Modelling the sugarcane value chain: an interactive decision-support tool

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Abstract Sugarcane is a high-volume, low-value crop that is highly susceptible to damage during harvest and deterioration after harvest. Included crop residues negatively impact on milling performance. Mechanical harvesting and transport costs in Australia can approach 20% of total product value, and avoidable losses in the form of reduced cane quality and reduced yields can demonstrably exceed direct harvesting costs. Managing harvesting costs by increasing equipment output then typically exacerbates the potential for loss of value. Harvest Best Practice emerged as a concept to reduce harvesting losses by limiting harvesting speed and extractor system settings. This increases harvesting costs, however, the net impact on the value chain is highly variable and difficult to quantify. Significant previous work in Australia and internationally has generated datasets that correlate aspects of harvester operation with losses, cane quality and ultimately sugar recovery, but limited work has been undertaken to understand the complexity of the interactions among multiple factors in the value chain. A spreadsheet model was developed that has been used in the Australian industry and internationally. The Sugarcane Harvesting and Logistics Optimisation Tool (SCHLOT) is a web-based multi-parametric mathematical tool developed from the model. Input on physical and agronomic properties of the crop, field parameters and harvester configuration and operational parameters allows probable cane yield, composition and quality, and, from that, final sugar, molasses and bagasse production to be derived. Cost data are also derived from the relevant inputs and known relationships. The paper briefly describes the methodologies by which the model determines the impact of harvesting, transport and milling on both subsequent operations and direct costs and allows users to balance direct costs of an operational strategy against loss of value. This allows harvesting strategies to be optimised on a field-by-field, or even time-of-day basis.

Key words Sugarcane, sugarcane harvesting, logistics optimisation, value chain, web-based tool

INTRODUCTION
The post-harvest sugarcane value chain involves the recovery of large volumes of low-value, low-density and perishable material from the field, transport to a factory and recovery of the remaining value for sale. Up to 35% of the total biomass in the field prior to harvest is leaf material (Schembri et al. 2002), which does not contain recoverable sugars, and has a deleterious effect in the factory. Direct costs in the value chain, eg harvesting and transport costs, are relatively easy to measure and manage, but the loss of potential value at each stage is much more difficult to quantify. Since full mechanisation of the Australian sugar industry in the mid-1970s, industry productivity has had a consistent downwards trend (Garside et al. 2004). Over the past 15-20 years, cost pressures have forced significant increases in the daily output of the harvesting sector, resulting in 50% fewer harvesters in the industry (Anon. 2014). Over the same time, fibre in the cane product delivered to the mill, which is a measure of cane quality, has worsened significantly (Kent et al. 2014), with adverse impacts on milling performance and recovered product value (Kent et al. 2010). This value destruction adversely impacts industry viability, and current payment systems among the milling, growing and harvesting sectors exacerbate the problem.

MANAGING HARVEST VALUE
Previous research (Sandell and Agnew 2002; Vitale and Domanti 1997; Whiteing et al. 2001) has established that, with modern chopper harvesters:

- cane loss increases with extractor fan speed, but actual cane loss is also a function of field conditions and physical properties of the cane;
- extractor fan speed does not have a consistent impact on the amount of trash in delivered cane;
- leafy trash levels in the harvested cane increase with harvester pour rate;
the relationship between pour rate and cane loss is complex;
- reduced billet length improves load density (bin weight) to a point, but other factors, such as billet-slenderness ratio, can be as important as billet length, per se; and
- reducing billet length increases billeting losses and subsequent rate of deterioration, and can impact on extractor losses.

Identification of these relationships led to the concept of ‘Harvest Best Practice’ (HBP), where billet length is set to maximum and cleanliness of cane is managed by modulating harvester speed whilst maintaining conservative extractor fan speeds (Sandell and Agnew 2002) to minimise cane loss. Higher operating costs, and difficulty quantifying benefits of HBP have resulted in limited adoption. Consequently, there has been an adverse trend in cane quality across the industry (Anon. 2014) as harvester productivity has increased and fleet size has reduced to manage costs. The value ‘destroyed’ at harvest can be demonstrated to have increased significantly through increased outright losses and reduced final recovery.

