pace and there has been a trend to fewer, larger bin sidings. This trend has to be balanced against the reduction in infield transport efficiency with longer haul distances.

With road transport, weighing systems are becoming common on infield transporters to maximise legal loads in containers. Concessional arrangements for occasional overloading are also used to improve average loads carried by road transporters.

A ticket consignment system is used to identify the farm, block and crop details for each pick up of cane by mill locomotives or road transport. Tickets are filled out by the farmer or harvesting crew and attached to the loads going to the mill. This system may eventually be replaced by electronic tagging systems, as on-farm weighing systems and mill cane-receival systems become more sophisticated.

COSTS OF HARVESTING

The costs of a fully mechanised harvesting system, such as that used in Australia, are based on capital, wages, fuel and maintenance inputs. The capital component of these costs is about 50%, and this usually falls as group size increases. Typical industry figures in the 1998 season were \$5.20–\$7.20 per tonne, depending on local circumstances. In general, growers pay more for harvesting green cane, because harvesting rates are slower and maintenance costs are higher.

Group size has generally increased (Table 1) to combat increasing capital costs, and the increase is more pronounced in districts that have invested heavily in modern harvesters and high-flotation transporters. Typical examples are two wet mill areas harvesting predominantly green cane that have average group sizes of 63 000 and 100 000 tonnes, respectively. Capital investment for the latest fulltrack harvesters and high-flotation haulouts used in these districts is about \$1 million. In contrast, districts with small group sizes commonly use second-hand equipment to reduce costs.

The potential for increasing group size depends largely on local circumstances, such as crop yield, row lengths and haul distance. Computer-based models have been developed to provide guidance in optimising harvest-transport systems. Typically, harvester delivery rates to mill transport are only 50–60% of harvester cutting rates due to time lost in turning at the ends of rows and waiting for infield transporters. Changes in row length are gradually being introduced, particularly in new areas, and model studies indicate optimum row lengths of 500–600 m.

Haul distance is critical in matching harvester and transporter capacity, and costs are higher for longer haul distances, due to the need for additional transport capacity. This has led to a trend to larger capacity transporters (12–14 t) and high-speed prime movers capable of road speeds up to 50 km/h for long-haul distances.

The other important strategy used in the Australian industry to increase harvesting capacity is extension of available time by ‘continuous cutting’ during the season, extended shift harvesting and double-shift harvesting. Continuous cutting typically involves changing from 5 days cutting in 7 days to 13 days cutting in 14 days, but various combinations are used, including daily cutting. Extended shift harvesting is common, with many crews working about 10 hours per day or, in a few cases, separate crews working two, 10-hour shifts. A typical example of the potential impact of these changes on group sizes is given in Table 2.

There are potential savings of up to 35% with multi-shift harvesting and continuous cutting. These practices are likely to become more critical if the industry adopts ‘best practice’ standards with restriction of pour

Table 2. Effect of shift harvesting and continuous crushing on potential group sizes.

Shifts		Potential group size (t)	Effective cutting time per day (h)
1 × 10 h	5 in 7 days	48 000	8
	13 in 14 days	63 000	8
2 × 8 h	5 in 7 days	72 500	12
	13 in 14 days	95 000	12
2 × 10 h	5 in 7 days	96 000	16
	13 in 14 days	125 000	16
3 × 8 h	5 in 7 days	102 000	17
	13 in 14 days	132 000	17

rates to improve cane quality and minimise stubble damage during harvesting.

THE FUTURE? ALTERNATIVE HARVESTING SYSTEMS

There are two major issues facing the Australian sugar industry that may lead to significant changes in harvesting systems. These are the opportunity for a vertical expansion in cane yield using high-density planting, and potential loss of productivity through deep compaction by heavy infield transporters. Compaction on or close to cane rows in current harvesting systems has reduced yields by up to 20% in ratoon crops.

Planting of four rows, 0.5 m apart on beds at 2.1 m centres has increased yields by around 50%. Dual-row planting on 1.5 or 1.8 m centres has increased yields by 10–20%. The success of both types of planting systems will depend on development of harvesting systems capable of cutting the larger crops green at commercial rates with minimal compaction and stubble damage.

Dual rows on 1.8 m centres with rows 0.5 m apart match current harvesting equipment wheeltracks and are well suited to controlled-traffic principles to minimise compaction close to cane rows. Some improvements to current harvesters are required to improve feeding of dual-row green cane and allow tracking of haulout equipment in the centre of the interspace. The alternative system of dual-rows on 1.5 m centres has higher yield potential, but accentuates compaction by single-row harvesters. This has been addressed on one large farm in the Burdekin by precision planting using a guidance system, and using a custom-built harvester with tracks on 3 m centres.

Success of the close-row system also involves precision planting, establishment of traffic paths between beds and dedicated harvesting and transport systems. Prototype equipment developed for cutting close rows incorporates improved green-cane feeding principles, four basecutters matched to the bed shape, narrow tracks on 2.1 m centres, and a wide gathering front (Figure 11). This equipment is also compatible with standard rows on 1.5 m centres and dual rows on 1.8 m centres. The future challenge in adopting these systems is commercialisation of the new harvesting equipment and managing the changeover from current practices.

Figure 11. *A four-row harvester has been developed to harvest cane planted under a close-row planting system.*