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State of the art: Sugarcane mechanical harvesting-discussion of efforts in Egypt

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***Abstract*— The design and commercial manufacturing of mechanical sugarcane harvesters have taken place firstly in Hawaii, Australia, Southern USA (Louisiana and Florida) and Japan where the sugarcane production is fully mechanized from about 4 decades. Significant researches of mechanical cane harvesting have also done in Barbados, Brazil, Trinidad, Cuba, India and several other countries. Currently, companies belong to countries such as Cuba, Porto Rico, UK, Germany and China fabricate types of sugarcane harvesters that represent variable levels of technology.**

Normally there are two sugarcane mechanical harvesting systems classified as follow:

1- Whole-stalk sugarcane harvesting system (the system which delivers whole stalk of canes). Large self-propelled whole stalk harvesters operated only within full mechanization systems. Other tractor mounted machines or small single axle walkman steering cane cutters are fabricated for the conditions of developed countries.

2- Cut-chop-harvesting or chopper harvesting system (the system which chop the cane into billets while harvesting). This system is also called sugarcane combine harvesting system.

The chopper harvester (sugarcane combine) represents full mechanization system for sugarcane harvesting. A transport trailers with especially basket design should move in the field parallel to the machine to receive the current of cane billets delivered from the chopper elevator. Moreover, with the use of chopper-harvesters, the vastly increased surface area of internal cane tissue, which is exposed to bio-chemical attach, causes rapid deterioration in cane quality. This factor is critical when cane processing to be delayed.

The large self propelled Soldier-Cane-Harvester or (Louisiana type) operated within full mechanization system followed by continuous loader or grab loader. McConnel cane harvesting system is a tractor attached whole-stalk-harvester developed for the conditions of Barbados. SASABY is a South African cane harvester developed for the conditions of South Africa. The McConnel machine was developed in 1971 when intensively field testes and modification were take place within few years where the performance of the modified version become satisfactorily.

All other cane harvesters are whole-stalk-harvesters developed to perform stalk base cutting as principle function and some of harvesters may include mechanisms for topping and/or windrowing in addition. Since manual harvesting of sugarcane is actually whole stalk harvesting by labors so that in changing from manual to a mechanical harvesting system, whole stalk harvesting may fit more easily. When replacing manual by mechanical harvesting whole stalk harvesting matches the existing system of reaping, transportation, storage and the feeding of cane into mill. Actually for semi mechanization, the machine will perform one or more of the functions done by the labor performing mix sugarcane harvesting system.

Developed countries apply full mechanization for harvesting entire production of sugarcane. Australia use chopper machines for full mechanization sugarcane harvesting. Japan and US applies full mechanization sugarcane harvesting systems either by choppers (in Hawaii and Florida) or by solider whole stalk harvesters (in Louisiana).

Countries grow large areas of sugarcane such as Brazil, India, Cuba, South Africa and China may have large agricultural sectors that economically apply full mechanization, medium sectors that apply semi mechanization and small size farms that still harvest sugarcane manually. These countries fabricate both of full and semi mechanization technology for sugarcane harvesting. Other countries such as Iran, Thailand, Indonesia, Vietnam and other developed countries fabricate successful semi mechanization harvesters except for Egypt no successful cane harvester has been developed so far. Several trails have been done to locally demonstrate imported sugarcane harvesters. The demonstrated machines were not accepted by the local farmers because of poor performance represented in poor cost saving, poor labor saving or poor time saving. Therefore, no advantages of the demonstrated sugarcane harvesters' performance attract the farmers to use them. Other trails to develop and test local designs of sugarcane cutter harvesters through graduate student research programs have not yet been succeeded.

***Index Terms*— Sugarcane mechanization- Cane mechanical harvesting- Types of cane harvester- full mechanization of cane harvesters- Semi mechanization of cane harvesters- Efforts to mechanize cane harvesting in Egypt.**

I. INTRODUCTION

Cane harvesting is the single most costly operation in sugar cane farming. Although more sophisticated self-propelled sugar cane harvesters are in use in developed countries, manual harvesting is still practiced in most of the developing countries. Sugarcane harvesting operation may be accomplished entirely manual, using semi mechanization equipment or full mechanization equipment. Either harvested manually or mechanically, sugarcane may or may not burnet before harvesting. Variable sizes and designs of semi mechanization sugarcane harvesting machinery are available. Full mechanization systems may be whole stalk harvesting system or chopper harvesting system (Meyer et al 2002). Although many issues have been solved in some industries, the move to green cane harvesting and many of the associated economic agricultural practices remain a challenging prospect for many sugar industries. The important issues that have to be addressed are improving harvesting rates and reducing extraneous matter levels of the cane delivered to the factory. In the absence of a quantum leap in hall ester cleaning system

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technologies, secondary cleaning systems are seen as one way to achieve this while minimizing cane loss. There is a need for plant breeders to develop erect, loose leafed or self-trashing varieties to facilitate easier harvesting operations. Further research is required to study the impact that crop residues have on ratoon crops especially under cool or wet conditions as well as alternative post harvest equipment and management systems (Meyer et al 2005). Sugarcane growers and miller are requested that an alternative approach to the current Local Area Agreement be investigated with the purpose of meeting the following primary objectives: 1. To match factory size to cane supply in an agreed length of season. 2.To ensure the proposed mechanism is cost effective, simple and easy to implement. 3. To provide growers with season length controls so that growers unwilling or unable to expand are not prejudiced by a reduced 'relative' recoverable value % cane. Secondary objectives included the following: 1. To provide an incentive for the miller to set realistic crushing targets. *2.* To provide an incentive for growers to align their delivery rate with the mill crush rate incentive for smaller delivery allocations to consolidate and capture size economies Wynne (2007). To address the problem of inadequate synchronization between the harvesting, haulage and milling fronts, a computer based model be developed which would adjust the target tonnages for each of the three functions based on data fed into it on a real time basis. Any deviations from the agreed milling rates due to breakdowns or other factors would be fed into the system, resulting in the adjustment of harvesting and delivery rates. In the same way, any changes in the set harvesting or haulage rates would be fed into the system allowing for timely adjustment in the rate of milling to prevent the mill running out of cane or cane stocks piling up in the supply chain (Chidoma 2007).

To facilitate building a sound background of mechanical sugarcane harvesting, the identification of some terminology should be clear as follow:

Burnet cane: Sugarcane may be burnet to reduce the amount of trash in the cane before delivery to mill. The cane field may be burnet before harvesting or the cane heaps may be burnet before loading to facilitate getting-red of the trash and dry leaves.

