A cane-loss measuring system for machine-harvested sugarcane

C Whiteing¹, L Giddy¹ and C Norris³

¹Sugar Research Australia, Brandon, Australia; 75cambo@gmail.com
²Norris Energy Crop Technology, Brisbane, Australia

Abstract Cane loss associated with trash extraction through harvester cleaning systems is a major cost to the Australian industry. Methods to measure these losses have been either inaccurate or slow and costly. This paper reviews the issue of cane loss and cane-loss measurement in extractor-type harvesters, and discusses the development of the mobile sugar-loss measurement system that is now being used as an extension tool in the Australian sugar industry. Initially, this system required a laboratory-based process to measure sugar in the field residue (trash blanket). Further developments utilised a mulcher to prepare the field residue sample, a blender to further disintegrate the sample with water to release the sugars, and a press to extract the liquid. A handheld digital Brix refractometer is then used to give a surrogate measurement of the sugar content. Brix readings from the liquid extracts have been calibrated against data on the actual sugar contents to give a robust and mobile method for assess harvesting losses. Combining the weight of field residue samples (t/ha) with the sugar content (%) then gives a measure of the total tonnes of sugar per hectare left in the field by the cleaning system. Losses measured over recent years from machines with competent operators have ranged from AUD 200/ha to well over AUD 1500/ha, so there are significant gains to be made by measuring losses and then adjusting machine settings such as fan speed to reduce losses whilst managing levels of trash extraneous matter. This system has been demonstrated to be a very powerful educational tool to demonstrate the levels of cane loss at different harvester settings at field demonstrations. Attendees can watch the sampling/processing and discuss the economic impact of different harvester settings.

Key words Harvesting, cane loss, fan speed, sucrose loss, Brix on trash

INTRODUCTION

Growing conditions, varieties and harvesting conditions can result in high levels of trash (dry and green leaf material) and other extraneous matter being forwarded with the cane to the mill. High levels of leafy extraneous matter (EM) reduce transport density and subsequently payloads, as well as impacting adversely on milling recoveries and sugar quality. The natural reaction to high trash levels in the delivered product is to maximise the harvester extractor fan speed, in an attempt to minimise trash levels. Research indicates that this strategy can potentially result in very high levels of cane loss, with only limited improvements in trash levels (Whiteing et al. 2001).

Determination of actual levels of cane loss, so that the balance between cane loss and trash levels can be optimised, is always a significant issue with extractor-type chopper harvesters. This is made more difficult because of the dissociation of the cane billets as they pass through the extractor fan, thus becoming an 'invisible' loss.

CANE-LOSS MEASUREMENT STRATEGIES

There are two broad strategies for determining cane loss from extractor type harvesters:

- ‘inferred measurement’, where cane loss is inferred by assessing differences in clean cane yield achieved from different harvester settings; and
- ‘direct measurement’, where an attempt is made to determine cane loss by measurements associated with the material that is exhausted out of the harvester extractor chute.
Inferred cane-loss measurement

Cane loss can be estimated by inference, in what is generically known as ‘mass balance’ harvester trials. The clean cane yield at different harvester settings is determined by measuring total product yield (t/ha) and product composition (% clean cane) at different harvester settings. The yield of clean cane is then calculated. The difference in calculated clean cane yield at different harvester settings can be compared and relative cane lost at the different harvester settings inferred. For example, harvester treatments of ‘extractor fans off’ and ‘extractor fans at maximum’ allow cane loss at maximum extractor speed to be inferred, as all other losses (e.g. pickup losses, base-cutting losses and billeting losses) are considered constant in a replicated controlled experiment. This methodology can also be used to compare yields and sugar recovery from machine harvesting and hand-cutting.

The problems associated with ‘mass balance’ cane loss measurement relate to both the logistics of the trials and potential error, with major sources of error in this trial method being:

- Variability of initial cane yield in the field. Yield variability between the areas harvested for different treatments can easily overwhelm the variance in yield between treatments associated with cane loss, and;
- Error in measurement of trash levels, and the subsequent determination of clean cane yield for each treatment.

