

ABSTRACT

This paper summarizes the ISSCT Workshop on "Cost-Effective Mechanization". Annual hours of machine use and actual output under prevailing field conditions are two of the most important factors determining cost effectiveness. Good machine management and mechanization planning are prerequisites for cost effective operations. We identified many instances where operations were unnecessary and others which could be replaced by more cost-effective alternatives. Cheap mechanization must not be confused with cost-effective mechanization; there is no value in performing a task cheaper if the result is not a net increase in profit. Many aspects of mechanized sugarcane production are covered.

Key words: Sugarcane, field mechanization, economics, costs.

INTRODUCTION

The ISSCT Workshop on Cost-Effective Mechanization was held at CIAT, near Cali in Colombia, from July 28 to August 2, 1991. We summarize here the key points of presentations, discussions and field trips during that time. More details and specific examples supporting the broad conclusions will be seen in the ISSCT Report on this Workshop.

With decreasing profit margins and with many sugarcane industries in dire straits, everything possible must be done to increase net profits. A 10% saving in production cost can give a 30% increase in net profit and mechanization is a major contributor to overall production cost of sugarcane. Even when cane is cut by hand, mechanization can contribute 50% of the total production costs. By critically analyzing all mechanical operations, sugarcane growers can therefore substantially decrease overall production costs.
BASIC PRINCIPLES

Mechanization costs can be reduced by maximum use of machines, increased field efficiency, system analyses and by program planning.

Maximum use

The total cost of operating any machine depends on the amount of work done per year. The cost of operating a $25,700 tractor for 500 hours per year is $18 per hour. At 1,200 hours per year the cost decreases to $11 per hour. A common mistake made by purchasers of expensive harvesting machinery is that predicted cost per ton handled is often based on the potential output and not on the actual output or use which will be realized under the relevant conditions.

Field efficiency

It is of little use to improve the use of any machine if it is not operating at maximum effectiveness while it is working. Field efficiency is a measure of the effective work done by a machine and it can be defined as the ratio between actual work done compared with what could be achieved under ideal conditions. Field efficiency is affected by factors such as management, machine reliability, field layout and condition, operator performance and type of machine.

Management: The standard of management will determine the effectiveness of any farming operation. In addition, the manager should always question the need of any operation, the method by which it is performed and its timing. The simplest way of reducing the cost of sugarcane production is to eliminate any operation which is not cost-effective. The manager must ensure that the correct machine combinations are used for each task.

Machine reliability: Unreliable, poorly adjusted and maintained machines cannot operate at high efficiencies. By scrupulously following a maintenance schedule the availability of every machine can be increased dramatically. This will also result in fewer machines being required for specific tasks.

Field layout and condition: The field surface should be smooth with no obstructions to impede the passage of any machine. There must be a minimum of short rows because turn-around time is time lost. Row lengths should be the maximum practical considering aspects such as seed, fertilizer and herbicide replenishment requirements and good conservation practices. A field machinery index can be calculated for each field. Row alignment and extraction roads must all be designed for maximum machine efficiency.
Operator performance: It is false economy to favor "cheap" poorly trained operators. Only well trained operators will achieve maximum efficiency from their machines and in addition, their machines will require fewer repairs. Operators' wage is a small component of the overall cost.

Type of machine: More complicated machines, performing sophisticated multiple tasks, generally have low field efficiencies. The field efficiency of, for example, a cane planter is about 45% compared with 80% for a disc harrow.

System analyses: Where the area can be sub-divided into sufficient major sections, a useful approach to mechanization planning is the establishment of a field section by field section system. By carefully analyzing every aspect of crop production, most effective cost options for practical, easily managed machinery systems can be determined. Only by system analysis can the number of machines required to perform any task be established. To analyze a machinery system, performance standards must be available. These standards must be realistic and relevant for the conditions under which the machines will operate. The establishment of performance standards is therefore a priority for cost-effective mechanization.

Program planning: Once the machinery requirements for various production systems have been determined, a mechanization plan for a field, section or estate can be drawn up. By calculating the total machinery complement required at different time periods, peaks in machinery demand can be identified on a weekly or monthly basis. By re-scheduling certain operations, for example, such as planting, or by implementing minimum tillage, it may be possible to smooth out machinery requirements, thereby reducing the total number of machines required, at the same time ensuring that there will be fewer times when expensive machines are under-used.