Manual sugarcane harvesting: The typical manual sugarcane harvesting system normally consists of manually felling, topping, de-trashing, bundling and loading the canes into the transportation vehicles. This still the normal practice in Egypt and many countries in Asia, Africa, and Latin-America where labor is relatively cheep.

Semi mechanization of sugarcane harvesting: Using simple or cheep machines to accomplish one or more of the harvesting operation requirements while the other requirements done by labors. Therefore, semi-mechanized sugarcane harvesting system includes mix between mechanical and labor operations.

Full mechanization of sugarcane harvesting: The harvesting operation done entirely mechanical and no labor involve the operation except for equipment operators.

Whole stalk sugarcane harvesting: Sugarcane harvesting operation that harvest, handle and deliver the crop in the form of whole stalk regardless with the level of mechanization.

Full mechanization whole stalk sugarcane harvester: The system also called Soldier- Cane-Harvester or (Louisiana type) which was mainly developed and used in Louisiana State in USA.

Chopper harvester (sugarcane combine): Also called combine harvester. Single large machine performs all the functions of sugarcane harvesting. The machine harvest, chop clean and handle the cane in the form of billets.

Variables controlling the economical operation of any sugarcane harvesting system discussed by Meyer (1997) a wide range of factors the growers should consider when contemplating a move away from a manual to a fully mechanized harvesting system. The more important factors must be practical to implement as well as being based on sound economic evaluations and principles. The economic viability of a mechanical cutting aid, a mechanical loader or a fully mechanized harvesting system is dependent on machine hourly output and total tonnage handled. The formation of harvesting syndicates or contracting groups will make the sophisticated and expensive fully mechanized harvesting machinery more viable. If cane growers are serious about partially or fully mechanizing their harvesting operations, special attention will have to be paid to field layout, row spacing and irrigation and drainage designs to ensure the high machinery output and efficiency necessary for acceptable operating costs. There are numerous advantages and disadvantages for both self propelled whole-stalk and combine chopper harvesting systems should be considered before selecting the full mechanization system. Selecting a sugarcane harvesting machine will depend on too many aspects related the particular sugarcane field subjected to mechanical harvesting system as follow:

1- Harvesting time; (in wet weather - in dry weather)
2- Cane varieties; (structure and characteristics of cane crop plants).
3- Agricultural practices; (row spaces, irrigation system, furrow depth, field size, etc.)
4- Different machines to be used; (cane cutters, topper-cutters, soldier-cane harvester “Louisiana type”, chopper cane harvester or entirely manual)
5- Machine operation parameters.(several parameters)
6- Burning alternatives; (before harvesting- burning heaped-green cane harvesting).
7- Prevailing cane to mill delivery system.
8- Economics of mechanical harvesting.

Equipment and experiences

Equipment of full mechanization sugarcane harvesting:

Full mechanization of sugarcane harvesting and delivery may be applied for the entire sugarcane production of Australia, USA and Japan. Countries such as Brazil, Cuba, South Africa, India, China and many other countries apply full mechanization for harvesting large agricultural sectors. The economy of owning and operating any sugarcane harvesting machine determines the existing level of mechanization at certain conditions. Characteristics and performance of harvesters in Okinawa, where mechanization of sugar cane harvesting is well advanced, were reviewed based on the results of past research. There was a trend for the greater the engine power of the harvester, the higher the working efficiency, and the trash ratio and harvesting loss were lower. It turned out that large- and middle- sized wheel-type harvesters did not perform well in rain, while small crawler-type harvesters were often more operational regardless of rain. The field was most affected by soil compaction when the row width was narrower and the harvester operation speed was lower. It is expected that small harvesters will not only be introduced in areas unsuitable for middle and large sized harvesters, but also play a complementary role in areas where large- and middle-sized harvesters are already in use (Akachi 2007). The recommendations of the ISSCT workshop about mechanical harvesting were concluded by Norris et al (2007). From the presentations at the workshop and observations at both the workshop and post workshop tours, it could be gleaned that:

a) There is an increasing rate of adoption of green cane harvesting throughout almost
all industries which have traditionally pre-harvest burn. While machinery developments have had a positive impact, changes in attitude towards green cane harvesting has been the primary driver. Importance of harvesting the crop green is becoming a bigger issue as we move toward a biomass crop.

b) There is a need for effective systems to manage sugarcane in a sustainable way
(environmentally and economically). Mechanization is the hub of the wheel with agronomy, processing, etc. as the spokes of the wheel. The question then remains as to how this subject matter fits into an interdisciplinary program.

From the point of view of the sugar factory manager, the ideal input is fresh, clean undamaged whole-stalk cane. When manual cane cutters are working to reasonable standards, hand-cut, hand-loaded cane comes closest to this ideal. Any degree of mechanization inevitably introduces more extraneous matter and a greater risk of cane damage. It also requires a higher standard of organization. In most countries, the successful introduction of mechanization has been a gradual process, usually beginning with mechanical loading. Experience has shown that to leap ahead to the use of chopper harvesters with no intermediate steps, involves the risk of costly failure and abandoned machines. Such a gradual process is most easily achieved by following the introduction of mechanical loading with a simple tractor-based cane cutter, retaining the same whole-stalk loading and transport system. The logical follow-up from this is a whole-stalk harvester as the same transport and factory cane storage system can continue in use, with consequent saving on capital outlay (Abdel-mawla 2000). Organizational requirements are less demanding with whole-stalk cane, because of simple buffer storage in both field and factory, as well as a much lower rate of deterioration of the cane.

I- Self propelled whole stalk harvester: The self propelled whole-stalk sugarcane harvester (Fig 1) as a machine for full mechanization of sugarcane harvesting should perform the following functions in sequence.

6- Positioning and handle the cane in respect to functional mechanisms

2- Cut the base of cane stalk.

3- Cut the green top of the cane stalk.

4- Clean cane stalks from dry leaves (de-trashing).

5- Place cane stalk in a suitable manner for further operations.

6- Or convey cane harvested from several furrows and place them together to form a windrow.

