

## MONITORING THE HARVESTING OF SUGARCANE AND GENERATION OF YIELD MAPS IN REAL TIME

By

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**KEYWORDS:** Sugarcane, Precision Agriculture, Yield Mapping, Wholestalk Weigh System, Harvest Monitoring.

### Abstract

IN A GIVEN area or plantation it is common to determine the variability in production that exists between harvested sugarcane fields or lots. The agroindustrial sugar sector in the Cauca River Valley of Colombia has appropriate mechanisms for determining and managing the variability of production among the cane lots, but it has not had sufficient alternatives for determining the variability within them. At present, the preharvest task of cutting the cane is done manually in most of the area, while the subsequent lifting of the stalks is done with self-driven equipment. CENICAÑA has developed a system that can be installed on the cane lifters, which records the weight of each bundle and its geographic position. The data are stored and transmitted by cell phone to a computer where they can be visualised for carrying out a precise monitoring of the harvest and generating yield maps. This work describes the structure of the system developed, the methodology for obtaining and transmitting the data, and how to interpret and analyse the yield maps. An analysis of a field harvest, for which it is known where there was fertilisation and where not, shows the value of each weight recorded. In this case, the best estimate of the production in the field is obtained by averaging the data from six consecutive bundles. Both the system for obtaining the data and the methodology for their analyses and the generation of yield maps can be implemented in other agricultural sectors.

### Introduction

Numerous studies have developed systems for monitoring and recording the yield and generation of production maps in manual and mechanically harvested sugarcane crops. Different tools have been developed for obtaining yield maps. Pierossi and Hassauani (1997) installed four compression load cells on an infield (haulout) wagon in a chopper harvesting system; other studies for producing production maps in different crops are reported by Cox *et al.* (1997).

Pagnano and Magahlaes (2001) used production maps to determine variability in sugarcane. Molin *et al.* (2003) generated production maps of manually harvested burned cane by relating the weight of a bundle from a mechanical loader to a georeferenced distance.

The weight of each grab was determined from the total weight of the load gathered in the wagon and the number of grabs.

The majority of the area planted by the agro-industrial sugar sector in the Cauca River Valley of Colombia is harvested manually, and the cane is piled in the field (windrow) to be picked up by self-propelled loaders and deposited in wagons that are taken to the factory by tractor or truck.

The Colombian Sugarcane Research Center (CENICAÑA) has been developing different systems for the georeferenced weighing of sugarcane. In 2006 the Agronomy Program began the instrumentation of a commercial-scale self-dumping wagon with load cells on its four sides,

together with a data storage system for weighing the Center's experiments at the different sugar mills. In this way they could obtain the weights of each plot with its treatments, whether by manual or mechanical harvesting. Later a system for georeferencing (GPS) was installed in the system in order to generate yield maps.

In 2007, the Geomatics Area at CENICAÑA began developing a geo-referenced weighing system that also made it possible to transmit the data and generate intrafield yield maps in real time, using the instrumentation of the cane lifter. This system was designed for use in the manual harvesting of sugarcane. It is important to quantify the within-field production in different zones. This is to allow management of the crop variability and to make more efficient use of resources when taking investment decisions with respect to a production area. The GIS and geostatistics are used to quantify the differences in production within the lots and then generate isoproductivity curves; while spatial analysis is used to carry out studies of economic efficiency and evaluate the differences in intralot productivity.

## Materials and methods

### Weighing system

A compression load cell (5000-kg capacity) was mounted in a mechanical system with four disks (Figure 1), which allowed pressure to be exerted on the cell every time that cane is picked up with the loader. The load cell then generates an electrical analog signal (millivolts), which is recorded by the weight indicator (Prometalic Scales, model PRO-1500), which stabilises the signal and sends the weight data via a serial port to a datalogger. For the georeferencing and sending the information, equipment was used that integrates a GPS and a wireless modem (Enfora Spider, model MT-G 2208). For the synchronisation, storage and transmission of the information, a datalogger (Campbell Scientific, model CR1000) was used with a dedicated a program written in CR Basic language.



Fig. 1—Mechanical load cell mounting system installed on the cane loader.

### Calibration

After mounting the load cell on the disks, a preliminary calibration of the weighing equipment was done, setting weights with predetermined values; and the corresponding voltage was

induced in the load cell. The PRO-1500 indicator was used in this process in order to establish the zero value of the weighing system.

### Data recording

The datalogger has four serial ports, of which two are used for connecting the GPS and the load cell. The weight indicator records the signal of the load cell, displays it visually and sends it to the serial port of the datalogger. The datalogger synchronises the recorded weight with the data on the position given by the GPS. Then the data are stored in the datalogger and sent by the modem through the GPRS (General Packet Radio Service) network to a Web server, where they are kept in a database.

