ABSTRACT

Most sugarcane today is harvested manually, but there is an ever-increasing trend toward mechanization. In many of these transitions, machine introductions occur before necessary preparations. This paper outlines the preparatory requirements for harvester mechanization including cultural practices, field layout, and transport system design.

**Keywords:** Mechanization, harvesters, transport, field layout, cultural practices, sugarcane, haulage.

INTRODUCTION

Along with the coming of a new millennium is the promise of economic prosperity on a global scale, with much of this new wealth developing in countries that formerly focused on agrarian production. Now cars, computer chips, and countless other products are the first order of business. Prospects for the future are extremely bright and filled with change. However, these developments will not always be good news for those industries unprepared for a rapid repositioning of the labor force. In general, the manufacturing sector provides higher paying jobs with more comfortable working conditions than the agricultural sector. This sets the stage for inflated labor costs, labor shortages with little notice, and ultimately, the need for large-scale mechanization. Now is the best time to prepare, before the tide of development becomes overwhelming.

Transition from hand-labor to mechanical harvesting of sugarcane should be a gradual process that allows time for complete understanding and tailoring to meet local needs without the pressures accompanying drastic and necessary change. Introducing numerous machines with inadequate preparation typically results in costly chaos. For this reason, preparations should begin several years before labor shortages become crisis.

Field preparation and harvesting/transport system design are primary issues addressed in this paper. Both should be settled prior to the arrival of the Combine Harvesters.

FIELD PREPARATION

The best starting point in preparing for mechanical harvesting of sugarcane is the modification of field conditions. Few fields that have previously been hand-cut are ready for full or even partial mechanization. Since most changes in field layout must wait until after the last ratoon, an early start is imperative. Adherence to the following 8 items will ensure that field conditions do not introduce inefficiencies into the mechanical harvesting system.

- Interrow widths should be not less than 1.35m with 1.5m being generally accepted as optimal.
- Row length should be as long as possible with 200 to 300m being a good initial target. If lengths are in
excess of 500m, field exit roads should be placed every 500m in fields with 100 tons cane/hectare. These exits will reduce transport time and field damage resulting from transport vehicles unnecessarily traveling the rows.

- Row shape and spacing should be uniform throughout the field. Ridges should be well formed and level on top. Furrows should also be well formed and smooth. Cane should be cultivated so it is centered on a ridge 10-20cm high by harvest time, but not more than about 30cm high.

- Trees, rocks, and debris should be removed from field.

- Headlands (infield roads) should be 5 to 6m wide. They should be level with the field and free of rocks, stumps, trees, and obstructions.

- Infield roads as well as haul roads may need to be improved or even established.

- Fields may require levelling to eliminate infield cross drains, hills, or depressions.

- Cane varieties may require change. Some characteristics to look for in selecting varieties for mechanical harvesting are: 1) high sucrose, 2) good root systems, so the stool does not uproot with lodging or mechanical harvesting, 3) good ratooning after being machine cut, 4) non-brittleness, and 5) leaf-shedding for easier cleaning.

**HARVESTING AND TRANSPORT SYSTEM DESIGN**

System design requires some knowledge of harvester/transport system capabilities and impacts. This section will provide the tools necessary for designing an efficient mechanized system.

**HARVESTING SPEED, OUTPUT PRODUCTION, AND EFFICIENCY**

The minimum output production objective for any cane combine harvester should be 60 tons/hr in fields with yields between 45 and 200 tons/hectare. Output production or "field rate", is the rate that the machine achieves in cutting and loading over an extended period allowing all contributing factors to be considered, such as lost time due to:

- Mechanical availability of the harvester and transport equipment.

- Availability and capability of operators and mechanics.

- Adequate numbers of transport vehicles.

- Infield maneuverability of harvester and transport equipment.

**Table 1 : Typical field rate outputs under ideal conditions**

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Yield of cane (tons/ha)</th>
<th>Est. output (tons/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>7.0</td>
<td>90</td>
<td>1.5</td>
</tr>
<tr>
<td>9.0</td>
<td>45</td>
<td>1</td>
</tr>
</tbody>
</table>

**The maximum speed at which most operators can coordinate machine and transport is 8 - 10km/h.**

**This table assumes 1.5m row spacing.**
With the aid of a stopwatch, determine the time required for a machine to fill a given size transport vehicle, timing only while cutting and not while turning or traveling on the ends of the field. Divide this known tonnage by the time taken to fill the transport. This is the “pour rate”.