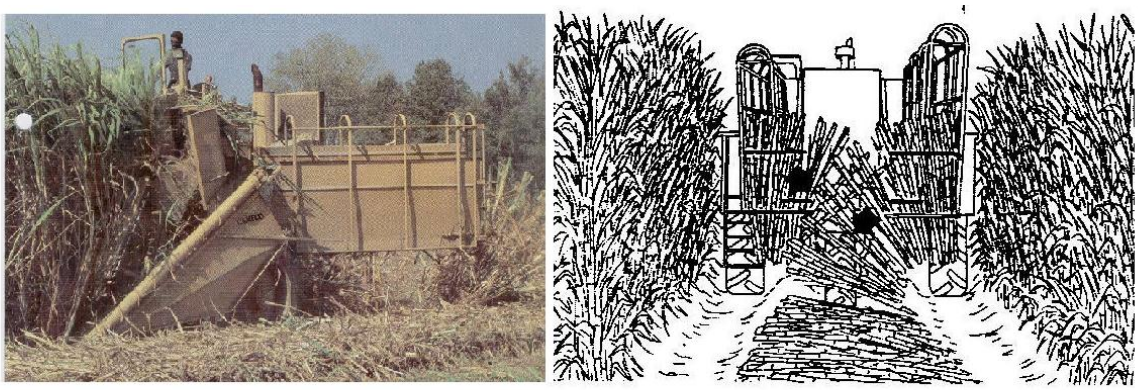


Fig (1) Self propelled whole stalk sugarcane harvester (Louisiana type)

Scott (1988) reported that the reason for the present domination of the harvester market by choppers is that the only whole-stalk harvesters of equivalent output are based on the Louisiana system. These machines cut cane green and remove the tops, but make no other attempt at cleaning. So burning is required, after cutting. They are also not as tolerant of recumbent cane and adverse field conditions as choppers have become, even though their performance in the right conditions is superb. Market attitudes will undoubtedly change when whole-stalk machines become available, equipped with internal cleaning systems and exhibiting performance and versatility comparable with choppers. Loading methods must also be offered to give matching output. The necessary elements of a whole-stalk harvester are:

1- Dividers to gather the cane in the row being cut, and to separate it from cane in adjoining rows.

2- Base-cutters to sever the cane at ground level.

3- A feeding device to take the cane from the base-cutters, and convey it through the machine.

4- A cleaning device to remove and discard trash and tops.

5- A bin to accumulate cane, and discharge it in neat piles, far enough from the cane face to allow passage of the machine on its next pass, and onto ground which has been cleared of trash. Huang and Wei (1989) reported the development of whole stalk harvester in China. A 67kW machine has been designed to harvest green cane yielding about 80 ton/ha. The power requirements are much lower than those required for chopper harvester thereby saving harvest costs. The first machine was developed at 1981 as a cane cutter; the tractor controls were reversed with the base cutter mounted on the 3-point linkage. The beaters covered with rubber were attached to the shaft of the base cutter in order to strike the whole-stalk cane to left side of the machine to form a windrow. In practice the wheel of the machine rolled over some of the buts, thus damaging the cane. In 1985 the machine was redesigned to reassemble a reasonable a Solder-type-Harvester has proved to be feasible for harvesting green cane yielding about 80 t/ha. The author concluded that the whole stalk sugarcane harvester operated efficiently in erect and semi erect cane. The pillars mounted on both sides of the machine saved field time losses. The engine power of only 67 kW was adequate and is much lower than that of chopper operating in similar conditions thereby reducing harvest losses. An effective field capacity of 23 t/h has been achieved in green cane with a yield of 80 t/ha in the past three harvesting season.

Advantages and disadvantages of whole-stalk harvester reported by Hudson (74) and Shukla (81) as follow:

Whole stalk harvesters/cutters: Advantages:
- Generally, whole stalk harvesting machinery is cheaper to purchase.
- Whole cane sticks deteriorate more slowly than chopped cane and can be stockpiled for considerably longer at trans-loading sites or in mill yards.
- Where field and crop conditions are suitable whole stalk harvesting systems will result in less cane loss and better quality cane compared with chopper harvesting. However, in badly lodged cane the situation could be reversed.
- Because the cutting and loading operations are conducted separately, there is more flexibility when breakdowns occur.
- In most instances whole stalk cutters are fairly simple machines that are easy to operate and require relatively unsophisticated maintenance staff and facilities.
- In South Africa, these harvesting systems permit the continued use of whole-stalk loading, mill receiving equipment, vehicles and facilities.

Whole stalk harvesters/cutters: Disadvantages:
- Whole-stalk harvesters are not always able to handle the crop. Lodged and recumbent crops present extreme difficulties for this type of machine, as do yields in excess of 120 t/ha.
- Separate infield loading equipment is required.
- Mechanical loading of whole stalk could increase soil content in the cane sample.
- Some whole stick machines (soldier harvesters) have a high centre of gravity, making them unsuitable where slopes exceed10%. Most other whole stalk machines cannot operate on slopes greater than 15-20%.
- Transport load densities are lower for whole stalk than for chopped cane.

II- Chopper harvester (sugarcane combine): Chopper harvester (sugarcane combine Fig (2) is the most capable single machine that performs all the operations needed for sugarcane harvesting in one pass. In the chopper harvester should be capable to perform the following sequence of functions:

1- Gather and feed the cane toward the functional mechanisms

2- Cut the base of cane stalk.

3- Cut the green top of the cane stalk.

4- Feed cane stalks inside the machine.

5- Chop cane stalks into billets.

6- Blow out green tops and dry leaves.

7- Elevate chopped cane up to be loaded on a vehicle.

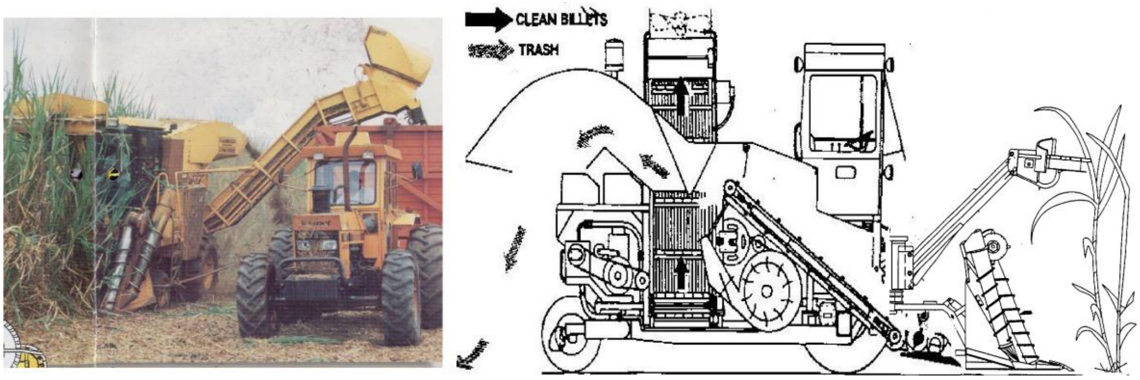


Fig (2) Chopper harvester (sugarcane combine)

However chopper harvester facilitates more convenient handling of the cane. Another advantage of the chopper harvester is its ability to gather and harvest sprawled and lodged crops. Field performance of chopper harvesters was also reported by several researchers such as Tambosco et al (1978) and Neto et al (1989). The most effective criteria were identified of the performance of chopper harvesting in green and burnet cane mostly tested for: 1- Effective speed (km/h). 2- Effective field capacity, (t/h). 3- Cane quality (purity % juice, poll % cane, fiber % cane). 4- Cane losses (stalks, fraction of stalks in the tops and fraction of stalks in the stubble). 5- Crop residues in the field after harvesting (green leaves, tops, dry leaves). Chopper harvester facilitates more convenient handling of the cane. Another advantage of the chopper harvester is its ability to gather and harvest sprawled and lodged crops. In this respect, it has a clear advantage over the whole-stalk harvester, which is severely limited to in sprawled cane. The gathering mechanisms have been improved over the years to the extent that heavy, sprawled crops lying flat on the ground across the ridges can be gathered.