Strategies to minimise these sources of error include:

- Selecting the most even fields possible;
- Selecting an appropriate plot size. Functionally, a variable plot size of the area required to fill a transport unit typically being at least one haul-out unit but typically two or three;
- Use appropriate statistically sound methodologies. Control the number of treatments to allow the number of replicates to be maximised, typically six or more replicates of each treatment are desirable;
- Ensure maximum possible accuracy of sampling of EM/clean cane proportions in the product produced at the different fan speed settings.

Because of the high leaf EM levels and very low load density associated with ‘fans off’ treatments, and the difficulty in collecting representative samples for determination of product composition and clean cane yield, ‘fans off’ treatments are not always the most practical or accurate option. Whilst zero extractor loss can only be achieved by a ‘fans off’ treatment, the very high levels of EM components and low load densities mean that errors in determining clean cane yield for this, the control treatment, can be high. A combination of low fan speed and low forward speed (pour rate 50-60 t/h) will typically remove around 50% of the leafy EM, whilst still achieving very low cane loss. The better sampling accuracy because of the lower leafy EM levels, as well as the increased area harvested to fill the nominated haul-out units, gives statistically stronger results because of reduced variability. An estimate of cane loss at the low extractor fan speed can be used to ‘correct’ the dataset.

With appropriate management and control, ‘mass balance’ cane-loss measurement protocols can give robust and statistically highly significant results. This is currently the preferred method for accurate benchmarking of cane loss, both between different harvester settings and between harvesting systems. Figures 1 and 2 give datasets for different harvesters illustrating the results from mass balance trial programs.

**Fig. 1.** Product composition from an older model harvester at different extractor fan speeds in a lodged crop.

**Fig. 2.** Product composition from a current model harvester at different fan speeds in a sprawled crop.
The data in both trials illustrates the typically observed relationships between extractor fan speed and component yield being delivered from the harvester. In the lodged crop conditions of Figure 1, the reduction in trash (leaf EM) as fan speed increases is less than the reduction in clean billet yield. Similar trends are evident in Figure 2. In both cases, the extractor is relatively in-effective in reducing the level of tops in the product delivered to the mill. The difference in clean cane (net) yield between treatments can be termed relative cane loss, as some loss is occurring at the low extractor fan speed, in addition to the other ‘visible’ and ‘invisible’ losses associated with other machine functions.

**Direct cane-loss measurement**

The strategy often used to indicate the level of cane loss from the extractor system is the collection of scrap cane in the material removed by the extractor. This strategy aims to give a direct measure of cane loss. This is done by a number of methods, the most common being:

- Sampling in the field after harvest using a randomised placement of a quadrant and collecting material for subsequent sorting;
- Placing a suitable sheet on the ground (e.g. a tarpaulin) in an area adjacent to the next harvester pass and lifting it immediately after the pass by the harvester to give a sample of the extracted material; or
- Collection of material in a ‘sock’ attached to the harvester extractor, or a trailer towed behind the harvester.

The extracted material is then sorted to determine the mass of cane stalk components and an assessment of cane loss made. Many researchers (Rozeff 1983, Ueno et al. 1995, Riviere et al. 1998, Ahmed and Alam-Eldin 2015) have utilised data collected in this way as the nominated measurement of cane loss. Many commercial operations utilise this ‘raw’ data as their primary method of recording cane loss for management of their harvesting operation.

Despite the ‘accepted usage’ of this measurement protocol, it significantly underestimates actual cane loss. The high tip speed of the extractor fan blades means that billets that are drawn out with the trash are effectively shattered into tiny fragments and dispersed amongst the trash, with the effect being greater at high fan speeds.

Ridge (1989) developed the ‘blue tarp test’, as an extension tool to better illustrate the magnitude of cane loss. A groundsheet is placed in the field adjacent to the harvester path. After the pass of the harvester, the groundsheet is collected and the material sorted and cane scrap retrieved. A multiplier related to fan speed, in conjunction with the length of row covered by the groundsheet and crop row spacing, is used to determine likely cane loss. The fan speed multiplier was developed from stationary harvester testing by Ridge and Dick (1987) and ranged from 1.5 to 4, depending on fan speed.

