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# SUGARCANE AND STRAW HARVESTING FOR ETHANOL PRODUCTION

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## INTRODUCTION

Brazil is currently confronted with the perspective of significant increase on ethanol fuel demand. This forecast is based on three main points: i) the success of flexible-fuel vehicles that can run on any proportion of gasoline (E20-E25 blend) and hydrous ethanol (E100), together with the mandatory E25 blend throughout the country which allowed ethanol fuel consumption to achieve more than 50% market share of the gasoline-powered fleet; ii) Brazilian exports of ethanol (the world's largest exporter) as function of the growing worldwide interest for blending ethanol-gasoline For example, in 2008 Brazil exported 4.85 billion liters, representing 18% of the production, and almost 50% of the global exports; iii) Brazilian option for biodiesel production using ethanol in the transesterification of vegetable oils.

A detailed analysis of the Brazilian ethanol production potential carried out by the Interdisciplinary Center for Energy Planning-NIPE, UNICAMP, shows that Brazil can produce 102 billion liters by 2025 to meet 5% of the projected world gasoline demand if an aggressive research agenda is conducted (CERQUEIRA LEITE *et al.*, 2009). This important production expansion can become a reality through the implementation of new plants, opening new sugarcane areas, but will demand, in parallel, a concentrated effort to increase overall productivity e.g. liters of ethanol/ha/year of planted sugarcane. This increase can be achieved primarily through two technological routes. The first route is by improvements in the agricultural phase e.g. introduction of new sugarcane varieties, through the intensification of the current genetic research programs, to increase overall productivity in tons of sugarcane/ha/year. The second route should focus on industrial technologies to allow the integral use of sugar ethanol production, or other renewable fuels e.g. through the development of the biorefinery concept which can add value to whole sugarcane chain by developing new products.

In a new paradigm of "energy cane" sugarcane would be collected (by optimization of the whole harvesting process), optimizing also the energy balance to increase the amount of the overall volume of biomass. In this context, billet sugarcane harvesting, now available, which does not use straw which is burned or left on the soil, depending on the harvesting system, would have to be replaced. One of the principal challenges to make possible the use of this material is the development of an automated harvesting system that contemplates the recovery of straw, at least partially, with acceptable cost and quality of this material as an energy source.

Processes tested up to now for straw recovery involve natural drying, followed by windrowing, baling, loading and transport. The windrowing process is responsible for high amount of mineral material incorporated to the sugarcane trash, which varies between 5 and 10%. The cost of recovery of the trash is over 20 R$/ton. Besides, the harvesting system presently available in the world market does not contemplate mechanical harvesting in areas with slopes superior to 12%, and thus is unviable in small areas, and is not justified economically for farmers that produce less than 100,000 tons of sugarcane annually.

Based in this scenario, in November of 2006 a second Workshop of the series on "Guidelines for Public Policy for Scientific and Technological Research on Bioenergy in the State of São Paulo" was accomplished. The objective of this specific workshop was to discuss the current technological apprenticeship of the of sugarcane and straw harvesting system, bottlenecks, challenges for the next few years and the new paradigms needed to allow the sustainable expansion of the sector.

Four fundamental subjects were discussed:

- Sugarcane harvesting by mills.
- Sugarcane harvesting by independent growers.
- Straw Recovery for energy purposes.
- Break of paradigms in sugarcane harvesting.

Bering in mind the specificities of the theme and shortage of research aimed at solving these issues, the organizer of this event invited speakers and panelists, in addition to researchers, specialists of the productive sector with recognized competence, that could contribute in an effective way to the debate, discussing new ideas and experiences.

## SUGARCANE HARVESTING BY MILLS

Unburned green sugarcane harvesting, including stalk tops and transport of the cane to the mills for processing, should receive special attention because of the associated costs and technological development. Until recently sugarcane was burned and harvested manually in Brazil, today this scenario is being changed rapidly without adopting the most suitable solutions to the technical reality (topography, industry, or manual labor). Therefore it is necessary to develop local solutions for harvesting systems and transport that consider local technical, social, economical and environmental conditions.

Even the sugarcane production cycle, today with around five cuts (ratoons) before replanting, initially idealized to maximize the sucrose content, should be reviewed within this new paradigm, seeking to maximize the production of biomass and also to minimize the negative environmental impacts. A prolongation of the cycle associated with a reduction of agricultural operations can reduce substantially the production cost.