In Australia where chopper-harvester were used extensively, as a consequence of these improvement, cane variety with good yields but with a tendency to sprawl can be grown and farmers use more fertilizer without fearing for difficulties in mechanically harvesting heavy crops. The principles of handling basic materials favor cane chopper harvesters which make transportation easier and results in a better utilization of transport. Cane-chopping harvesters eliminate cane lifters, required when using the whole-stalk harvesting system, and permit high cleaning standards, especially in the removal of soil.

Advantages and disadvantages of chopper harvesters may be listed as follow:

Chopper harvesters: Advantages:
- Chopper harvesters are complete combines and do not require separate infield loading equipment.
- Modern combine harvesters are able to handle both green and burnt cane in a wide range of weather and crop conditions, from erect to badly lodged cane.
- In pollution sensitive areas choppers harvesters have a distinct advantages because of their ability of handling green cane.
- The delay between harvest and crushing is minimal, resulting in higher sugar recoveries.
- Chopped cane feeds into the mill more easily and consistently.
- Chopped cane spillage en route to mills is usually lower than whole stalk.
- Labor requirement is reduced.

Chopper harvesters: Disadvantages:
- The high capital outlay makes this system appropriate only for large scale growers and contracting groups.
- Harvesting, transport and milling operations are linked, which means that communication and transport scheduling is vital to obtain optimum harvester utilization.
- Receiving facilities at mills that usually handle whole stalks would have to be adapted.
- Cane losses are generally higher compared with whole stick harvesting systems.
- Chopped cane deteriorates more quickly than whole stalks and ideally should be crushed within 12-14 hours after harvesting. This may increase transport costs.
- High levels of managerial/operator skill and technical support are required.

Equipment of semi mechanization sugarcane harvesting:

Equipment of semi mechanization of sugarcane harvesters are all whole stalk harvesting machinery. Sugarcane cutters may be tractor attached, ridden or walkman steering machine. Cutting the base of cane stalks is the primary function for any of the mechanical sugarcane harvesters. A semi mechanization harvester may include one or more function such as topping and/or cleaning in addition to stalk base cutting function.

I - McConnel sugarcane harvester of Barbados:

McConnell harvester system was basically designed for Barbados conditions, tested and reported by several investigators such as Alison (1974), Hudson (1978), (Anon 1978) and Blackburn(1984). The system consists of two machines, the first is a tractor front mounted harvester topper and the second is a tractor-trailed detracher and elevation. Fig (3) show the first stages of McConnel sugarcane harvesting systems.

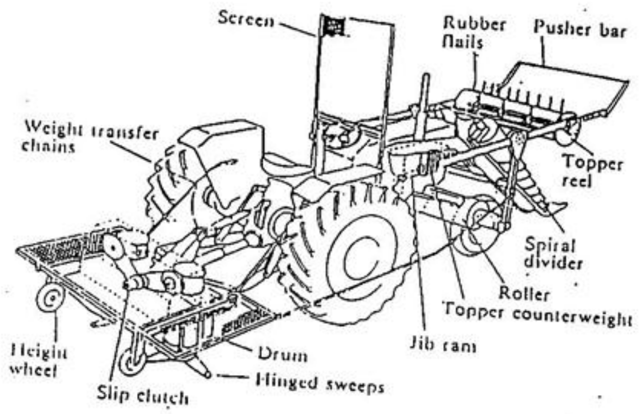


Fig (3) First stage McConnel harvester

The l-row McConnel harvester mounted on a standard 75 hp agricultural tractor worked in a wide range of field conditions during the 1973 harvest in Puerto Rico. No mechanical problems were encountered with the flail topper-cleaner nor with the base-cutter. The mechanical problems encountered concerned the prime mover and included engine cooling, air cleaner, hydraulics, and PTO power transmission which can easily be solved by fabricating a prime mover to fit the field conditions and harvesting components. The l-row harvester worked at the rate of 20 to 30 tons of cane per hour. By increasing the size from I-row to 2-rows and the tread width from 1,5 m to 3,0 m, production output should be in the order of 50 to 70 tons per hour. The increased tread width should permit the harvester to be utilized on steeper slopes than the l-row machine. Also the 2-row first stage machine will match the 2-row chopper-cleaner-loader of the second stage. The two-row prototype harvester was developed for row spacing of 1.1- 1.5 m had a crop lifter with spirals to guide the cane. The two flipper rollers mounted vertically between the base cutters, and a combing rolls and feed through scuff rollers. The performance of the system in gathering and cleaning cane may be described as follow:

Gathering: Cane is gathered into the machine by ground-following hinged sweeps. The gathering unit is actually a simple adaptation of the base 'cutter" of the Stage I machine. Gathering tops-first greatly facilitates this operation and a slow rotation is sufficient (about 80 rpm). Rocks are pushed sideways from the 1.2 m wide throat because they cannot climb the ramp up which the cane is passed.

Cleaning: The cleaning mechanism exploits the fact that leaves are flexible whereas cane is rigid. Each "hurler" drum is formed of three treaded rubber pads which accelerate the canes rapidly from the conveyor. Leaf material tends to wrap around these drums and as the cane is projected rearwards this leaf material, trailing to each side is knocked off by the counter-rotating cleaning drums above and below. The movement of leaves attached to the "coot" is sufficient to break it from the cane and eject it from the machine. (Thus, in both the Stage I and Stage II machines topping exploits the same naturally weak point in the immature inter-nodes) .The cleaning drums consist of four metal paddles rotating at about 3 times the speed of the hurlers. They also move a certain amount of air and have been called "fans" but an investigation into the importance of this air movement was not concluded at the time of writing. The idea of handling cane in-line by rubber- covered drums is not new, but the method of cleaning is, we believe, novel and has been patented. Several hundreds of analyses during trials in Barbados (1975, 76) and in Natal (1976) indicate that total extraneous matter levels for green whole-stick cane, cut, cleaned and loaded by the new system, is usually less than 10% and many samples were below 5% .Cane variety and yield are the main variables.