FARM PLANNING

A proper farm plan is the foundation for all operations. A farm plan accommodates factors such as climate, topography, soils, natural watercourses and management principles while providing field layouts for maximum machine efficiency, good surface water management, and, if required, a well designed irrigation scheme. Extraction roads and transloading zones will be sited and specified on the plan. A well-designed cane extraction system will result in the least amount of effort expended to deliver the cane from the field to the factory. Soil conservation measures will also form part of the farm plan with cane row direction, waterways and, if necessary, strip re-planting and strip harvesting indicated for specific fields; likewise those fields where trash blanketing is required and areas requiring subsurface or open drains will be indicated. Field sizes and dimensions will be...
Determined according to daily harvesting allocations and to suit various harvesting practices. Access will be provided to every row. Once a farm plan has been implemented, a process requiring about 10 years, management of all operations will not only be easier but much more cost-effective.

STOOL ERADICATION, LAND PREPARATION AND PLANTING

Stool eradication

Millions of tons of sugarcane are lost annually by diseases transmitted to the new crop due to ineffective eradication of the previous one. The traditional method of repeated deep tillage operations, attempting to destroy the old crop while simultaneously preparing a seedbed for the next planting, is expensive, often practiced regardless of prevailing weather conditions or soil type, and is usually ineffective. Much better results are obtained by splitting the operations, killing the old crop first.

Shallow mouldboard ploughing to a depth of 100 to 150 mm, followed by light disc harrowing is a very effective method of eradicating cane on heavy soils during dry periods. A rotary hoe operating at the same depth followed by a light disc harrow again during the dry period, achieves the best result on sandy soils. Many other implements can be used effectively and cheaply as long as the principle of working shallow is followed and the timing is correct. Chemical stool eradication must be practiced only during peak growing periods and when all shoots have emerged. For countries with an abundant labour supply, hand chipping during the drier months is an extremely effective method of removing cane stools. Any difference in costs between these stool eradication methods are insignificant when the total cost of re-establishment is considered. The cost advantages of gaining one or more additional ratoons as a result of effective stool eradication also far exceed any possible cost penalty of implementing these methods. Follow-up operations may still be necessary to ensure volunteer-free fields.

Land preparation

In many countries it is believed that deep tillage is required for high sugarcane yields. Deep tillage may be necessary for certain soil types, climatic conditions or for the deep placement of ameliorants, but in many conditions this very expensive operation may not be cost-effective.

The equipment used for land preparation varies from country to country and depends on factors such as soil type, soil moisture, topography and the scale of operation. However, the importance of timing and the difficulty of selecting the
most effective implements for a particular circumstance is evident from the wide variation in the number of cultivations carried out by different growers under basically the same conditions. Some growers are obviously carrying out too many operations.

Considerable progress has been made with minimum tillage land preparation methods. Machines have been developed to create a suitable planting tillth in the old interrow, even under a trash blanket. There is usually little or no significant yield difference following conventional or minimum tillage. On sandy loam soils and especially under marginal moisture conditions, minimum tillage can be expected to give higher yields. Other advantages of minimum tillage include a shorter fallow period between crops, far less exposure to soil erosion, greater moisture retention and reduced cultivation costs. Costs can be considerably reduced by preparing only a narrow seedbed strip where the cane is to be planted. This practice can be implemented in association with manual, mechanical or chemical stool eradication. Cane growers must continually question the need for any traditional cultivation practice and only implement those which are cost-effective.

**Planting**

In most countries sugarcane is still planted manually. Earlier interest in single row cutter planters has waned due to their low output and frequent gaps in the cane row caused by skipping. The widespread use of complex and expensive billet planters is doubtful, except in countries such as Australia, the USA and Cuba. A universal planting method is the use of tractor-drawn trailers operating in pre-furrowed fields followed by hand dropping. This system is usually more effective because the likelihood of skips is small. Subsequent covering can be done mechanically two rows at a time. High planting rates are possible and cost per hectare planted is low.

Progress is evident in several countries in reducing the cost of nursery-raised seedlings. Transplanting may therefore become increasingly important. It eliminates the need for gap filling and the quality of the seed material can be better controlled.

**CROP MAINTENANCE**

**Stool pruning**

The most cost-effective method is to avoid stool pruning altogether. In many instances this is an unnecessary operation and its need must be carefully assessed. If it is proved to be necessary, a variety of implements, using discs, rotary hoes or chemicals, can be employed; all appear to cost roughly the same per hectare.
With proper base-cutter control, this operation should not be necessary. Several
modern harvesters, and even some simple mechanical cane cutters, offer some
degree of automatic base cutter height control and there is no excuse for poor
performance. There should be no need to stubble shave hand-cut cane; if cutters
refuse to cut properly, the time has come to introduce mechanical cutting.