Key questions in this area of development:

- How should sugarcane be harvested within 5 years or 10 years?
- Can the current model of harvesting be altered?
- How can harvest losses be reduced while increasing efficiency?
- Why two-row harvesters are not available since they could be use as a strategy to reduce traffic and harvesting cost?
- Is 12% slope the real limit for sugarcane land use when it is mechanically harvested? Is not there engineering technology for off road vehicles to increase this limit up to 30%?

Sugarcane harvesting in the current, and new expansion areas, will became eventually totally mechanized, leaving just semi-mechanization in areas of difficult access for the harvesters; burning prior to harvest should be completely eliminated within the next few years. This forecast is based on restrictions imposed by the legislation which is restricting the areas allowed to be burnt, difficulties with cane cutters, cost reduction in relation to the semi-mechanized harvesting and to the expansion of the sector.

One of the principal challenges to be overcome by the harvester is its operational limit of 12% slope. The support equipment such as tractors and wagons, do not have that limitation, due to the adjustment allowed to the equipment track width. To be able to implement 100% of mechanization in sugarcane, it will be necessary to have equipments capable to work in fields of greater slopes. The development of harvesters capable to operate in more accentuated slopes has some advantages. One of them is associated with the possibility of the machine to harvest two simultaneous rows, requiring an increase of the track width, improving the stability and making harvesting possible in areas currently restricted.

With two rows, it is possible to increases the harvester field capacity and to reduce the traffic in the field, bringing benefits in relationship to soil compaction and subsequent crop yield. However, difficulties do remain and need to be overcome e.g. increasing the harvester cutting and processing capacity (sugarcane mass for unit of time), associated to losses, visible and invisible, and the quality of the raw material.

Although considerable efforts have been made in the last few years to reduce losses and extraneous matter (vegetable and mineral) presents in the load received at the mill, progresses has been slow and not very significant, with affect raw material quality. Data from the Center of Sugarcane Technology (CTC) in Piracicaba, SP, indicate that the visible and invisible losses during sugarcane harvesting can be as high 10%, while for other crops, such as soya bean, these values are in the order of 1%.

The harvesters currently available in the market are technically old and require a lot of new investment to increase their efficiency e.g. a more efficient system for base cut height control, as a monitoring system to control sugarcane losses, or impurities. Currently the control of these parameters depends upon the communication capacity between the sugarcane reception area at the mill and the operator.

A further improvement is the correct control of furrow opening to receive the cane stalks for billet planting. These can help to improve the mechanical harvesting quality, contributing to the reduction of sugarcane losses, ratoon damage; and extraneous matter incorporation. The adoption of the precision agriculture in the sugarcane planting, cut and loading system can contribute in a significant way to the efficiency of the production system.

Energy cane requires that harvesters are adapted to harvesting varieties with different characteristics from the current ones. In order to recover trash for energy generation some mills are collecting stalks and trash, and transport to the mill where a dry cleaning station separates the sugarcane from the trash. If that tendency is maintained the project of the harvester should be revalued. The reduction of the engine power, due to lower demand of the cleaning mechanism, is also one of the alternatives.

From the environmental and economic point of view it is necessary to reduce the soil compaction during harvesting. The harvesting equipment consists of a single row harvester, with a 350cv engine weighing up to 20 ton, which cuts the stalks at ground level and delivers cane billets into an in-field wagon unit alongside the harvester, weighing up to 30 ton when fully loaded, pulled by a 180cv tractor weighing 10 ton. The result is that each inter-row is trafficked twice by the harvester and at least twice by each wagon (usually there are two wagons connected) and a tractor. The result is poorly matched equipment with crop row spacing and single row harvesting with considerable potential for soil compaction, adverse effects on crop yield, reducing the longevity of the sugarcane filed and forcing to accomplish the subsoiling operations during replanting. Traffic control is one of the possible solutions to overcome this problem; other alternatives include re-design of harvesters or the development of a totally new sugarcane harvesting system.

Improvements of the harvesting process should also include new and improved genetic varieties more suitable for mechanical harvesting. The development of semi mechanized systems to facilitate manual cutting could also be an option in areas in which the harvester is not the appropriate solution. This will contribute to minimize the social problem originating from of the rapid mechanization of sugarcane. Within the next 10 to 15 years technological progress should make possible to harvest mechanically even in today restricted areas.