Fibre levels in milled cane have increased significantly in the last 15 years (Kent et al. 2014). Whilst there may be some varietal effect, this increase can be argued to predominantly be a function of both increasing extraneous matter (EM) levels and an increase in clean billet fibre caused by juice loss during billeting. The increase in leafy extraneous matter is a function of increasing harvesting speeds (Whiteing et al. 2001; Anon. 2014).

The industry has actively adopted shorter billet lengths to mitigate the adverse impacts of increasing leafy EM on load density. There has been a move from six-blade chopper assemblies when the current industry standard ‘15 inch’ machines were introduced to eight, 10 and 12 blade systems (Anon. 2014) now used. Previous industry research indicated mass losses of up to 10% with short (150-160 mm) billets (Hockings et al. 2000), and further research has suggested actual impact on final sugar recovery can be even greater (James 2003).

**PAYMENT SYSTEMS**

Growing, harvesting and milling operations are effectively standalone sectors in the Australian industry, despite some cross ownership among sectors. Each, therefore, attempts to maximise financial performance, within the normal operating and payment parameters applicable to that operation, and often at the expense of the other sectors. Figure 1 illustrates how the harvesting sector drives costs and revenue of all other sectors, and yet is paid only by the grower.

![Fig. 1. Industry sector interactions.](image_url)
Harvest payment

Despite the impact of harvester operation on recovered cane yield and quality, and the subsequent impact on transport and milling, the harvesting sector is almost exclusively paid on the basis of gross tonnes harvested, with no measure of quality.

Grower payment

The cane price paid to the grower is generally based on the measured recoverable sugar in the cane, the CCS (Commercial Cane Sugar) minus four units and the underlying sugar price, with minor adjustments to this formula between districts. The CCS formula, developed around 1895 in an era of handcut and cleaned unburned cane, estimates recoverable sugar content from the Brix and Pol of first expressed juice and of either measured fibre or average (group) fibre. There is also various ‘equity’ factors used to correct for the ‘CCS curve’, thus compensating growers for cane harvested outside the optimum period of the harvest season. The miller generally retains the difference between the realised price of all products, and the cane price paid to growers.

Australian research (Brotherton 1980; Kent et al. 2010) and comparison against international research outcomes (Reid and Lionnet 1989; Muir et al. 2009) indicate that the accuracy of the CCS determination is adversely affected by higher levels of extraneous matter. The payment system does not reflect the impact of high fibre from extraneous matter on actual mill recovery, productivity and associated costs.

MODELLING FOR OPTIMISATION

Modelling of components of the sugarcane harvest, transport and milling processes is widely practiced to assist in system optimisation, including in cane supply management, transport management and mill process control. Significant resources have been applied to the issues of harvest scheduling for both optimisation of crop sugar content and transport systems, both in Australia (Muchow et al. 2000) and internationally, e.g. Jorio et al. (2006).

Despite being one of the most significant direct costs in the sugar production value chain, and being responsible for the most significant value destruction in the field-to-raw sugar value chain, the harvesting sector has had limited exposure to modelling. The BSES Harvest and Transport model (Ridge et al. 1996) attempted to assist in the understanding of the impact of changing field and machinery parameters and to give guidance in the optimisation of machinery selection. Ridge and Hobson (2000) undertook a desktop study on the impact of harvesting factors on the industry value chain. Sandell and Prestwidge (2004) undertook an analysis of full mill areas, assessing the probable impact of HBP on industry returns, confirming other observations that there was a net cost to the harvesting sector associated with this strategy, with the benefits flowing to both miller and grower.

Maximising industry value

The harvest, transport and processing of sugarcane creates many opportunities for direct and indirect losses of value. Harvesting losses can be ‘visible’ (loss of visible product) and ‘invisible’ (predominantly juice and fibrated cane components). High levels of EM or product prone to accelerated deterioration (short and/or damaged billets) reduce both mill capacity and recovery, as well as increasing direct and indirect milling costs. Payment systems and competition have driven the increase in harvester throughput, and, with this, there has been a demonstrable increase in both direct and indirect value destruction in the industry. Maximising industry value means balancing these sources of value destruction against the cost of the harvesting, transport and milling operations. Given the complexity of the interactions in the process, this can be demonstrated as being well beyond the scope of intuitive assessments, or simple ‘back of the envelope’ reckoning. Modelling the harvesting operation, utilising as many ‘real time’ parameters as possible is the most viable strategy available to optimise the total value chain.