Advantages of this system are as follow:

1-The various devices are fitted onto ordinary wheel tractors which, when not required for reaping, are free to be used for other purposes. Thus the capital cost is lower than that for many other mechanical harvesting systems.

2-Stones and rock do not affect the performance of the machine, there are no cutting blades.

3- The harvesters can operate on any slope that can be negotiated by a tractor.

4- Extraneous matter is usually less than 10 percent and often less than 5 percent.

5-The output of the machines under Barbadian conditions are Stage I Green Cane, up to 40 tons per hour.

The cleaning components separate 75 to 85% of the extraneous material from the cane stalk without materially damaging the cane (cane cut with this method has been successfully used for seed); thus reducing the extraneous material left on the stalk to the 4 to 6%level. The flail topper-cleaner requires time to clean and top the cane. Topping and stripping of leaves achieved by rubber flails rotating vertically at relatively slow speed. The slow tip speed of the flail is essential in preventing damage to the malleable portion of the cane. Thus, to achieve effective cleaning the forward speed of the stage I harvester is limited to between 0.5 and 3.2 km/h. The flail cleaner is complemented with the slow speed floating base-cutter that follows the contour of the soil surface and completes the snapping of the cane at or just below the soil surface. One of the limitations of this base-cutter is that the stool must be held firmly by the soil and the bud of the seed piece must be well below the soil surface to prevent uprooting of the stool. Also, varieties that are brittle and break and shatter easily are unsuitable for this type of base-cutter. However, these limitations usually adversely affect other types of base-cutters as well. Since the shear blades are floating, the operator needs no control of cutting depth.

II. SASABY SUGARCANE HARVESTER OF SOUTH AFRICA:

SASABY developed in South Africa for green cane harvesting. Boast (1985), Meyer (2002) and Meyer (2005) In South Africa, the SASABY harvester has proved to be a very useful tool in the improvement of mechanical harvesting sites and harvester performance. Mechanical harvesting under experimental conditions does not affect cane yield. It is expected that sugarcane will be manually harvested in the short to medium term in the South African sugarcane industry. The current apparent shortage or unwillingness of labor to harvest sugarcane can be ascribed to several reasons. While high capacity sugarcane harvesters are commercially available from overseas, these are expensive to operate and in many instances not suited to large areas of South Africa. It is therefore vital that alternative sugarcane harvesting aids be developed to improve manual cutter productivity. On the other hand sugarcane growers should ensure that infield conditions and their field layouts are such that these are more acceptable to using harvesting machinery than is currently the case. One of the major challenges facing the South African sugarcane industry is that of moving to green cane harvesting regime. Green sugarcane cane harvesting presents the opportunity to develop new technologies and make significant advances in productivity and profitability while at the same time ensuring soil sustainability and protecting the environment. The cane harvester that Fig (4) can handle up to 25 tons per hour was developed in South Africa. These made the initial trials with a test rig to prove the principle of "in-machine topping and cleaning". And finally the construction and testing of a prototype harvester named SASABY(Fig 5).

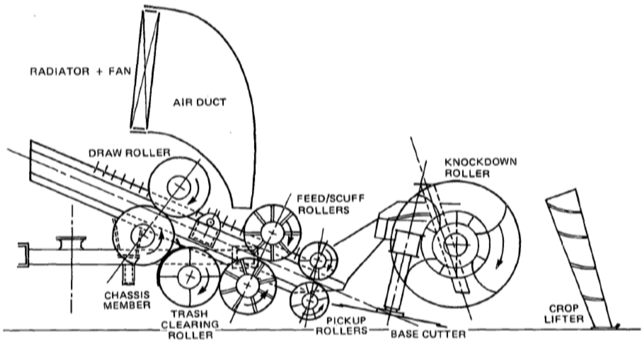


Fig (4) Schematic of the South African SASABY sugarcane harvester

III. OTHER TRACTOR MOUNTED SUGARCANE HARVESTERS:

Tractor attached sugar cane harvester cutters may be front mounted, midway mounted or rear mounted machines as reported by Meyer and Worlock (1984). The authors highlighted the most important demands have to be satisfied in sugarcane cutter are:

a- Able to cut unburned cane of up to 100 tons per hectare.

b- Tolerant of rough- and-ready field preparation, able to cut from furrows, ridges, tied-furrows or flat-planting.

c- Able to work in stony conditions.

d- Tolerant of variable row spacing and of wide Raton stools.

e- Able to negotiate difficult headlands, in-field ditches.

The importance of fabricating cheep efficient sugarcane harvester that can perform economically under the conditions of developing countries discussed dy several researchers such as Hudson 1974, Beer 1980 and Srinivas **et al (2013).** Starting from the conventional system of cutting and stacking manually, a grower cane mechanize by degrees, initially incorporating only a mechanical cutter. The main problems to be overcome with a green cane harvesting system related to vision, especially setting and seeing obstacles in the path of the base-cutter; row-following in lodged cane. If the machine contains topping and gathering mechanisms, base cutter, etc., it may be too expensive in relation to the throughput permitted by this cleaning mechanism. Lubis (2014) reported that the South African made sugarcane harvester VICRO (Fig 5) equipped with full-hydraulic drive. It can continuously and automatically complete the whole harvesting process of picking up fallen cane, topping, cutting, transmitting, truncating, separating cane and top, loading with truck elevate. The purpose of the sugar Cane Harvester is to be able to harvest and top burnt sugar cane as well as un-burnt sugar cane. The sugar cane harvester is attached to any tractor by means of the two point tractor linkage. The sugar cane cutter was designed and built in South Africa. The cane cutting machines are easily disassembled and shipped to any country in the world.

Fig (5) VICRO South African made sugarcane harvester

Boast (1989) reported that a front mounted base-cutter has been developed for standard agricultural tractors of the 50 kW class. The base cutter is driven hydraulically from a pump coupled to the front crankshaft pulley or to the rear PTO shaft, depending on the tractor model. The tractor's internal hydraulic oil supply is used but is augmented by an additional 50 liters in an external oil tank. Alternatively all oil can be supplied from a tank mounted on the 3-point linkage of the tractor. The base-cutter operates automatically once it has been lowered to the land surface. Automatic ground following is effected by means of an intensifying pressure cylinder which controls base cutting height according to the resistance to culling. This allows the tractor operator to devote his attention to driving and makes cane culling a simple task. Without automatic height control a base-cutter mounted ahead of the front wheels of the tractor would result in unacceptable base culling. One of the advantages of this implement is that, when locked in the raised position, it fits neatly onto the front of the tractor, making the tractor available for any other task on the farm. The best quality of base cutting it was found to be desirable to have the blade just contact with the ground. It is evident that system pressures change constantly during the cutting operation, hence a range of conditions has to be accepted if the automatic height control unit is to be used. Figure (6) and Figure (7) show two types of the whole stalk linear windrower.