Sandell and Agnew (2003) found the factor developed by Ridge and Dick (1987) varied with variety and harvesting conditions (as well as fan speed), and to correlate with actual cane loss the multiplier ranged from x2 to x10 under different harvesting conditions. The correlation between ‘tarp cane loss’ and actual cane loss was primarily determined by the ‘appropriateness’ of the correction factor rather than the actual mass of cane scrap measured in the extracted material. Other research in Louisiana (Viator et al. 2007) using a current series harvester noted that “less than 15% of known cane loss could be found” when the calculated ‘missing cane’ from the yield of the different treatments was compared against the material found from measuring visible losses in the field after harvest.

Field and workshop trials correlating measured cane loss with the cane scrap have been conducted by different researchers, with examples shown in Figures 3 and 4. In these trials, there was generally little change in the mass of recovered cane stalk material with increased fan speeds, but there was a strong correlation between fan speed and mass of product extracted (Whiteing et al. 2004). The data on ‘scrap cane found’ and inferred cane loss from the ‘mass balance’ trials in Figures 1 and 2 is presented in Figures 5 and 6. The issues with ‘missing’ visible scrap causing a dramatic under-estimation of actual cane loss meant that demonstrating the magnitude of cane loss to Industry participants was difficult.
**Fig. 3.** Field trials in Argentina (Gomaz, pers com) indicated that visible stalk components in the material extracted was a small percentage of lost cane at higher extractor fan speeds, even in burned cane.

**Fig. 4.** Workshop trials in Australia (Whiteing et al. 2004) indicated that, under controlled conditions, less than 25% of known ‘missing cane’ could be identified in the material collected from the harvester extractor.

**Fig. 5.** Inferred cane loss and mass of scrap cane found in the trial reported in Figure 1.

**Fig. 6.** Inferred cane loss and mass of scrap cane found in the trial reported in Figure 2.

**CANE LOSS MEASUREMENT: AN ALTERNATIVE STRATEGY**

The primary error in the utilisation of mass of visible cane components in the extracted product is the dissociation of the cane billets as they pass through the extractor fan. The juice, shredded rind and fine pith components are distributed throughout the product flow ejected from the extractor, with a portion of the juice also being absorbed onto leaf material. Measurements of the sucrose on the trash before and after harvest (Crook et al. 1999) indicated a significant increase in apparent sugar on trash during the harvest process, but the use of a press to extract liquid from the trash for analysis meant that results could only be obtained with relatively moist trash. This was assumed to be due to dry trash components absorbing the juice.

Davis et al. (2001) assessed sucrose losses as cane flowed through the harvester. They assessed potential methodologies to measure the accumulation of sugars on trash, by both tumbling trash samples with water and disintegrating trash samples in water, prior to extraction by pressing. They selected the tumbler system with hot water and a 30 minute residence time to measure the transfer of sugars from damaged stalks to trash as the cane matter passed through the harvester. They were able to detect increasing levels of sucrose on the trash as the material progressed through the harvester from the gathering and feeding processes through to the harvester elevator.
Berding et al. (2002) undertook a ‘sugar balance’ exercise on a commercial harvesting operation. They utilised near infrared (NIR) spectroscopy technology on crop components from the field prior to harvest, on the extracted trash and on the harvested product. They noted that very high levels of sucrose could be detected on the trash extracted by the harvester, equating to very significant cane loss through the harvester billeting and trash extraction processes.

Sichter et al. (2005) undertook a series of trials where a sucrose solution was sprayed on trash, and then they subjected this to an extraction procedure where a sample was shredded in a known quantity of water, pressed and the extract recovered. This extract was frozen and sent for high-performance liquid chromatography (HPLC) analysis. The recovery of added sucrose ranged from 82-98% (average 90%). Sichter et al. (2005) then progressed to field trials in the Bundaberg region. Trash from quadrants across the field from different harvesting treatments were collected, weighed and shredded, then sub-sampled. The sub-samples were snap frozen and then analysed for sucrose in the laboratory by disintegration with water and pressing. In these trials, sucrose measured with the trash accounted for an average of 55% of the cane loss indicated by the mass balance trials.

The concept was then further developed, with the goal being a field-based system to measure sucrose on the trash as a measure of cane loss. A number of options for measurement of sucrose on the trash were evaluated, including a hand-held NIR Spectroscopy unit. Whilst none were successful, a strong correlation was noted between the Brix (sugar contentment of the aqueous solution) levels in the extract and sucrose levels as determined by HPLC analysis.