The process of recording the data is controlled by the loader operator who presses a recording button that communicates with the datalogger. The end user accesses the information using a Web explorer with SVG (Scalable Vector Graphic) support. The communication between the server and the user is done via a Hypertext Pre-processor (PHP, a Personal Home Page tool)

### Sending the data

The cellular modem uses the GPRS commercial network for sending the information that is extracted from the serial port of the datalogger, making use of AT commands for obtaining the data from the GPS, which includes the UTM (Universal Transverse Mercator) hour, geographic position and the quality of these data (Figure 2).

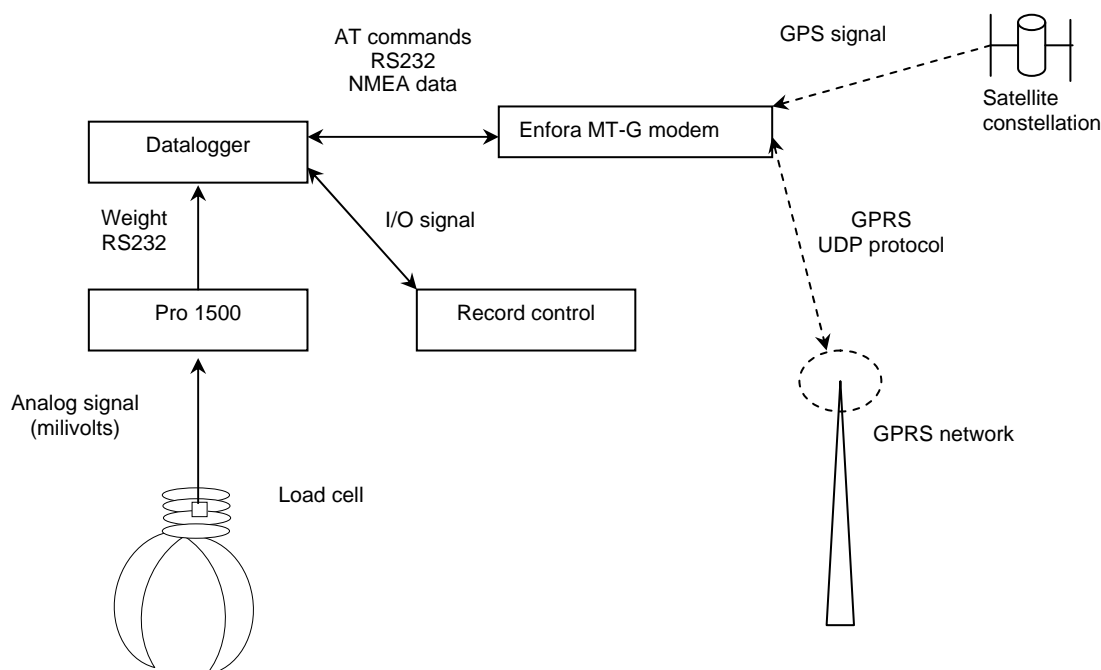


Fig. 2—Schematic of the weighing system installed on the cane lifter.

### Productivity maps

The yield map is generated with the information on the weight and its geographic coordinates. This map depends on two variables:

- The number of furrows per windrow of cane (5 or 6 cut furrows piled in a single row) and;
- The distance between the furrows.

The loader obtains the data from a nominated area every time that a certain distance is run, piling the cane to be lifted later; it is necessary to obtain the starting and the end points of each run of the lifter and the respective weighing in order to determine the production area. Each production area is connected to the previous one, which means that every time that the lifting process is begun,

the operator has to mark the starting point of the windrow to establish the first production zone. Figure 3 shows the diagram for producing the yield maps in real time in each windrow.

All data are stored in a PostgreSQL-PostGIS database; and by means of a geospatial operation, the information is obtained on the plantation/lot in which the cane is being picked up.

The PHP language was used to create an application that takes into account the position, weight, the azimuth between points, and the distance parameters between furrows and number of furrows per windrow to generate the production areas.

The output format of the graphic that the PHP generates is SVG, which is an XML (Extensible Markup Language) format that can be seen on the Web explorer. The application calculates the yield for each production area in TCH (tonnes of cane per ha), classifying each area in a range of yield.