## HARVESTING BY SUGARCANE INDEPENDENT SUPPLIERS

Mechanization represents the best option for sugarcane harvesting, from an ergonomic, economical and environmental point of view, since it makes feasible green sugarcane harvesting, including trash use for energy purposes.

Today concept of sugarcane harvesters were originally developed in Australia by Austoft, and later widely copied by other companies. The machine cuts the cane at the base of the stalk, chop it in billets, remove the leaves blowing the thrash back onto the field and transfer the cane into a transporter that runs aside. There are small variations depending on the manufacturer e.g. feeding system or transport of the material inside the harvester.

For about 20 years the evolution of mechanical harvesting in Brazil was slow, it suggests that this is a quite restricted and uncompetitive market. For example, the original high price and maintenance cost, makes this option unfeasible for the small and medium growers.

Key questions in area of development:

- Should sugarcane independent suppliers continue to exist in the future?
- Which are technological requirements to harvest unburned sugarcane?
- Do smaller harvesters based on existent technology solve the problem?
- Are sugarcane mechanical harvester contractors a feasible solution?

Data from the 2008/2009 sugarcane crop season (Ministério da Agricultura, 2009) shows that 61.8% of all sugarcane processed in Brazil comes from areas managed by agro industry units (mills) (even if part of these production areas belong to partners), 39.2% of the processed cane are produced by independent suppliers. The size of the area cultivated by the suppliers varies from 20 ha up to 4,000 ha.

Orplana represents 26 associations of sugarcane growers in SP, MG and MT, with 16,406 producers, and 125.5 million tons of sugarcane produced in the 2008/2009 season, or 24.9% of the sugarcane produced in the Center-South region. The farmers from Piracicaba-SP region are an example of difficult area for sugarcane mechanization. They have a predominant Kandiuldult and Lithic Hapludoll soils with high slope. It is a traditional sugarcane production area, with 3,072 independent suppliers producing in an average area of 39 ha.

Recognizing the importance of the sugarcane suppliers CTC has been contemplating the support and technology transfer to this group and counted in 2006 with 13 growers associations as members of the CTC. Those entities answer for 400,000 ha of sugarcane distributed among 12 thousand growers.

Under the present scenario sugarcane expansion it can be concluded that growers should continue to exist, because:

- there is an interest of the mills for the sugarcane produced by independent suppliers (relationship cost-benefit);
- the sugarcane supplied by independent farmers presents quality at lower costs;
- there is a predisposition from the mill to increase the amount of sugarcane supplied by independent farmers;
- the independent farmers create more jobs and improve income distribution.

Most of the suppliers have low investment capacity besides having difficulties in creating a production cooperative or harvesting cluster. On the other hand the contractors are usually more capitalized and have operational involvement with the mills, what facilitates the logistic planning and usually employ more specialized labor to operate tractors and harvesters. The cooperatives and associations that until now have been focusing in political-social issues, begin now to discussions technical aspects, relative to harvesting mechanization. These cooperatives of suppliers could be potentials contractors.

The green harvest technology to be made available to the growers should consider environmental issues, labor availability, cost and efficiency of green sugarcane manual harvesting as well as the handling of the straw. The current harvesting equipments are large and designed to fit large areas. Smaller harvesters, (i.e of smaller field capacity) do not solve the problem, because some technological problems, such as the harvester efficiency, soil compaction and need of systematized areas remain.

Sugarcane growers are reluctant to new technologies, but mechanical harvesting will be adopted for economical reasons, independently of the pressures for the maintenance of job.

## STRAW RECOVERY FOR ENERGY PURPOSES

The present processes of manual or mechanical harvesting seeks the use of the stalk only. The harvesting process includes a sequence of simple operations; the cut of the base, and the top of the stalk; piling up of the stalk (manual harvesting) or cutting it in billets (mechanical harvesting). In both cases the use of the straw is not part of the harvesting process.

The harvesting process is suffering modifications as function of legal and environmental restrictions, associated with the increasing interest in the use of the straw for other applications, such as cogeneration and vegetable mulch for conventional or organic horticulture. A new concept of sugarcane harvesting process, that seeks the integral use of the plant, involving additional operations for separation and compaction of the straw is being developed.