Based on this correlation, a decision was made in 2008 to undertake research to ‘Measurement of Infield Sucrose Loss by Mobile Refractory’. This project aimed to develop a fully mobile sugar-loss measurement system that would allow staff across the industry to measure cane loss in the field immediately after harvest. Whilst the primary goal was a system to measure cane loss quickly, the second goal was to increase awareness of the cane-loss issue and strategies to minimise it.

Field methodology: collection of material

Two methods were initially trialled to collect the samples in the field after harvest:

- Placing a groundsheet adjacent to the row being harvested and catching the trash/billet fragments/juice exiting the extractors, or
- Raking up residues from within measured areas or ‘quadrants’ following harvest.

Both systems are still used, but the groundsheet method is fastest and gives the most consistent results (Figs 7-8). The trash collection is undertaken at least six times when a ‘spot check’ is being undertaken on a harvester, or at least 10 replicates per treatment are conducted when trials comparing harvester settings are being undertaken.

**Fig. 7:** Lifting the groundsheet after the pass of the harvester to collect the product extracted by the harvester extractor system. This product is weighed to allow calculation of extracted product/ha, and sub-sampled.

**Fig. 8:** The trash sample of about 10 kg is shredded in the field, mixed and sub-sampled, with the sub-sample being snap frozen. For accurate results, the shredding, sub-sampling and snap freezing of the trash must be achieved within 30 minutes of harvest.
After weighing, a sample of approximately 10 kg of the collected product is taken and shredded in a modified heavy duty garden mulcher. This shredded product is then thoroughly mixed and a 250-500 g sub-sample taken, and snap frozen. Initially, the samples were taken back to a laboratory for further processing. The samples were disintegrated in a known quantity of distilled water. After pressing, the extracted liquid was tested for Brix content and samples re-frozen and sent for HPLC analysis. A good correlation ($r=0.82$) was found between HPLC measurement of sucrose and brix of over 300 sample taken in the first year of the development phase of the project. After inclusion of a single empirical constant multiplier, the Brix data also correlated well with the derived cane loss from ‘mass balance’ trials.

Whilst this system identified a consistent relationship between Brix in the extracted trash and known extractor cane loss, the process and the time taken between harvest and availability of results was excessive if the system was to be utilised as a tool for the Industry to increase awareness of cane loss. The next requirement was to develop a fully mobile system.

The fully mobile system consisted of a trailer, set-up with the engine powered shredder, a 220 V electrical system, a freezer (for short term storage of samples), scales, disintegrator and press. Brix from the filtered extracted juice is processed in duplicate optical Brix meters. The Brix reading, combined with the measured trash yield is then used in ‘look-up’ tables to determine sucrose/ha and subsequently cane loss in the trash blanket extracted by the harvester. As the strategy inherently always under-estimates total cane loss (100% of cane fragments and juice will never be recoverable), a conservative correction factor is utilised to partially correct for this.

**Field results**

Figure 9 presents data on measured sugar loss/ha versus extractor fan speed for a common harvester operating in a crop of cultivar Q200. The crop was erect and topped. The cane loss is then derived from the estimated sugar content of the cane stalk. The inferred cane loss for the different treatments in the trial, derived from mass balance, are presented in Figure 10. The relationship is strong, but the correction factors used in the sucrose measurement system are conservative.

![Fig. 9. Estimated cane loss is derived from the measured sucrose loss and the estimated sucrose content of the crop.](image)

![Fig. 10. Relationship between inferred cane loss from mass balance measurements and cane loss derived from sucrose on trash.](image)

Several hundred field trials assessing cane loss associated with different harvesting scenarios have been conducted. The method has been shown to be a fast and effective method to illustrate the impact of changing machine parameters on cane loss. The relative speed of measurement has meant that a large number of parameters relating to field performance of modern harvesters have been able to be explored.

Results from trials on a common harvester are presented in Figure 11. Whilst the typical relationship between extractor fan speed and cane loss is clearly visible, significant variability in cane loss at a given extractor fan speed is clearly evident, this being a function of a number of factors, such as initial trashiness, stalk diameter, harvesting conditions and a range of other variables.
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Figure 11. Cane loss versus fan speed for a modern harvester fitted with 1.5 m extractor system and 'ex-factory' blades.