THE TOOL

We have developed the Sugarcane Harvesting Logistics Optimisation Tool (SCHLOT) that is a web-based development of our Crop Value Model, which has been used extensively in international and Australian consultancy work. A simplified version with reduced inputs forms the engine of the Australian Sugar Milling Council (ASMC) Sugar Industry Value Chain...
Analysis Model (Pollock 2013). SCHLOT builds on the capability of the earlier models to evaluate the impact of each stage of the harvest, transport and milling process on the biomass components and potentially recoverable sugar; from the crop immediately prior to the commencement of the harvesting process through to anticipated sugar and by-product recovery. Being web-based, the tool offers numerous advantages over a spreadsheet model, including greater accessibility from portable devices, improved user interface, and live updating, including real time and near real time data. The tool simulates a defined ‘Harvest Event’, and estimates the outcomes, including:

- Recovered cane quality (CCS, Fibre);
- Grower and harvesting contractor payment;
- Harvest and transport costs.
- Mill transport costs and crushing rates based on crop bulk density and fibre; and
- Final sugar and molasses recovery and value and bagasse production.

Over 250 individual parameters are considered in a simulation. In order to improve usability, the interface uses a combination of ‘layering’ parameters and reference libraries to generate representative values for several parameters from a minimised number of user inputs. Simulation parameters are stored in a framework referred to as a ‘harvest event’. The harvest event framework groups parameters according to their frequency of change and dependence on other parameters into the following sets:

Parameters describing the physical field or paddock, including distance to the transloading site, are not generally variable, and are considered static unless specifically updated.

Parameters describing the planted crop including variety and planting configuration (row spacing) change only after replanting. This group is also considered static for the duration of the crop cycle, with the crop class indexing after each harvest event.

Parameters describing the crop at harvest inputs information on anticipated yield and apparent maturity (likely CCS range), which in conjunction with parameters relating to the planted crop, utilise a library to access/derive properties such as leaf:stalk ratio, stalk diameter and clean stalk fibre. This information has been derived from Australian industry plant breeding databases and other sources and literature reviews. In addition, the ‘Crop presentation’ is rated on a scale from ‘Erect’ to ‘Heavily lodged and tangled’.

The harvesting contractor’s equipment and costs are derived from inputs of:

- Equipment make and model (including tracked or wheeled to cross reference with allowable harvesting and field travel speeds);
- Configuration of the chopper system (blades/drum and billet length setting or % maximum feedtrain roller speed);
- Configuration of the extractor system (fan blade diameter and blade type, deflector plate setting, etc);
- The number, size and capacity and relevant performance data on of haulout units.

These parameters allow the general performance of the harvester to be determined at nominated harvester operational settings.

The actual conditions at harvest impact on harvester performance. The impact of moisture on a harvest event is summarised in a single parameter that is highly significant in predicting the efficiency of the cleaning system at extracting both cane stalk (cane loss) and leaf material. It is a non-linear scale from ‘Rain or heavy dew’ through to ‘Hot, crisp trash’. The impact of pre-harvest burning (if performed) on the harvest is also summarised in a single parameter that is significant in determining the initial sugar loss due to the burn, the rate of deterioration between burn and crush, and the residual level of leafy extraneous matter. This parameter is a non-linear discrete scale from ‘Harvested green’, to ‘Extremely hot burn, no leaf material remains’.

**Simulation logic**

The model estimates the change in total biomass and recoverable sugar and operating costs through the process from immediately pre-harvest to final mill outputs. Losses and changes in product composition at each machine-crop interaction are estimated, commencing at either the pre-harvest burn if applicable or at the topper unit in green cane. The estimated impact is based on relationships derived in published data, and from analyses of Australian and international trial results as indicated. Features incorporated into the model are considered below.
Sucrose loss

‘Kill to mill’ sucrose loss is estimated based on work by Foster et al. (1977), Gomez et al. (2006), Lyne and Meyer (2005), Saska et al. (2009) and others, and considers:

- direct loss of recoverable sucrose occurs at the time of burning, dependent on the nominated heat of the fire;
- deterioration between burn and harvest and harvest-to-crush associated with typical burn-to-harvest delays, and rate of deterioration after harvesting correlates with the burned/unburned status, ambient temperature conditions, billet damage and billet length.