Dividing the field rate by the pour rate gives an “efficiency ratio”. This efficiency ratio should be closely monitored as a gauge of ongoing harvesting system improvements as well as new problem development. Efficiency ratio influencing factors include operating speed, field/crop conditions, row length, spacing and shape of the row, turning/travel time, and transport availability.

FUNDAMENTALS OF CANE HAULAGE

The term “harvest” is used to describe the process of cutting, loading, and transporting cane to the mill. The goal of the harvest is to deliver stalks (billes) of high quality to the mill in the most economical manner. Of all factors affecting the efficiency of newly mechanized plantations, transport is by far the most common. Coordination of a transport system even under ideal conditions can become a difficult task. Many factors may contribute to a less than ideal system including inadequate equipment, transport that is not under the direct control of the harvesting operation, mill unloading problems, etc. In this era of stiff competition, transportation is one component of the sugar industry that is being more carefully analyzed. The next few pages will touch upon some of the more important precursors to transport effectiveness.

COMPACTION

One of the most important factors to consider when designing a sugarcane transport system is damage to the ratoons caused by excessive ground pressure and poorly spaced wheels. In addition to creating a root barrier of compacted soil, root shearing may also occur, especially when using truck type tires too close to the stubble. The center to center track width of the wheels should closely match the row spacing. The ideal is to have the tractor and wagon track the same as the interrow spacing. Under this condition the tractor and wagons operate like a “train going down a track.” However, track widths equal to the interrow widths may not be practical in all situations, but an effort should be made to get as close as possible. In some cases it may be better to design the transport to track over two rows. This will introduce an element of improved stability. Likewise, care should be taken when selecting tires and wheels to be certain that a large enough footprint is selected to minimize ground pressure. If these factors are taken into proper consideration, the result will be less cost for replanting and a higher yield per hectare.

FLOTATION

In certain areas such as New South Wales and Louisiana due to the great amount of precipitation or the high level of the water table, the efficiency of the transport system during harvesting season is reduced considerably. In these conditions, tracks or oversized high flotation tires are used to minimize field and equipment damage.

EFFICIENCY

The power of a prime mover can be identified from three perspectives: as “power required”, “power available”, or “power usable”. Power required is the energy needed to get the job done. Power available is the energy capability of the machine. Power usable is available power limited by the job conditions. Let’s consider the forces that determine the power requirement.

‘Rolling resistance” is the retarding force of the ground against the wheels of a vehicle. This force must be
overcome before the vehicle will move. Rolling resistance is measured in kilograms of pull. “Grade resistance” is the retarding force of gravity, which must be overcome to move a vehicle uphill. It too is measured in kilograms of pull. If the vehicle is going downhill, gravity produces a helping force called “grade assistance”. Many factors determine the rolling resistance or retarding force against a rolling wheel. Some of the more important ones are tire flexing, surface type, and depth of tire penetration. A “rule of thumb” has been developed to estimate the effect of these factors. This effect measured in kilograms of pull, amounts to roughly 2% of the gross wheeled vehicle weight when traveling on level hard surface roads. This means 20kg of pull or push is required to move 1,000kg wheeled vehicle on a level hard surface. This value is the “rolling resistance factor”. From this we can construct the formula for rolling resistance of a wheeled vehicle:

Rolling Resistance = Weight on Wheels × Rolling Resistance Factor

Ground conditions vary to an infinite degree, and therefore, the rolling resistance varies equally. For practical purposes, general factors have been established to estimate most conditions and interpolation will establish intermediate factors.