Figure (6) Front mounted whole-stalk topper linear windrower

Fig (7) Front mounted sugarcane whole-stalk harvester linear windrower

Abdel-Mawla et al (1997) reported a tractor midway attached sugarcane harvester tested in the sugarcane farm of Malawy Research station during the harvesting season of 1995. The machine is an Australian made Bonnel type windrower topper sugarcane harvester (Fig 8). The machine included mechanisms for cane stalk base cutting, topping and windrowing. The performance of the machine showed poor compatibility with the existing agricultural practices such as inter-row spaces. The operation of the machine is also restricted to the erect cane.

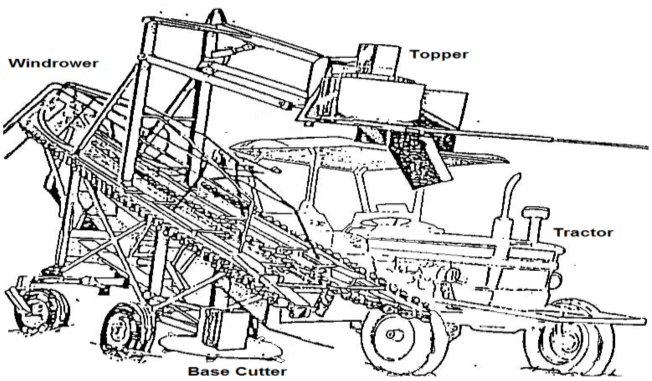


Fig (8) Australian midway mounted sugarcane harvester windrower

Sharma and Singh (1980) as well as **Yadava (1991)** reported the IISR tractor rear mounted cane cutter developed in India. An isometric of the IISR illustrated in (Figure 9). The IISR tractor rear-mounted sugarcane harvester serves the purpose of stalk base cutting of single row of sugarcane stalk and windrowing the harvesting crop. The machine represents a mechanical harvester option for small sugarcane farms in India.

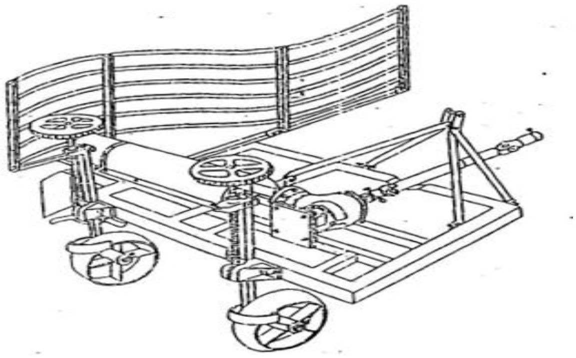


Fig. (9) IISR tractor rear mounted Indian sugarcane harvester

IV. Ridden and walking-man steering sugarcane cutters

Ridden type sugarcane harvesters (Fig 10) have been fabricated in Japan and other Asian countries. Yinggang et al (2013) reported the small size whole stalk harvester, mounted on hand tractor (11-14 kW) manufactured by Guangxi Wuling-Guihua Machinery Manufacture Company (Fig 10). The machine type is 4GZ-9 whole stalk harvester, mounted on 11-14.7 kW hand tractor, which was developed in 2002 by Guangxi Institute of Agricultural Machinery. The sugarcane stalks are laid down on the ground beside the machine after cutting. It can be used when the sugarcane is not seriously lodged. Its productivity is 0.1-0.15 ha/h, and it is adapted to row spacing ≥1.0 m.

Fig (10) Ridden type sugarcane harvester tested in Mataana RS 2010

Kiatiwait et al (1992) developed a selph-propelled walking type sugarcane harvester-windrower in Thailand. The machine (Fig 11) is a one row single-axle walking-behind-type. It works on the principle of impact cutting by knife blades. As the machine moves forward along the row, the cluster of cane stalks is guided from the divider by a two sets of lugged chains and a spring loaded guide frame. At the narrowest point of guided path, the canes are cut by blades of the base cutter, revolving at peripheral speed approximately 42 m/s. A pair of solid rubber-gage tractor wheels mounted in the front part of the machine prevents the base cutter blade from striking the ground and control the height of cut. The tread width can be changed by shifting a lock-pin along the shaft to make adjustment for various spacing along the adjacent rows.

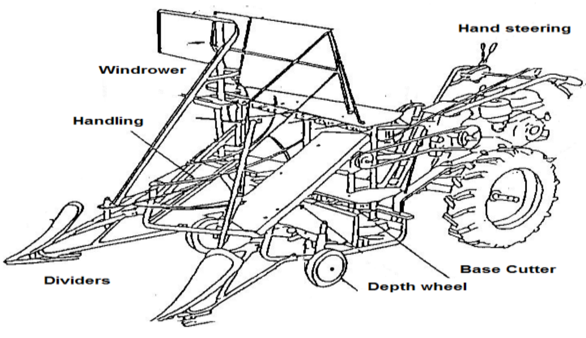


Fig (11) Walking-behind-type cane harvester windrower

Gupta and Kiatiwat (1996) A new low-cost, self-propelled, single-axle walking-type sugarcane harvester (Fig. 12) powered by 6-kW (8-hp) gasoline engine. It was primarily designed for farmers of developing countries who cannot afford to purchase expensive sugarcane harvesters used in developed countries. This machine reduced labor requirements for cutting and windrowing sugarcane stems. In field tests, the average field capacity of the machine was found to be 0.13 ha/h (0.32 acre/h) with average field efficiency of 71%. Figure (12) show two types of the walking man hand steering sugarcane harvester.

Fig (12) Walking type sugarcane harvesters in operation

Lyne et al (2007) stated that labor for cutting sugarcane is becoming a constraint because of a rising standard of living, labor aspirations and the fact that manual cutting is classified as hard work. In addition, manual harvesting in South Africa is often favoured because of the high cost of mechanical harvesters and steep slopes. To deal with this, a brush-cutter with a redesigned blade configuration, called the Illovo mechanical cane cutter, was developed and various performance parameters were measured in field trials. The cutter efficiency, blade durability, performance standards, ergonomics and economics were measured and analyzed. These were carried out during field tests where the system was introduced to a commercial farming operation and operated in parallel with the conventional system. A work study was carried out to collect performance data, and an ergonomic study was carried out on both the mechanical and conventional system. The tests highlighted some problems and, with further development, these were dealt with and the system is now a functional cutting system. The system offers a viable alternative to the conventional method of manually cutting sugarcane. The brush cutter is shown in Figure (13).