This approach has other implications such as lower cane losses, and less mineral contamination of the straw when compared to the conventional process of manual and mechanical harvesting. It is important to highlight the efforts accomplished by users and equipments manufacturers to adapt the sugarcane harvester the new reality, the success has been partially and everything indicates that principle of those equipments need to be reformulated to face the new demands of integral harvesting of the plant.

With that perspective becomes pertinent to discuss the new propose that turns the green sugarcane harvesting more attractive than the burned sugarcane harvesting, as a form of consolidating its implementation without the pressure of the law or of the environmentalists. It is important to reminding that the current process inefficiencies will increase as the sugarcane production growth.

Key questions for development:

- How to harvest the sugarcane and the straw in an efficient way? Whole? Billeted? At what cost? With what level of mineral and vegetation impurities?
- Does the harvesting of integral sugarcane demand the construction of dry cleaning stations? Are these stations efficient? Are they economically viable? The transportation cost is justified?
- How to make feasible the straw transportation for large distance?
- Are the current levels of soil compaction generated by the traffic of harvesters, tractors and wagons compatible with no tillage farming?

Sugarcane trash is composed of the material left in the field after harvesting, which includes the straw (green and dray), soil, weeds, tops and roots. In a study done by CTC, Tufaile Neto (2005) shows that moisture content of trash varies between 13.5 and 82.3% depending on its composition; the ash content, carbon free and volatile materials do not vary a lot among its components; and the higher heating value (HHV) does not vary significantly as function of the sugarcane variety or age.

According to Ripoli *et al*. (2000) a ton of trash is equivalent to something between 1.2 and 2.8 barrel of oil equivalent (BOE), and the yield per hectare is around four to nine tons of dry matter. Consequently the non use of trash means energy waste.

Manechini (2005) evaluated the problems and the benefit of maintaining the soil covered with the mulch originating from sugarcane trash. Among the benefits they detach the protection to the soil against erosion; reduction in soil temperature variation and protection against direct radiation; increase of the biological activities; better water infiltration; better water availability due to smaller evaporation; and better control of the weeds. Some disadvantages mentioned by the authors are: fire risk; difficulties of doing mechanical cultivation during or between seasons; delay in ratoon sprouting and consequent decrease of the productivity; and increase in the population of pests that benefit from mulch for protection and reproduction. The authors attempted also to define which would be the minimum amount of residue that should stay on the soil to obtain the maximum agronomical benefits from mulching. They led experiments during a three to five years period, in three different plots in the state of São Paulo, analyzing the effect of different trash percentages (100%, 66% 33% and 0%) left in the field after mechanical harvesting. They analyzed the population of weeds with different initial degrees of infestation. The authors concluded that with 66% (about 7.5 t/ha/year, d.b.) the probability of getting similar effect of chemical herbicides is high. In relationship to the sugarcane yield, the authors did not come to a final conclusion. They observed that with the increase of trash in some cases there was a pol per hectare reduction, but this variation probably is more related to sugarcane variety, climate, degree of pest' infestation, among other, suggesting that futures works should be conducted.

Trash represents an option to increase the biomass availability for cogeneration at the mills. Most of the Brazilian mills already began a process of optimization of the thermal balance of their plants, with the objective of marketing the cogenerated energy surplus. Today, the installed potential for power cogeneration using bagasse is 90 kWh/tc. This potential is not entirely utilized as function of the energy sale price. The remuneration system now used by the mills for payment of the sugarcane to suppliers is not encouraging integral harvesting, necessary to produce surplus material for cogeneration. To help reaching the benefits longed for the "energy cane" it is necessary to use the fiber content and not only the sucrose content in the formula for producers' remuneration.

The potential cogeneration capacity of the sugar-ethanol industry sector is 30 million MWh/year, which represents 9% of the energy generated in Brazil in 2006. The sector can increase even more its cogeneration capacity, with no need for additional investments in new plants by making available, at relatively low cost, the straw resulting from green cane harvesting.

The use of the straw for energy proposes is not a simple system ready to be used; it demands financial and technological solutions. A great current difficulty is related to conditioning, handling and transporting this material from the field to the thermo electrical plant.