Leafy EM removal

The primary function of the trash extractors on the harvester is to reduce leafy EM levels in the cane being delivered. Figure 12 presents data on trials on the two main harvesters currently in use in the Australian Industry. The observed relationship between cane loss and extractor fan speed is similar for both machines, and of a similar characteristic shape to that noted on older machines. The difference in absolute values is associated more with specific harvesting conditions than with differences in the machines characteristics of performance. Significantly, as extractor fan speed increases, the mass loss of cane is typically more significant than the reduction in leaf EM mass levels. The different relative leafy EM levels is likely to be related to differences in harvesting conditions rather than difference in typical harvester performance.

Figure 12. Typical relationships between cane loss and leafy EM at increasing fan speed settings for the two major 'full size' harvesters.

The relative speed and accuracy of the system has allowed a significant increase in effort relating to managing cane loss and cane quality. Widespread acceptance and usage of this new method for cane-loss measurement in the Australian sugar industry is driving a reduction in cane loss levels, however with this change comes issues associated with higher EM levels. Increased profitability due to higher sugar yields is pushing investigations into alternative approaches to cane cleaning.

INDUSTRY OVERVIEW OF LOSSES

In Australia, a typical harvest contract size for a single harvester and associated haulout equipment is 900-1,100 ha. In higher yielding areas this typically equates to higher tonnages in the contract. Data in Table 1 illustrates that in the initial surveys utilising this cane-loss measurement technique, the most common loss range was between AUD 100,000 and AUD 300,000/year. Over 40 harvesters were operating with losses with sucrose value in excess of AUD 400,000/year. Two harvesters tested has losses in excess of 16%, and in the typical crop conditions under which these machines operated, anticipated annual losses exceeded AUD 1,000,000.

The full magnitude of these losses are not necessarily recoverable; however, the magnitude of the losses illustrates the importance of cane loss as an issue to the industry.
Table 1. Estimated value of sucrose lost over a harvesting season and number of harvesters in each loss category.

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<th>Estimated value of sucrose lost/year (AUD)</th>
<th>Number of harvesters</th>
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<tbody>
<tr>
<td>&lt;$100,000</td>
<td>4</td>
</tr>
<tr>
<td>$100,000-$200,000</td>
<td>31</td>
</tr>
<tr>
<td>$200,000-$300,000</td>
<td>24</td>
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<td>9</td>
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<td>$700,000-$800,000</td>
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<td>&gt;$800,000</td>
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CONCLUSIONS

The equipment and technology developed under the project ‘Measurement of Infield Sucrose Loss by Mobile Refractory’ has been demonstrated to be a major step forward in the ability to rapidly assess harvester cane loss. It can be used both as a tool in harvesting research trials and as a demonstration tool of the impact of harvester operating parameters on cane quality and cane loss.

- The mobile sugar loss measurement system provides a rapid/accurate and more direct measurement of cane loss at harvest than previous methodologies.
- Same day feedback enables operators/growers/millers attending field demonstrations to actively discuss the economic impact of varying harvester settings.
- Many more machines can be assessed per harvest season, which creates widespread impact in terms of adoption of practices to minimise harvest losses and/or manage the relationship between cane loss and cane quality.
- The flexibility of the system enables researchers to measure losses for a whole range of harvester operational settings.
- Several mobile loss measurement units are now in use across the Australian industry.

The data from the large number of trials conducted demonstrate the complexity of the relationships between harvesting conditions, extractor fan speed and cane loss. The consistent finding is, however, that increasing extractor fan speed always equates to increasing cane loss. However, the impact on actual leafy EM levels is variable and often minimal.

The magnitude of the losses measured in the surveys, and the wider understanding of these issues is pushing the industry to explore options to manage EM levels whilst minimising cane loss on the harvester.