Ratoons management

The practice of inter-row subsoiling or ripping in ratoon crops is highly question-
able. Several delegates reported experiments showing yield depressions due to
root damage caused by this practice. Even when ratoons are ripped in an attempt
to ameliorate the effects of compaction caused by heavy harvesting equipment
on wet soils, yield responses were usually insignificant or even negative and did
not pay for the cost of the operation. A possible exception is where it can be
proved that fertilizer must be placed in the soil.

Trash management

Even after burning and hand-cutting with mechanical loading, significant heaps
of trash can be left in the field. Where yields are very high the problem can be
serious and yield reductions can occur due to the smothering of stools. Cost
effective methods to handle large amounts of trash are needed. In burnt fields
yielding less than 120 t/ha, scattered tops and remaining trash should be left.
This material conserves moisture, helps to prevent soil erosion and does not
adversely affect herbicide efficacy. It may however be necessary to line trash on
the cane row to allow the passage of water for furrow irrigation.

Until conclusive evidence proves otherwise, there is no need to apply fertilizer in
the soil underneath a trash blanket. Fertilizer can simply and cheaply be spread in
a band, or even broadcast, on top of the trash.

Mechanical weed control

With the advent of effective herbicides, interest in mechanical weeding has waned.
There is little data on the relative cost-effectiveness of rakes, spring tines, rotary
hoes and rolling cultivators. Timing of the operation is much more important
than the type of implement used. The use of depth wheels is increasing and gives
more precise results: overly deep or shallow cuts or too many passes can
cause bad results. Timing has a major influence on results.

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techniques must therefore be geared for maximum effectiveness of the chemicals, even if this increases the cost of application. Ground-, and row-, following devices can affect savings in the quantity of chemicals used. Shields and thickened sprays can be used in windy conditions. An excellent example of improved cost effectiveness due to timing came from a country where herbicides are now mainly applied at night. This improves the uptake of the chemicals and causes fewer environmental problems from volatization and drift caused by higher daytime winds and temperatures. System to increase the output of manual knapsack operators include pressurized tanks recharged from a 5,000 litre mobile tank at the endge of the field. By eliminating hand pumping, operators can concentrate on directing the spray and their output also doubles. VLV and ULV spraying and prepacked herbicide cartridges are other means of securing more cost-effective herbicide application.

**Fertilizer application**

There is no evidence that precision placement of fertilizer results in higher sugarcane yields, but it may lead to less fertilizer being required without reducing yield. Agronomists need to resolve this question. Ground-wheel drive increase precision application. In Swaziland anhydrous ammonia is applied behind a tyne positioned directly in front of the tractor's rear wheels—this results in excellent sealing of the soil, giving a material saving of 30%.

The field efficiency of fertilizer spreaders can be very substantially increased by faster re-charging methods. In one instance a laborer empties 50 kg bags of fertilizer into a hopper outside the fertilizer store while the sprayer is in the field. The same man then winds the full hopper with the aid of a simple gantry high enough so that the sprayer can stop underneath the hopper where it is loaded in seconds by simply opening a flap valve.

Cost-effective spreading or placement of bulky materials such as filtercake and compost has been developed in several countries and should be copied more widely.

**Drainage**

The flatter the topography, the more important field drainage becomes for cost-effective mechanization. The first requirement is to provide free drainage of surface water in a reasonable time from every cane row. This means that the field must be smoothed and if very flat, graded to provide a fall in the cane row direction. It is very important to eliminate all low spots where water will accumulate and which will stay wet, because these are the areas where machines will bog down and at the same time cause severe field and cane damage. The use of laserbeam technology in field grading has greatly improved the precision to
Sympathy this can be done. Collector drains may be necessary to remove drainage water from the fields. Where water tables are high, subsurface drains may be required. For some soils, mole drains could offer a cheaper alternative than underground pipe drains.

In addition to growing good sugarcane crops, the objective of field drainage is to provide a stable and relatively dry surface for the movement of equipment required for all operations.

In very wet situations, turtle-backs or cambered beds may offer the best compromise for effective mechanization. To provide adequate drainage some countries grow sugarcane on very high ridges. None of these measures preclude effective mechanization and in some places, such as Louisiana, machinery systems have been developed to suit these field layouts.