Topping

Three topping options at ‘not topped / lightly topped / aggressively topped’ can be selected. This, in conjunction with the input of ‘Crop Presentation’ is utilised to derive the probable efficacy of the topping operation. ‘Aggressive’ topping in an erect crop assumes approximately 80% of tops are removed (Anon. 2014), with other input parameters modulating this efficiency.

Gathering and feeding

In lodged crops, increased stalk damage associated with gathering the crop is reflected in an assumed increased level of stalk damage and subsequently reduced billet quality and higher rates of deterioration (Fuelling 1980; Norris et al. 1998).

Billeting

The performance (losses and billet damage) of the billeting system is related to crop stalk characteristics (fibre, diameter), total mass rate through the machine, chopper configuration (blades/drum) and billet length settings (% maximum roller train setting). The relationships utilised are based on further analysis of the trials conducted using the BSES chopper test rig (Hockings et al. 2000).

Extractor losses

General relationships between extractor fan speed and both cane loss and leafy trash removal are well publicised (Anon. 2014). In their modelling Sandell and Prestwidge (2004) used ‘average’ relationships that had been developed for older harvesters fitted with ‘4 foot’ extractor systems:

- Cane loss (t / ha)= 0.0334 * e0.0048 *fan speed, and
- Extraneous matter = 0.1 − 0.00395 * fanspeed+ 0.101 * elevator pour rate.

Differences in crop and conditions very significantly impact on both cane loss and trash extraction and measured performance can be very significantly higher or lower than the ‘averaged’ result. Equations that describe the performance of modern harvesters have been developed from Australian and international datasets, with tuning to better represent the significant field to field variability that exists in both cane loss and final EM levels. Factors, which have been correlated in the model with this variability, include:

- Field conditions (hot and dry to dewy or wet), and crop presentation;
- Trash levels entering the harvester that have been modulated by the efficacy of topping and/or degree of trash reduction by the pre-harvest burn and variety effects;
- Harvester pour rate, harvesting speed and probable flow rate variability through the throat of the machine; and
- Harvester billet length setting, deflector plate setting and nominal billet diameter (a varietal effect).

Load density and transport costs

Load density is the function of a number of parameters, including cane stalk density, billet length and slenderness ratio, and leafy trash levels. Whilst billet length and leafy trash levels are primary drivers of load density, variety and crop yield also impact on density via the slenderness ratio of the billets (Vitale and Domanti 1997; unpublished data). Relationships have been derived from published and unpublished Australian and international trial data to maximise the accuracy of load bulk density data, based on the billet length and composition of the product in the load. This is then utilised in calculations
in SCHLOT to predict the load density of product transported. The algorithm developed has been demonstrated to give good correlation with measured data.

Deterioration

Deterioration between harvest and crush is calculated in the model as being a function of billet damage rating, billet length and billet storage temperature (Saska et al. 2009). Deterioration rates are also influenced by the crop being harvested green or burned, with higher rates of deterioration after hotter burns, based on published data (Foster et al. 1977). Juice on trash, associated with chopper losses, is assumed to deteriorate rapidly (Sichter et al. 2005).

Mill recovery and performance

Whilst grower payment is assumed to be made based on the CCS of composite product assumed to be passing into the milling train, this is known to over-estimate mill recovery (C. Palmer pers. comm.; Kent et al. 2010) under conditions of high trash levels in the product being milled. Similarly, the increase in fibre impacts adversely on milling rate, extraction and overall recovery.

The Brix, Pol and fibre of the composite product entering the milling train are calculated based on the relative mass and composition of the different components. The composition of the billets calculated from the anticipated crop CCS input into the tool and the typically observed composition of non-cane components. The Brix, Pol and fibre of the non-cane components is related to variety crop maturity and yield and derived from several data sets including the dataset associated with the work by Crook et al. (1999).