Table 2: Rolling resistance factors

<table>
<thead>
<tr>
<th>Rolling resistance factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A hard smooth roadway without penetration (concrete or blacktop)</td>
<td>2%</td>
</tr>
<tr>
<td>A firm smooth roadway flexing slightly under load (gravel top road)</td>
<td>3.2%</td>
</tr>
<tr>
<td>A soft dirt road (freshly graded)</td>
<td>4%</td>
</tr>
<tr>
<td>A rutted dirt road, flexing considerably under load - (1&quot; to 3&quot; penetration, average dry cane field)</td>
<td>5%</td>
</tr>
<tr>
<td>Rutted dirt road, soft under travel (4&quot; to 6&quot; tire penetration)</td>
<td>7.5%</td>
</tr>
<tr>
<td>Soft, muddy rutted roadway or sand</td>
<td>10% - 20%</td>
</tr>
</tbody>
</table>

Another important factor affecting the rolling resistance and power requirement is the track width of the wagons. Whenever possible, wagon wheels should be the same gauge and tires no wider than the tractor. Field damage in wet weather can be reduced considerably if the tractor and wagon gauges are the same. As we have seen, rolling resistance increases as penetration increases. For example, in a wet field a tractor is sinking 10 cm and the wagon following behind the tractor trench is sinking 3 cm, the tractor is pulling the wagon up a virtual grade corresponding to 3 cm. If the wagons are not tracking directly behind the tractor and they too are sinking 10 cm, then the tractor must pull itself plus the wagons up the virtual grade equal to 10 cm penetration. Once tractor, wagons, and row width are matched, field damage will be held to a minimum. Required horsepower and tractor weight will also be lowered. However, too narrow a wagon gauge will result in instability.

Grade resistance is the force of gravity that must be overcome when going uphill. It is the gravity component of the entire weight of the vehicle acting downhill and parallel to the incline. Grade is usually measured in percent slope. This is the ratio of the vertical rise (or fall) to the horizontal distance in which the rise (or fall) occurs. A rise of 5 m in 100 m horizontal distance would be a 5% grade. When traveling over level terrain, a vehicle must overcome only rolling resistance. When traveling uphill, a vehicle must overcome rolling resistance and grade resistance. When traveling downhill, a vehicle must overcome rolling resistance less grade assistance. Based on field experience, each 1% of grade produces a hindering or helping force approximately equal to 1% of the total vehicle weight.
Grade assistance or resistance = Vehicle weight \times 0.01 \times \%\text{grade}

Example: How much pull is needed to haul a loaded cane wagon (10,000kg total weight) up a 10% slope with muddy road conditions?

$$\text{Pull} = \text{Rolling resistance} + \text{Grade resistance} = (\text{Total weight}) \times RR \text{ factor} + (0.01)(\% \text{ grade})$$

$$= (10,000)/0.1 + 0.01(10)$$

$$= (10,000\text{kg})(0.2) = 2000\text{kg}$$

If the wagon is going downhill:

$$\text{Pull} = \text{Rolling resistance} - \text{Grade assistance} = (10,000)(0.1 - 0.01(10)) = 0\text{kg}$$

Engine power is the primary factor determining power available from a prime mover to do work. However, some engine manufacturers rate engines stripped of accessories. The actual power available at the flywheel, allowing for altitude (small effect in most cane areas) and all parasitic loads such as the fan, generator, and hydraulic pump is 10 to 20% less than the rated engine power. This flywheel power is available to supply the drive train.

The flywheel power is further reduced by two factors, resulting in usable power. First, the drive train is responsible for losses amounting to 15 to 20% of the flywheel power. The other factor is traction, the gripping action of wheels on the surface of the ground. This interaction between the wheels and the surface varies according to the weight on the driving wheels and the type of surface on which the vehicle operates. If the wheel spins, we can either add more weight or improve underfoot conditions.

A specific type of underfoot condition can be represented by its “coefficient of traction” which is the ratio of the usable tractor pull to the actual weight on the driving wheels. If we say that the coefficient of traction for rubber tires on dry sand is 0.20, this means that a rubber tired tractor can produce pull that corresponds to 20% of the weight on the driving wheels. To determine the amount of usable pull, the following formula can be used:

Usable pull = Coefficient of traction \times Weight on driving wheels

<table>
<thead>
<tr>
<th>Surface</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>0.90</td>
</tr>
<tr>
<td>Dry clay loam</td>
<td>0.55</td>
</tr>
<tr>
<td>Firm earth</td>
<td>0.55</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0.45</td>
</tr>
<tr>
<td>Loose earth</td>
<td>0.45</td>
</tr>
<tr>
<td>Wet clay loam</td>
<td>0.45</td>
</tr>
<tr>
<td>Rutted clay loam</td>
<td>0.40</td>
</tr>
<tr>
<td>Wet sand</td>
<td>0.40</td>
</tr>
<tr>
<td>Loose gravel road</td>
<td>0.36</td>
</tr>
<tr>
<td>Wet clay field with cane trash</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Example:

What is the maximum usable pull of a 7000kg, two wheel drive tractor with 65% of the weight on the driving wheels and operating in rutted clay loam?