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REFERENCES

Méthode de mesure de pertes en canne avec des récolteuses de canne à sucre

Résumé. Les pertes en canne dues à l’extraction des pailles par les systèmes de nettoyage de la récolteuse représentent un coût important pour l’industrie sucrière australienne. Des méthodes pour évaluer ces pertes sont soit inappropriées, soit lentes soit coûteuses. Ce papier passe en revue la perte de canne et sa mesure pour des récolteuses avec extracteur et discute du développement d’un système de mesure mobile de perte de sucre, maintenant utilisé comme un outil portable en Australie. Auparavant, la mesure nécessitait un laboratoire pour mesurer le sucre dans les résidus au champ (pailles). Les nouvelles mesures ont utilisé un mélangeur pour préparer l’échantillon de résidus au champ, un mixeur pour désintégrer l’échantillon avec de l’eau afin d’extrait les sures, et une presse pour extraire le liquide. Un refractomètre digital portable a été ensuite utilisé pour le Brix afin d’obtenir une valeur estimée de la teneur en sucre. Les lectures de Brix des extraits liquides ont été calibrés avec des données de teneur réelle en sucre pour obtenir une méthode robuste et mobile afin d’évaluer les pertes à la récolte. En combinant le poids des échantillons de résidus au champ (t/ha) avec leur teneur en sucre (%) on obtient une mesure du tonnage total de sucre par hectare laissés au champ par le système de nettoyage. Les pertes mesurées ces dernières années avec des opérateurs compétents vont de 200 AUD (dollars australiens)/ha à bien au-delà de 1500 AUD/ha, aussi y-a-il des gains significatifs à faire à évaluer les pertes pour, par la suite, adapter les réglages de la machine comme la vitesse du ventilateur afin de réduire les pertes en gérant les niveaux de rejet des non-cannes. Lors de démonstrations au champ, la méthode s’est avérée être un outil pédagogique performant pour mettre en évidence les niveaux de perte de canne en fonction des réglages de la récolteuse. Les participants peuvent observer l’échantillonnage, la procédure de mesure et discuter de l’impact économique de différents réglages de la récolteuse.

Mots-clés: Récolte, perte en canne, vitesse du ventilateur, perte en sucre, Brix du pailles

Un sistema de medición de pérdida de caña en la cosecha mecanizada de caña de azúcar

Resumen. La pérdida de caña asociada con la extracción de la materia extraña a través de sistemas de limpieza de cosechadoras es un costo importante para la industria australiana. Los métodos para medir estas pérdidas han sido ya sea inexactos, o lentos y costosos. Este trabajo analiza la cuestión de la pérdida de caña y la medición de la pérdida de caña en cosechadoras de tipo extractor, y se analiza el desarrollo del sistema móvil de medición de pérdida de azúcar que ahora está siendo utilizado como una herramienta de extensión en la industria azucarera australiana. Inicialmente, este sistema requería un proceso de laboratorio para medir el azúcar en el residuo de campo (manto de basura). Desarrollos posteriores utilizan una trituradora para preparar la muestra de residuos, una licuadora para desintegrar aún más la muestra con agua para liberar los azúcares, y una prensa para extraer el líquido. Un refractómetro Brix digital de mano se utiliza para dar una medida sustituta del contenido de azúcar. Lecturas Brix de los extractos líquidos han sido calibradas con datos del contenido real de azúcar para dar un método robusto y móvil para evaluar las pérdidas de caña. Combinando el peso de muestras de residuos de campo (t/ha) con el contenido de azúcar (%) se obtiene una medida del total de toneladas de azúcar por hectárea que quedan en el campo para el sistema de limpieza. Pérdidas medidas en los últimos años en máquinas con operadores competentes han oscilado entre AUD 200/ha a más de AUD 1500/ha, por lo que hay un ganancia significativa por lograr mediante la medición de pérdidas y luego hacer ajustes en la máquina, tal como la velocidad del ventilador para reducir las pérdidas, gestionando los niveles de materia extraña. Este sistema ha demostrado ser una herramienta educativa muy poderosa para mostrar los niveles de pérdida de caña con diferentes configuraciones de cosechadoras en demostraciones de campo. Los asistentes pueden ver el muestreo/procesamiento y discutir el impacto económico de las diferentes configuraciones de cosechadoras.

Palabras clave: Cosecha, pérdida de caña, velocidad del ventilador, pérdida de sacarosa, Brix en materia extraña