Some well succeeded initiatives already exist in the way of handling straw for energy purposes. Several systems to remove trash from the field were already tested such as bulk transport of straw and billets, round, square and cottom bales of trash. Studies developed by Esalq in partnership with Cosan Industries indicate that bulk handling of straw and billet, also called the integral system, offers the lowest recovery cost. This results were confirmed by Michelazzo (2005) that accomplished a cost sensibility analyzes for several methods of straw and trash recovery. An important aspect to be considered when doing straw or trash recovery analysis is the level of contamination with mineral residues.

The tendency is the introduction of specific equipment for trash recovery, other than the current sugarcane harvester. The cane harvester configuration could be simpler if the cleaning blowers were eliminated by adopting the integral system of billet and straw handling. Stationary dry cleaning station would be used at the mill to separate the straw from the billets.

The companies specialized in cogeneration solutions are already making available projects for mills interested in taking advantage of the straw cogeneration. The system considers that the thermo electrical plant should work during almost the whole year, and not just during the harvesting season. This implies in the production of safe and reliable equipments for steam generation condensation.

It is probable that in the near future some mills will make investments for the integral use of the sugarcane (sucrose, bagasse and straw) to produce exclusively energy, opting for no sugar production. The new technologies in study for ethanol production through hydrolyze of bagasse have fundamental impact on the speed at which these changes take place.

## BREAKING THE PARADIGMS OF SUGARCANE MECHANIZATION

To overcome some barriers existing in sugarcane agricultural some technological changes should be tried. The straw should be considered a product to be harvested with similar priority as cane stalks. Sugarcane planting should move to no-till farming in order to become more sustainable in terms of protecting the soil as well as the social and economical investments that are being done in this sector.

Currently sugarcane is planted in rows spaced about 1.5 m. Harvesting is conducted with a single row harvester, which delivers cane billets into in-field double wagons pulled by a tractor that runs alongside the harvester. The result is an intense traffic on the inter-rows that are trafficked twice by the harvester and at least twice by the tractor and the wagons. The traffic condition becomes more severe as a result of the existing miss-match between crop row spacing and the equipment, each having different track width (~1.8 m), mostly wider than the crop. About 60% of the soil surface is heavily trafficked yearly. These conditions promote low operational performance and higher operational cost besides a strong potential for soil compaction which contributes to force replanting every 5 years.

Reducing the traffic most likely would reduce the need for ploughing, subsoiling or disking operations allowing a gradual implementation of no-till farming. Well succeeded long term commercial results in grain production as well as field trials of sugarcane under minimum tillage done by CTC in the eighties showed that this agricultural practice could bring sustainable cost reduction, soil conservation and yield increase. The controlled traffic approach based on permanent traffic lines combined with wide track width equipments (above 8 m) would allow to have higher traction efficiency for the wheels combined with non compacted soil for the crop. This combination is particularly important specifically for sugarcane where approximately 400 ton are produced and handled over a 5 year cycle, from plant to plant, different from grains where about 3 ton are harvested and transported in a cycle. This concept has great potential to be applied on the less steep uniform fields of the sugarcane expansion areas in Brazil.

This concept was successfully tested with in the USA, Israel and Canada, but it did not reach a commercial stage mainly as a result of the sugarcane small market size as compared to grains. The main driving force for investments in mechanization technologies comes from the agribusiness related to grain production. About 700 million hectares are devoted to grains worldwide, but just 22 million to sugarcane.

Key questions in mechanization development for sugarcane:

- Is it possible to break the paradigm of traditional sugarcane mechanization?
- What benefits an alternative mechanization could bring to the sector?
- What is the land size of a sugarcane that would benefit from this technology?
- What companies could be interested in manufacturing this equipment and what would be the cost?

The present technology for sugarcane harvesting is based on the social, economical and technological conditions existing in Australia, USA and Cuba in the middle of the $20^{th}$ century. In all those cases the harvesting principle was focused on the recovery the stalks, eliminating the straw in the most economical way, usually through burning, or in the case of green sugarcane, the straw was maintained for soil conservation.

The main principles tested for sugarcane harvesting along the last 50 years are:

- **Soldier or Louisiana system** that harvests the whole stalk, windrowing them on the soil, parallel to each other. It executes the base cut and the topping efficiently and can only cut green sugarcane as leaves assist the chains to grab the stalk. There are no straw removing devices in this machines and the green cane is pilled in windrow to be burned on the ground before it is grab loaded into wagons or trucks for transportation.
- **Push-Rake system** that cuts and grab loads whole stalks totally disordered, without cutting the tops, with low load density and with destruction of the stool during the harvesting operation.