Usable pull = (Weight on drivers) x (Coefficient of traction) = 0.65(7000kg)(0.4) = 1820kg

Note that this pull is not sufficient for the 10,000kg wagon in the previous example.

Example:

What is the maximum usable pull of a four-wheel drive tractor of the same weight and underfoot conditions as the previous example?

Usable pull = (Weight on drivers) x (Coefficient of traction) = 7000kg(0.4) = 2800kg

If the required pull exceeds the usable pull add weight to the tractor, reduce the load, or change tractors.

The power to move a load under certain underfoot and grade conditions can be determined from the following formula:

Power (kW0 = [Gross vehicle weight in kg x (Grade + RR) x (Speed in km/h)] / (265)

Typical losses in gear and engine efficiency are included in the constant (265).

Example:

Using our 7000kg tractor, 10,000kg cane wagon and the same slope and underfoot conditions assumed in the preceding examples, what power is needed to move up the 10% grade hill at 12km/h?

Power = (17,000kg x (0.1 + 0.1) x 12km/h) / 265 = 154 kW

Use these calculations to determine the power necessary to match both the speed requirements of the harvesting operations and the wagon capacity.

Another important consideration when looking at efficiency is cycle time. On any haulage job, a machine at work moves according to some semi-repetitive pattern (loading, hauling, unloading, returning, and waiting). Once a project is in operation, simply time several complete cycles and then take an average. However, if there is no equipment on site - we estimate. This is the situation faced by a new plantation or one undergoing a transport equipment change. By studying factory requirements, job limitations, and power requirements an accurate cycle time can be estimated. From this, production and most important, cost can be estimated.

The most important reason for studying cycle time is to reduce it, through better planning or change in field layout. If fields are rearranged and good haul roads established it is over with once and for all, except for maintenance. But, if an inefficient field layout is tolerated, it costs in efficiency every time the crop is harvested. To reduce cycle time ensure all field preparations mentioned earlier have been observed, use high output harvesters, use suitable infield transport, use efficient transloading (tractors with large hydraulic pumps for self-tipping operations), and employ proper organization, handling, and storage methods in the mill yard.

Mill yard design, topography, infrastructure, climatic conditions, and field configurations should all be considered when designing a transport system. Typically, if the fields are near the mill (1km to 7km) field transport traveling directly to the mill may be appropriate. These transport units should have high floatation tires and be capable of high travel speeds. If the fields are more than 7km from the mill transloading should be considered. The most effective and efficient type of transloading is an infield unit self-tipping directly into a highway truck.
Haul-out units must be continuously available to the harvester to optimize cost effectiveness. A system with tractors hauling directly to the mill must consider the time to load each unit (assume a loading rate of 1 ton per minute), the time to travel to the mill, the average time spent at the mill waiting and unloading, and the time to return to field. With at least two harvesters operating, one at maximum distance and one at minimum distance the transport units can be minimized. This idea may be expanded to several harvesters operating on two or more fronts. The following example will illustrate:

**Example:**

**Assume two harvesters are operating between 1km and 7km of the mill. Further assume that the field transport units carry 10 tons of cane, the average travel speed is 15 km/hr, the average wait and unloading time at the mill is T3 = 30 minutes, and the average harvester output is 60 tons per hour.**

*First we find the time to load one unit:*

\[ T_1 = \frac{10 \text{ tons}}{60 \text{ tons per hour}} = 10 \text{ minutes} \]