HARVESTING

Machine use and actual output achieved are of extreme importance for cost effective mechanical harvesting. The effect of the machine system on the quality of the product delivered to the factory must also be considered. An enterprise must be of a certain size to warrant the cost of harvesting machines. A simple cutter mounted on a tractor might be economical at 5,000 tons per year while a chopper harvester may require 40,000 tons or more. The actual tons handled per machine is important, not the potential capacity. The more sophisticated the mechanized system, the higher the standards of field preparation required for effective machine performance. Wider row spacings are preferred and they must be compatible with the wheel tracks of the equipment. Tramline ("pineapple") row spacing could be an alternative. Row lengths must suit both harvesting and transport equipment. Variety selection should include erectness and self-trashing as criteria.

Many mechanized harvesting systems have failed because of a lack of proper maintenance and poor management. However, there are examples of the opposite, such as a fleet of 24 chopper harvesters with machines averaging 60,000 to 80,000 tons per 200 day harvesting season. To maintain this performance each harvester is serviced for an eight hour period out of every 24. Spares and service are provided by workstations set up within 1 km from the harvesting front.

Cutting attachments

As an alternative to mechanical loading, the cutting operation could be mechanized. If simple cutting attachments are fitted to standard tractors, small producers could use the tractor for other purposes, thereby increasing its annual use
which will decrease the overall operating cost. By mechanizing the cutting operation less specialized labor will be required for subsequent cane handling.

Whole stalk harvesting systems

If field conditions meet specified standards and if the cane is relatively straight and upright, fully mechanized whole-stalk harvesting systems are available which can harvest cane with little loss, good quality and at relatively low costs. Both one and two row models are available which can give excellent results and can place cane from as many as six rows into a single windrow. Cane is cut green and burnt subsequently in the windrow. Mechanical loading follows after burning.

Chopper harvesting

Chopper harvesters are currently preferable to whole-stalk harvesters for heavier lodged crops, especially of green cane. Harvesting rates depend on field conditions but pour rates of 100 t/h in burnt and 60 t/h in green cane are attainable. Overall field capacity will be about 50% of the pour if field conditions and transport back-up are good. With poor cane yields and bad field conditions; the field capacity can be below 15 t/h. Trash content of chopper harvested cane varies from 2 to 15%. Field losses consist not only of 0 to 10% cane left behind in the field, there are also losses of juice and cane fragments so small that they cannot be gleaned. These losses will vary from 2 to 15% depending on varietal characteristics and machine setting and maintenance. More capital is usually required to implement a chopper harvesting system and cost per ton harvested is normally higher than for whole-stalk systems. At present chopper harvesters are the only commercially available option if cane is to be harvested mechanically without burning.

LOADING

Overall cost-effectiveness must be considered when selecting a loading system. A more expensive system which delivers cleaner cane to the factory may actually be more cost-effective overall than an apparently cheaper alternative.

Manual loading

This method will give the cleanest cane but is only acceptable if abundant labor is available and willing to perform this task. The cost of a manual loading system must include the downtime of the vehicle into which the cane is loaded.
Self-loading trailers

If labor is available to cut and make 4 ton stacks of sugarcane, self-loading trailers afford a simple, cheap and flexible cane handling system. This system is better suited for steep terrain, stony fields and generally poorer field conditions than are more mechanized systems. Capital investment is low and this system is especially suitable for smaller growers.

Grab loading

This is a well developed and reliable loading option. A wide range of machines are available, of different designs, capacities and operational characteristics. Some high capacity loaders achieve loading rates of 100,000 tons per 200 day season and a number of machines have exceeded a million tons each. Performing like this, cost per ton loaded is very competitive but this can be achieved only under good field conditions and with excellent management. Conversely, high capacity loaders can be found which average only 20 t/h or even less because of poor management or a bad match with the transport equipment. Row spacing and ridge dimension may need modification to be compatible with a specific loader. Some loaders, especially heavy, high powered machines, can cause unacceptable field damage and uprooted cane stools if not operated carefully.

Soil in mechanically loaded cane

The quantity of soil loaded with cane depends on field conditions, equipment design and very importantly, operator skill. Good results are achieved by a pushpiler mounted on a four bar linkage which allows it to float on loose soil. An elevating chain to pick cane up as it is engaged by the loader can be used to minimize the bulldozing action and sliding of the cane on the ground. Preventing the grab from entering the ground when catching the bundle also reduces soil inclusion. By forming small piles of cane instead of a continuous windrow, cane can be loaded without any pushpiling, thereby minimizing soil and stone pick-up.