Relatively simple strategies are utilised to better assess probable mill recovery, with the assumption that the magnitude of the outcome is conservative. The anticipated sugar recovery is calculated by averaging the estimated recovery from different methodologies/research findings:

- **CCS formula:** The standard CCS formula, the CCS payment formula and published coefficient of work indices are used to determine anticipated sugar and by-product production.
- **South African RV formula** (Wynne et al. 2009): This is a dynamic formula that assesses estimated recoverable sugar (ERC) from standard inputs of Brix in cane, Pol in cane and fibre, with the composition being determined from laboratory analysis of samples taken after the shredder. Greater emphasis is placed on the impact of fibre on final recovery than is incorporated in the CCS formualae (consistent with the argument by Brotherton 1980) and the constants in the formula are regularly updated to represent real factory recovery. Recent published constants are used and updated.
- **Sucrose losses:** Analysis of sugar recovery based on process benchmarking (Wright 2005), where the derived impacts of trash and other EM on the different losses in the milling and processing of the cane, including an assessment of the observed impact of high EM levels on undetermined losses (Palmer pers. comm. 2010).
- **Kent et al.** (2010) determined the anticipated impact on recovered sugar of increasing trash levels and expressed the reduction in anticipated recovery in terms of the impact of fibre associated with EM.
- **Reid and Lionnet** (1989) determined the impact of increasing tops and trash levels on actual sugar recovery relative to the clean-cane ERC. The relationship adopted from this work utilises the fibre of the EM as the functional variable in determining the anticipated depression in recoverable sugar.
- **Muir et al.** (2009) investigated the impact of increasing trash levels in chopper harvested cane via composite shredded samples and utilising standard laboratory analysis. The composition by weight of EM components in chopper harvested cane was used as the functional variable with respect to the derived reduction in anticipated sugar recovery.

Value of products

Sugar, molasses and bagasse prices are user inputs.
Harvesting costs

Estimated harvest cost includes capital, operating and overhead components. The time and motion profile for each harvest event takes into account both static (row spacing, yield) and dynamic (bulk density, number of bins) parameters. Transport costs are based on a cost per trip per transport unit, and unit payload/bulk density.

Impact of changing harvester operation utilising the model

The tool allows direct comparison of harvest strategies (Fig. 2). For each strategy, the tool estimates recovered cane yield and quality, harvest and milling rate and gross financial outcome for each sector. Harvest cost is calculated as outlined earlier, and the harvesting price is used to calculate growing and harvesting sector financial outcomes. Estimated milling sector outcome is the difference between total product value and grower cane payment, minus estimated mill transport costs.

Fig. 2. Tool output of comparison between two harvesting scenarios for the same block of cane (4.8 ha of Q208 yielding 100 t/ha).

Figure 2 shows the comparison of a low harvest cost (left) and maximise cane payment (right) harvest strategy. Maximising cane payment involves a lower total biomass yield (due aggressive topping and higher extractor speed), but increased
cane quality (CCS), due reduced extraneous matter, significantly increases cane price, and paddock gross return. Paddock harvest cost also increases significantly, due to lower harvesting speed, and reduced bin bulk density (haulout trips). In this hypothetical case, the increase in cane payment (AUD 6914) is nearly six times the increase in harvesting cost (AUD 1200). This suggests that there is scope for the grower to pay the harvester more, for a better job, and to still improve financial performance.

CONCLUSIONS

While proficient at controlling direct costs of harvest and transport processes, the Australian industry currently lacks any real way of quantifying value lost during the harvest. This therefore limits the ability to truly optimise the harvesting operation to maximise total recovered industry value. This inability to quantify value loss makes it difficult for all sectors of the industry to be able to negotiate mutually beneficial outcomes based on increasing total value, so minimising costs is usually the primary objective.

Our harvesting optimisation tool uses a wide range of research and trial results to model the harvest/milling value chain (value and costs) and allow users to estimate the real impact of changes in harvesting strategy. This ability to quantify the impact on the harvest/milling value chain has the potential to greatly improve transparency, and provide a basis for negotiation and decision making. Growers and harvester operators are more prepared to agree to a change in harvester operating parameters, resulting in an increase in harvesting costs if the probability of significant further gains are indicated.

By quantifying all major sources of cost and loss throughout the value chain, it allows users to target these sources with appropriate longer-term strategies.