*If we assume harvester-1 (H1) is operating at 1km (2 x 1km both ways) from the mill and harvester-2 (H2) is operating at 7km from the mill then:*

\[ T_{2H1} = \frac{2 \times 1 \text{ km}}{15 \text{ km/hr}} = 8 \text{ minutes} \]

\[ T_{2H2} = \frac{2 \times 7 \text{ km}}{15 \text{ km/hr}} = 56 \text{ minutes} \]

*Thus the total times are:*

\[ T_{H1} = T_1 + T_{2H1} + T_3 = 10 \text{ min} + 8 \text{ min} + 30 \text{ min} = 48 \text{ min per transport cycle} \]

\[ T_{H2} = T_1 + T_{2H2} + T_3 = 96 \text{ min per transport cycle} \]

*The number of transport units needed then is,*

\[ N = \frac{T}{T_1}, \]

\[ N_{H1} = \frac{48 \text{ min}}{10 \text{ min}} = 4.8 \text{ (5 units)} \]

\[ N_{H2} = \frac{96 \text{ min}}{10 \text{ min}} = 9.6 \text{ (10 units)} \]

\[ N_{\text{total}} = N_{H1} + N_{H2} = 15 \text{ units}. \]

*Now we can see that if both harvesters were operating at 7km, 20 transport units would be needed and if both were at 1km only 10 units would be needed. Either way we would have a problem as 10 units would not be enough at 7km and 20 units would be excessive at 1km.*

*If we assume circular symmetry of the field distribution about the mill and we test our estimate at a distance from the mill that corresponds to the area before and after that radial distance being equal. At this “equal area radius” the two machines should converge and operate at the same distance from the mill. This equal area radius is,*

\[ D_{\text{mid}} = \frac{D_{\text{max}}}{\sqrt{2}} = \frac{7\text{km}}{1.414} = 4.95\text{km}. \]

*If we substitute this distance from the mill into our previous equations we have,*

\[ T_{2H1} = T_{2H2} = \frac{2 \times 4.95\text{ km}}{15 \text{ km/hr}} = 0.66 \text{ hours} = 39.6 \text{ minutes.} \]

*Thus,*

\[ N_{H1} = N_{H2} = \frac{39.6\text{ min} + 10\text{ min} + 30\text{ min}}{10\text{ min}} = 7.96 \text{ (8 units)} \]

*And N_{\text{total}} = 16 units, which is the maximum number of transport units needed for two harvesters if the harvesters are deployed properly.*

*If the harvesting operation is beyond 7km and transloading is to be used, the main concern is having enough highway trucks available to support the harvesters. The calculations are done similar to those above.*
The number of infield self-dumping units needed is simple. Three units per harvester are recommended for an average 2km round trip from the harvester to the truck and back to the harvester. Also recommended are wagons of 8 to 10 ton capacity to be used with 90 to 112 kW powershift tractors. The earlier section on power will demonstrate the need for this type of tractor. Especially, if we consider the speed (10km/h) and fast infield acceleration needed for harvesting operations.

CONCLUSIONS

It is best to profit from the experiences of those that have experimented, failed, and eventually succeeded through decades of trial and error. Accepting and implementing these successful methods will quickly put your project on par with the finest mechanized systems in the world. Then you will be in the enviable position of managing a system that is cost-effective, while searching for a better way.

PREPARACIÓN PARA LA COSECHA MECANIZADA

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RESUMEN

Actualmente, casi toda la caña se cosecha manualmente, pero existe una tendencia creciente hacia la mecanización de la cosecha. En el proceso de transición, ocurre la introducción de cosechadoras sin haber adelantado un alistamiento previo del campo y de la fábrica. Este artículo describe los requisitos previos para la mecanización de la cosecha incluyendo las prácticas de cultivo, los diseños de los campos, y el diseño de los sistemas de transporte.

PREPARATION A LA RÉCOLTE MECANIQUE

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RÉSUMÉ

La majorité de la canne à sucre aujourd’hui est récoltée manuellement, mais on observe une grande tendance d’augmentation à la mécanisation. Dans certains cas, l’introduction de la mécanisation nécessite des préparations adéquates. Ce document fait ressortir les conditions favorisant la récolte mécanique, notamment les techniques culturales, l’aménagement du parcellaire et le matériel de transport.

MC: Mecanisation, coupeuses, transport, aménagement du parcellaire, techniques culturales, canne à sucre