- **Billet system** can be considered a more resourceful solution as compared to the previous two. It became available more or less simultaneously in Cuba and in Australia with the intention of replacing scarce labour and to eliminate the grab loading operation, necessary in the systems that handle whole stalks.

Five important reasons turn the present scenario significantly different from the existing one in the historical moments described above:

1. The product to be harvested is not only the stalk but the straw as well.
2. The socio economic conditions of the sugarcane areas turned labor limited.
3. There exists a good knowledge on the characteristics and performance of the several harvesting systems already tested.
4. Risk and development cost are nowadays lower. Several engineering tools are available which are capable of modeling, simulating and optimizing the phenomena involved in the development of new harvesting prototypes as well as in the process of taking them into commercial products.
5. Genetic engineering should accelerate the development of new sugarcanes varieties with grater yield, consequently taller and more difficult to be harvested using the current technology.

Present harvesting technology does not seem to be adequate when analyzed from the stand point of the following factors:

- environmental legislation;
- efficiency of biomass recovery from the stand point of quality and losses of both straw and stalks;
- sustainable use of the soil;
- capacity to operate on expansion areas considered topographically inadequate.

Some paradigms about mechanical harvesting prevail among the technicians, users, manufacturers and machine dealers as described below; they must be broken if better harvesting approaches are to be introduced.

- **The base cutter must be attached to the harvester feeding system (main frame)**

The double disk base cutter used by chopper harvesters performs two functions simultaneously: base cut and stalk feeding. This combination makes difficult to improve each function without affecting the other. This mechanism is wide and heavy, with slow dynamic answer in the process of following the soil surface; it has a cutting profile inadequate for the furrow profile; it promotes movement of large volume of soil and demands proportional hydraulic power to drive the disks. It is desirable that the base cutter performs only the cutting function, using just one disk, similar to the configuration used by the Louisiana soldier harvester. This simple alteration would sharply reduce the energy demand, will have better adaptation to the soil profile, will have less mass and consequently better flotation capacity on the soil surface and will be able to discharge soil particles laterally instead of feeding them on to the incoming stalks. The single disk base cutter allows harvesting multiple rows at narrower row spacing conserving the advantages described above, just installing an independent disk for each row.

From the above considerations it can be conclude that the problems usually allocated to the base cutter are in reality problems associated with the stalk feeding process, i.e. difficulties to extract the stalk from the plantation and to place them inside the harvester.

- **One row harvest**

Even if the base cut can be solved satisfactorily through the use of an individual floating disk for each row, it remains to develop an appropriate solution to feed the stalk into the harvester after the base cut is completed. In present chopper harvesters the base cutter with double disk participates in the feeding process facilitating the entrance of the base of the stalks into the first pair of feeding rollers. It can be anticipated that the single row harvester paradigm could be broken if a feeding system was developed able to remove the stalks from the plantation after the base cut is done that would leads them to a parallel arrangement before entering the chopper or a storage container in the case of harvesting whole stalks.

- **Maximum land slope is 12%**

The restrictions that hold back the operation in steeper areas are associated with the harvester stability to the overthrow and lack of directional control. The restriction of stability can be solved increasing the width of the harvester by harvesting a larger number of rows. The restriction of directional stability can be solved through the use of four-wheel drive and steering. This resource allows for compensation of the lateral drift or slip angle resulting from soil and tire deformation caused by the side weight of the machine running on a steep terrain. Hydraulic or electric transmissions can be used to facilitate individual steering of each wheel. With relationship to the capacity of a tire to generate traverse forces as a function of the wheel angle is verified that angles in the order of 5 degrees are enough to generate traverse forces of the order of 50% of the weight, in other words, enough to balance the weight components, for steepness of up to 30%.

- **Separation of stalks and extraneous matter should be pneumatic**

The pneumatic cleaning system used by billet harvesters depends on the cut of the stalk and leaves and subsequent separation using the differential terminal velocity principle. This system presents restrictions that make the separation of leaves just partial, always remain 5 to 6% of vegetable extraneous matter (EM) among the billets to be delivered to the mill.