REFERENCES


Modélisation pour optimiser la logistique de la récolte et du transport de la canne à sucre : un outil de gestion et de décision interactivf

Résumé. La canne à sucre est une culture de grand volume, de faible valeur, pouvant facilement subir des dégâts pendant la récolte et à se détériorer ensuite. La présence de non-canne impacte la performance de l’usine. Les coûts de la récolte mécanique et du transport peuvent atteindre 20 % de la valeur du produit, et les pertes évitables pour ce qui concerne la qualité de la canne et de rendement peuvent manifestement dépasser les coûts directs de la récolte. La gestion des coûts de récolte par une augmentation des équipements accroît les pertes de revenu. La Bonne Pratique de Récolte s’est développée comme un concept pour réduire les pertes à la récolte en limitant la vitesse de récolte et de l’extracteur. Cela augmente les coûts de récolte, cependant, l’impact sur la compétitivité et la performance globale des activités de récolte et de transport est variable et difficile à quantifier. En Australie et dans le monde, de nombreux travaux antérieurs ont fourni des données corrélant les conditions de récolte aux pertes, à la qualité de la canne et au final au sucre récupérable, mais peu de travaux ont été conduits pour comprendre la complexité des interactions entre la performance des activités de récolte et de transport. Un modèle, utilisé en Australe et dans le monde a été développé. Le « Sugarcane Harvesting and Logistics Optimisation Tool” (SCHLOT) est un modèle mathématique multiparamétrique sur le web. La saisie des propriétés physiques et agronomiques de la culture, des paramètres de terrain, de réglage de la récolteuse permant de déterminer le rendement en canne possible, sa composition et sa qualité, et, à partir de cela, la production de sucre, de mélasse et de bagasse qui en résulte. Des données de coûts sont aussi déduites des saisie pertinentes et des relations connues. Le papier décrit brièvement les méthodologies selon lesquelles le modèle détermine l’impact de la récolte, du transport et du brouillage tant sur des opérations ultérieures que sur des coûts directs et permet aux utilisateurs d’équilibrer les coûts directs d’une stratégie opérationnelle contre la perte de valeur. Ceci permet d’optimiser les stratégies de récolte d’un champ à l’autre, ou même au cours de la journée.

Mots-clés: Canne à sucre, récolte de la canne, optimisation de la logistique, outil en ligne

Modelización para optimizar la cadena de valor de la caña de azúcar: una herramienta interactiva de asistencia para toma de decisión

Resumen. La caña de azúcar es un cultivo de alto volumen y bajo valor que es altamente susceptible a daños durante la cosecha y el deterioro después de la cosecha. Los residuos de cultivo incluidos causan un impacto negativo en el rendimiento de la molíenda. Los costos de cosecha mecánica y transporte en Australia pueden acercarse al 20% del valor total del producto, y las pérdidas evitables en forma de una menor calidad de la caña y rendimientos reducidos pueden exceder los costos directos de cosecha. La gestión de los costos de cosecha mediante el aumento del rendimiento de los equipos suele intensificar el potencial de pérdida de valor. La Mejor Práctica de Cosecha surgió como un concepto para reducir las pérdidas de cosecha mediante la limitación de la velocidad de cosecha y ajustes en el sistema de extracción. Esto aumenta los costos de cosecha, sin embargo, el impacto neto en la cadena de valor es muy variable y difícil de cuantificar. El trabajo previo en Australia e internacionalmente ha generado conjuntos de datos que correlacionan los aspectos de la operación de la cosechadora con pérdidas, calidad de la caña de azúcar y la recuperación en última instancia, pero
limitado trabajo se ha realizado para entender la complejidad de las interacciones entre múltiples factores en la cadena de valor. Un modelo de hoja de cálculo se ha desarrollado que se ha utilizado en la industria de Australia e internacionalmente. La Herramienta para Cosecha de Caña de Azúcar y Optimización de Logística (SCHLOT) es una herramienta matemática multi-paramétrica basada en la web desarrollada a partir del modelo. Input sobre las propiedades físicas y agronómicas del cultivo, los parámetros de campo y la configuración de la cosechadora y parámetros operativos permiten estimar la producción de caña probable, la composición y calidad, y a partir de eso, el azúcar, la melaza y final de la producción de bagazo que se derivan. Los datos de costos también se derivan de las aportaciones pertinentes y relaciones conocidas. Este artículo describe brevemente los métodos empleados por los cuales el modelo determina el impacto de la cosecha, el transporte y la molienda en ambas operaciones posteriores y los costes directos y permite a los usuarios equilibrar los costes directos de una estrategia operativa contra la pérdida de valor. Esto permite que las estrategias de cosecha sean optimizadas campo por campo o incluso por hora del día.

**Palabras clave:** Caña de azúcar, cosecha de caña de azúcar, optimización de logística, cadena de valor, herramienta basada en la web