Continuous loaders

The high capacity of these machines makes them suitable for large operations, but only if sufficient transport is available.

TRANSPORT

Cost-effective cane transport is a compromise between the requirements for infield and road transport. Infield operations demand the lightest possible vehicles on low pressure tires with wheel tracks to suit cane interrow spacing. For low
cost road transport, large payloads carried only high pressure speed tires on vehicles conforming to road ordinances, are required. For distances of less than 5 km from the factory; direct delivery by 8 ton semi-trailers pulled by 50 kW tractors will usually be the most cost-effective, but the factory must have the capacity to accommodate large numbers of relatively small vehicles.

Up to 12 km from the factory, direct delivery of 60 kW tractors pulling 10 to 12 ton semi-trailers are recommended. Payloads over 12 tons are required for longer distances and conditions must be very good to allow vehicles of this capacity into the field. One alternative is to hitch and unhitch trailers at field edge, thereby ensuring manageable loads infield. Alternatively, special infield tractors can be used to pull combinations of trailers through the field, with high speed tractors taking over for delivery to the factory.

For distances exceeding 15 km, transloading is usually recommended. Infield haulage should then be confined to 4 to 8 tons tractor/trailer rigs, taking the cane to transloading zones within 1 km from the field for loading into large trailers pulled by truck tractors (mechanical horse) or tractors suitable for high speed haulage. Payloads would normally exceed 20 tons. For all haulage vehicles the ratio of payload: total vehicle tare, including the prime mover, should be at least 1:1, with 1.5:1 a better target.

There are examples of large vehicles being used successfully for direct delivery. On one estate, rigid trucks with trailers with a total payload of 24 tons have been used infield for more than 20 years with no discernible effect on cane yields. The transmission ratio of the engines used to pull these trailer rigs makes it possible to load the trailers at speeds required for haulage.

Engine power and torque characteristics as well as gear ratios of tractors used for haulage must be matched to the demands of the task. Traditional "ploughing" tractors seldom offer sufficient gear overlap at the speeds required for haulage. Special haulage tractors with high speed differentials, matched synchronized gearboxes or automatic transmissions and equipped with wheels and tires for high speed operation are available.

Dead weight must be reduced to a minimum. To improve traction, trailer and tractor hitches must be designed for maximum safe weight transfer from the loaded trailer onto the tractor. The extent of weight transfer is usually limited by the load-carrying capacity of the tractor's wheels and tires. No ballast is required on the tractor. Trailer mass must be minimized. Wheels and tires must be chosen for flotation and for least field damage. Trailer wheels must follow in the tracks of the prime mover.

Transport and loading equipment can be completely eliminated from infield if a whole stalk harvester could be developed to accumulate up to 3 tons of cane while it is cutting. It would then dump the cane on cross roads spaced at 150 m
intervals for cane yielding up to 130 t/ha. The harvester would proceed straight across the road into the next block. Loaders operating on the road would then load the cane into highway vehicles for delivery to the factory.

SOIL COMPACTION

The effect of harvesting traffic on sugarcane yield is difficult to quantify. Changes in soil physical properties such as bulk density and resistance to penetration caused by infield traffic do occur and can be measured, but do not necessarily result in eventual yield reductions. Where yield effects have been measured it has not been possible to differentiate between soil compaction and stool damage as the cause of the reduction.

As a general rule, the wheels of heavy harvesting equipment must be confined to the interrow, especially when soils are wet. Equipment entering sugarcane fields should be as light as possible.

CONCLUSIONS

1. The standard of management largely determines the cost-effectiveness of all sugarcane production systems.
2. A number of operations can often be eliminated without adversely affecting net profit.
3. Skilful machine management is usually more important than the details of choice of machine or method.
4. Operator performance is important, not only for sophisticated harvesting machines but also for simpler operations such as application of herbicides.
5. Timing of operations is important and a mechanization plan for each field must be integrated into a program plan for the whole estate.
6. To be cost-effective machines must be fully used and their output must be increased.
7. System analyses of all operations is required, not to determine the cheapest, but the most cost-effective, option. This requires a thorough understanding of the effect of each operation on net profit.
8. Net profit, not maximum yield, should be the criterion against which the cost-effectiveness of each operation should be judged.
9. Cost-effective trash handling methods must be developed for green cane harvesting. This could be the subject of a future ISSCT Workshop.