A promising way to break this paradigm is to harvest integral sugarcane. A partial cleaning in the harvester associated with a stationary dry cleaning station at the mill seems to be the most appropriate combination; this reduces biomass losses in the harvester and allows to adjust the amount of straw recovered for energy proposes, leaving in the field only the amount of straw necessary for weeds control as well as conservation of soil and water.

- **Trash should stay on the soil**

The straw, the stems and good part of the tops are processed simultaneously in the harvester. At the pneumatic separation chamber the trash is thrown onto the soil and the billets are transferred to the infield wagon. In the current concept of "energy cane", where large expansion of the planted areas is foreseen, the need to reformulate this paradigm will arise so that the straw, that represents approximately one third of the cane energy, could be recovered with cost and quality adequate for energy use.

Three important changes can be pointed in the processes of straw recovery that would contribute to accelerate its energy use: the increase of straw density for transportation, a reduction of the handling cost and a reduction of soil contamination.

- **There is no alternative to reduced the intense traffic of machines in the inter rows**

The necessary traffic to make possible the current system of sugarcane and straw harvesting demands soil tillage at replanting. This traditional soil management approach opposes the principles of no-till farming that has showed positive results for other extensive crops such as soybean, corn and wheat with cost reduction and increase of sustainability. Billet harvesting and hauling processes represent the principal impediment for implementation of the no-till or minimum tillage approaches. The elimination of the traffic in the cultivated areas would allow a progressive reduction of soil tillage to finally reach the no-till stage.

The paradigm of intense traffic in the inter row can be appeased through the use of multiple row harvesters and standardized track width for all the equipment used for in field operations. A more radical traffic decrease could be obtained by introducing specific mechanization for sugarcane based on controlled traffic and wide track width machines.

The six paradigms discussed above block the technological development of sugarcane harvesting and hauling in the following aspects:

- reduce cane losses and extraneous matter content;

- harvesting green sugarcane with no economical difference in relationship to the burned harvesting;
- reduce mechanization cost;
- reduce investment for harvested ton of sugarcane;
- reduce topographical restrictions;
- reduce costs for straw recovered;
- increase sustainability of the sugarcane production.

The paradigm of traditional mechanization can be broken through new investments for research and development in some fundamental points such as: cane stalk cutting and feeding processes, reduction of biomass losses; new approaches for straw recovery; field traffic reduction; yield maps generation and analysis; soil property maps on fine GPS grid; new varieties fitted for low traffic and new demands of quality for integral energy cane.

The solutions here proposed are different for each productive sector. Feeding and detrashing processes, simple and efficient, operating with whole stalk cane can assist growers with areas smaller to 1,000 ha. Multiple rows harvesters mounted on wide frame structures operating under controlled traffic can be used, with the advantages described above, in units with areas over 10,000 ha.

The multiple row harvesters or even the wide frame structures have a potential market in the order of 5,000 machines. In Brazil there is a large number of sugarcane producers, planting and harvesting more than 10,000 ha. The wide frame structures are simple machines, primarily composed of steel structural pieces and of machines elements such as engines, tires, hydraulic, electric and electronic components. This size market and type of equipment may not be interesting for the traditional tractor and harvesters manufacturers, but they can be produced by other manufacturers of agricultural machines.

## FINAL CONSIDERATIONS

On the subject of "Sugarcane and straw harvesting for Ethanol production" the following conclusions can be withdraw.

- There is no disagreement on the need of investments to improve mechanization of green sugarcane harvesting, for both, large and smaller producers, and that available technology does not attend the user's expectations in several aspects:

1. lower operational cost;
2. capable to operate on steeper land;
3. capable to harvest more than one row at a time;
4. less soil compaction;
5. capable to harvest stalks and straw for energy uses.

- The sugarcane independent suppliers, which are usually less capitalized, need lower cost equipments for mechanization.
- To consider straw as a co-product of "energy cane" an adequate technology for recovery should be made available.
- Several technologies available in other areas of engineering could be used to improve the performance of harvesting and hauling process, reducing the operational costs and improving sustainability aspects of the ethanol production.
- The creation of a consortium among the private and public sectors could help to joint research and development resources required to create innovative technology for this sector.
- Government investments are required for the development of new high risk technologies.

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