Fig. (13) Illovo brush type cutter with steel knife tested for harvesting sugarcane.

V. Discussion of Sugarcane Mechanical Harvesting Efforts in Egypt:

I- Demonstrations of imported sugarcane harvesters:

Several types of mechanical sugarcane harvesters have been imported and tested. The most recognized demonstrations reported by Nour and Allam (1980) Zawahry and Youns (1986) Abdel Mawla et al (1997). These repots mainly discussed efficiency and feasibility of sugarcane harvesting in Egypt. The data of Table (1) collected from non-published reports of the sugarcane mechanization research program supervised by the author. The demonstration of the mechanical sugarcane harvesters have been sponsored by Agricultural Engineering Research Institute (AEnRI), Sugar Crops Counsel and the Sugar and Integrated Industry Company. The following notes may conclude the results of the data collected while demonstrating the imported sugarcane harvesters:

- The chopper harvester is incompatible with the sugarcane transport system. The machine is also incompatible with the existing agricultural practices concerning inter-row spaces, infield irrigation channels and transverse ridges necessary to control irrigation water. Either at the time of demonstration or currently, the cane delivery system is not ready to use chopper harvesters.
- Sugarcane harvesters that contain a mechanism for topping reduce the advantage of utilizing green tops of cane to be used as cattle feed. The major percent of the farmers need the green tops for feeding their cattle. Therefore, mechanical topping is not desired function for most of the Egyptian sugarcane farmers.
- The machines that include a windrowing mechanism always windrow to the right side of the machine. Therefore the machine has to be operated in one direction only and

travel back empty or the farmer has to manually harvest a strip around the field which is difficult.

- The mechanical windrowing of the harvested cane may not save any labor power or cost because the farmers has to pick the cane again top it, clean it and arrange it in thick piles.

- The small sugarcane cutters performs just base cutting are of low field capacity of and need more than one labor that may not save considerable labor power or effort. The data of the reports show that the sugarcane mechanical harvester may not save costs compared to traditional harvesting.

Table (1) Mechanical harvesters tested in sugarcane production areas so far.

Season	Harvester & test data	Summary results	Technical notes
1984	*Type:* Bonnel Australia made *Drive:* Tractor mounted *Function:* Base cuter, topper & windrower *Test location:* Mallawy RS *Ref. Figure:* Fig (8) *Tested by:* Naway project team 1984	*Losses %:* 4.5 % *Damage %:* 2.5 % *Capacity:* 0.2 Fed/h *Efficiency:* 70% *Labor saved:* 30 % *Cost saved:* Negative	- The machine is heavy, expensive and of poor maneuverability. - The machine is incompatible with agricultural practices. - The farmer has to re-clean the harvested cane. - The machine cannot be operated to harvest lodged cane.
1986	*Type:* KPT1 Cuba made *Drive:* Self propelled chopper *Function:* Full mechanization *Test location:* Mataana RS *Ref. Figure:* Similar to Fig (2) *Tested by:* Zawahry & Youns 1986	*Losses %:* 6 % *Damage %:* 3 % *Capacity:* 0.7 Fed/h *Efficiency:* 0.80 % *Labor saved:* 90 % *Cost saved:* Negative*	- The machine chopper harvester (sugarcane combine) that is a very expensive machine. - The machine is incompatible with the cane transport system. - The performance of the machine was poor because the incompatibility with all existing agricultural practices.
1995	*Type:* South Africa made *Drive:* Tractor front mounted *Function*: Base cutter *Test location*: Mallawy RS *Ref. Figure*: Similar to Fig (6) without the topper *Tested by*: Abdel-Mawla & Ammary 1986	*Losses %:* 2.5% *Damage %:* 3 % *Capacity:* 0.25 Fed/h *Efficiency:* 85 % *Labor saved:* 20% *Cost saved:* Negative*	- The machine is a base cutter place the cane linearly to pass between tractor wheels. - The machine can only be operated in erect cane. - The machine is expensive powered by auxiliary hydraulic power system that is driven by the tractor PTO.
2007	*Type:* Brazil made *Drive:* Small power unit *Function:* Base cutter *Test location:* Armant *Ref. Figure:* Similar to Fig (12) *Tested by:* Ammary & Sugar Company team 2007	*Losses %:* 3 % *Damage %:* 3 % Capacity: 0.2 Fed/h *Efficiency:* 75 % *Labor saved:* 0.0 % *Cost saved:* Negative	- The machine is a base cutter with no parts for directing the fall of cut stalk so that two labors have to hold the cane before harvesting. - The machine does not save either labor or cost.
2010	*Type:* Chinese made *Drive:* Small power unit *Function:* Cutter windrower *Test location:* Mataana RS *Ref. Figure:* Fig (10) *Tested by:* Abdel-Mawla & Sugar Company team 2010	*Losses %:* 2 % *Damage %:* 2 % *Capacity:* 0.25 Fed/h *Efficiency:* 70 % *Labor saved:* 20 % *Cost saved:* Negative	- The machine does not have capabilities to top or clean the cane. - The farmer has to pick the cane from the windrow top it, clean it and pile it in a suitable size bundles. - The windrowing mechanism that complicate the machine did not save any cost or effort.

*Negative: The cost of harvesting a unit area of sugarcane using the machine is more than the cost of manual harvesting.

VI. PROTOTYPES DEVELOPED THROUGH GRADUATE STUDENTS PROGRAMS:

Three prototypes of sugarcane cutter harvesters have been developed through graduate students programs. The sugarcane cutters either tractor mounted or powered by a small engine classified as small whole-stalk harvesters. Therefore the operation of such machines should be limited to erect crop because it is very well known that whole stalk harvesters may not perform efficiently in lodged cane crop. The performance of these prototypes in harvesting the erect sugarcane crop only presented in Table (2). The most important remarks concerning the experiments done to test these machines may be:

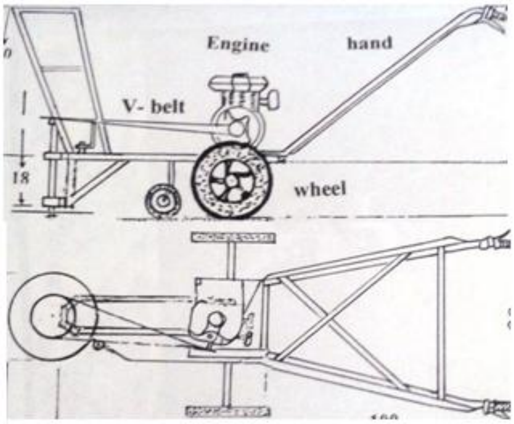
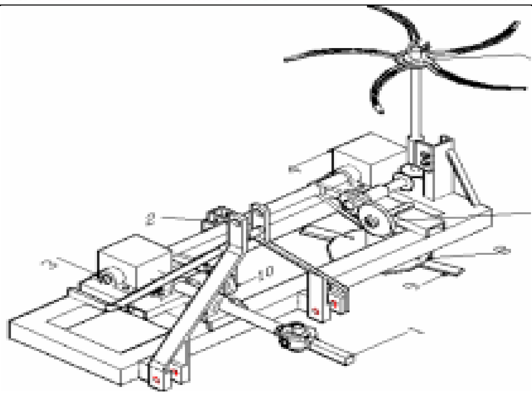
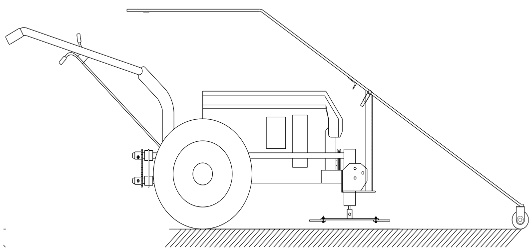
1- The first sugarcane cutter prototype locally developed and tested during 2002 harvesting season (the configuration of the machine shown in Table 2). The machine is the most simple small cane cutter consists of a frame on which a small engine that drive the base cutter by the mean of pulley and V shaped belt is fixed. Two towed wheels carrying the machine frame. A labor pushes the machine to move forward while operation because no mechanical power transformed to drive the machine wheels. It was very clear during the test that the labor power is not sufficient because of high resistance due to soil roughness. The labor exhausted after short time and the machine advancing toward the cane hill become very slowly.

Other labor has to hold the cane while cutting similar to the action shown in Fig (12) so that the rate of the machine may not be more than that of manual harvesting.

2- The tractor rear-mounted sugarcane harvester prototype developed and tested 2011 included a star-wheel that push the cut cane stalks to fall behind the machine. The star-wheel may represent a simple windrower or handling mechanism. Major problems faced the operation of the machine may represented in poor control of cutting height, poor performance in lodged cane and failure of the star wheel to direct the cane stalks behind the machine unless the cane stalk is erect or lodged toward the falling direction. The farmers' has also to manually harvest a strip around the field because the machine frame expanded to the left side of the tractor and could not be changed. Excessive losses may be occurred in case of harvesting a lodged part of the cane row. A configuration of the machine is tabulated in Table (2).

3- The small sugarcane cutter fabricated by mounting the base cutter on the front of a small power unit as illustrated in Table (2). The machine is provided with a divider to separate the cut cane row and to help for determining the falling orientation. The divider could be adjustable toward the right or left sides. While experiments, it was clear that the distance of the power wheel is not matching row spaces. The machine divider was supposed to perform moderate except for some problems related to poor fabrication quality. The operation in lodged cane represented a problem and the machine rate was also small that did not significantly save labor effort or costs.

Table (2) Prototypes of cane cutters developed through graduate students' programs

<table>
<tr><th>Year</th><th colspan="2">Information & prototype performance</th><th>Prototype configuration</th></tr>
<tr><td rowspan="2">2002</td><td colspan="2">Student name: Sayed B. M. Refai
Degree: MsC
Title: A study on mechanization of sugarcane harvesting.
Institution: Al-Azhar University
Machine type: Walking man pushing
Machine function: Base cutter + diflector
Powered by: Small Engine (6 hp)
Test location: Al-Oksor
Average performance in erect cane:</td><td rowspan="2">
</td></tr>
<tr><td>Losses %: 3 %
Damage %: 2%
F. capacity: 0.07 Fd/h</td><td>F. efficiency: 65%
Labor save: null
Cost save: null</td></tr>
<tr><td rowspan="2">2011</td><td colspan="2">Student name: Mahmoud H. Ali
Degree: PhD
Title: Development of a single row harvester for sugar-cane
Institution: Al-Azhar University
Machine type: Tractor rear mounted
Machine function: B. cutter + star-wheel
Powered by: Tractor PTO
Test location: Shandaweel RS
Average performance in erect cane:</td><td rowspan="2"></td></tr>
<tr><td>Losses %: 4 %
Damage %: 3%
F. capacity: 0.12 Fd/h</td><td>F. efficiency: 70 %
Labor save: 20 %
Cost save: null</td></tr>
<tr><td rowspan="2">2014</td><td colspan="2">Student name: Mohammed I. M. Ahmed
Degree: PhD
Title: Developing a sugar cane harvester according to the physical properties and field condition
Institution: Assiut University
Machine type: Walking-man cane cutter
Machine function: B. cutter + divider
Powered by: Small single axle tractor (14 hp)
Test location: Mallawy RS
Average performance in erect cane:</td><td rowspan="2"></td></tr>
<tr><td>Losses %: 3.5 %
Damage %: 2.5 %
F. capacity: 0.08 Fd/h</td><td>F. efficiency: 60 %
Labor save: 10%
Cost save: null</td></tr>
</table>

VII. Conclusion:

Sugarcane mechanical harvesting systems may be fully mechanized or semi mechanized systems. In the full mechanization systems, the mechanisms of the sugarcane harvester perform a set of functions in sequence to complete harvesting operation. Full mechanization systems of sugarcane harvesting may either be self propelled whole-stalk harvesters or the chopper harvesters. Semi mechanization technology represented in the tractor mounted and small cane harvesters perform one or more of the functions done by the full mechanization harvester. Variable types of tractor mounted as well as small sugarcane cutters have been developed for the conditions of developing countries.

Several types of sugarcane mechanical harvesters have been locally demonstrated for farmers' acceptance. Most of the demonstrated harvesters cut the bases of cane stalks and leave them lying on the ground. The farmer has to pick the cane stalks, top it, clean dry leaves and arrange it in a pile suitable for loading. Therefore, the farmers determine that the use of cane cutters do not save cost or effort. The attempts of developing a local cane harvester limited to graduate students research with no chance for field demonstration. It seems like all the countries producing sugarcane have developed successful cane harvester for their local conditions except for Egypt. A national research program sponsored by the concerning organizations should be started to develop a sugarcane mechanical harvester suitable for crop conditions as well as Egyptian farmers' socioeconomically constrains.

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