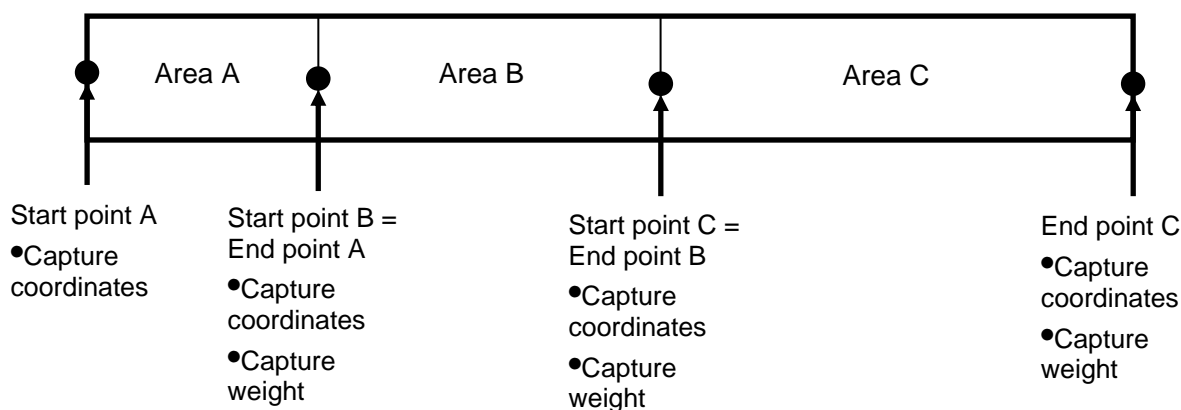


Fig. 3—Diagram for generating the yield map on-line in each windrow.

### In-field evaluation

The system was evaluated in a manually harvested field at Cenicaña (30° 21' latitude North, 76° 18' longitude West) in November 2008. The lot had an area of 8748 m<sup>2</sup>, and was planted with variety CC 85–92, at a distance of 1.5 m between furrows.

There were two fertilisation treatments: one with fertigation (windrow 3, 6 and 8) and the other with conventional fertilisation, applied mechanically (windrow 2, 4 and 9). There was one check without fertilisation (windrow 1, 5 and 7).

Each treatment had three replications formed by six furrows along field 8. An 80-hp lifter (Metalagro, model AC-80) was used, on which the previously described equipment was installed. In total, there were nine windrows, each one formed by six furrows corresponding to each treatment and replication.

The furrows were oriented in an east-west direction, and each treatment was placed along the furrow (108 m long). In total, the equipment recorded 318 weights with their corresponding coordinates. The windrow weights were analysed, yield determined and the results graphed.

The data were analysed using descriptive statistics and Kolmogorov-Smirnov's and Shapiro-Wilks' normality tests. An analysis of variance was applied for the treatments, using Tukey's test, with a 95% level of confidence.

### Results and discussion

The descriptive statistics for each windrow are given in Table 1. Windrow 1 and 7 had values very close to the mean, the median and the mode and a coefficient of asymmetry less than 1, indicating a symmetric distribution of frequencies; thus they are near a normal distribution.

Similar results were obtained when the Shapiro-Wilks test was applied to all the windrows. All the windrows, except for 1, 7 and 9, had data discrepancies (very high), which should be revised

carefully, as well as the very low weight values in windrow 3 and 6. The null hypothesis for this test was that the weights of each windrow were characterised by a normal distribution (P-value > 0.05).

**Table 1**—Descriptive statistics for the weight (kg) of the nine windrows.

Statistic	Windrow 1	Windrow 2	Windrow 3	Windrow 4	Windrow 5	Windrow 6	Windrow 7	Windrow 8	Windrow 9
Mean	318	337	347	377	366	338	325	343	365
Median	310	330	338	365	350	338	333	330	360
Mode	310	330	320	325	380	370	315	345	310
SE	6.92	11.31	13.09	15.58	15.89	8.66	5.98	14.14	9.20
SD	40.91	69.71	78.52	89.51	85.55	49.00	30.51	81.25	53.67
Sample variance	1674.03	4860.03	6164.98	8011.70	7318.47	2401.21	930.96	6602.32	2880.86
Kurtosis	-0.54	4.05	8.58	4.60	5.31	1.81	0.38	14.46	-0.02
Coefficient of asymmetry	0.03	1.19	2.22	1.69	2.11	-0.83	-0.39	3.28	0.80
Range	170	385	455	470	395	230	135	470	205
Minimum	230	210	225	235	245	185	250	250	295
Maximum	400	595	680	705	640	415	385	720	500
Sum total	11 120	12 800	12 505	12 425	10 600	10 820	8445	11 335	12 425
No. of data	35	38	36	33	29	32	26	33	34
Level of confidence (95.0%)	14.05	22.91	26.57	31.74	32.54	17.67	12.32	28.81	18.73

The ANOVA revealed that windrow 1, 5, 6 and 7 were similar among themselves, but different from windrow 2, 3, 4, 8 and 9.

Similar tests were done with the TCH data in accordance with data for just one weighing (one bundle), two consecutive weighings (two bundles) and so on, successively, until reaching yield values for 8 bundles together.

Table 2 shows the P-values for the Shapiro-Wilks and Kolmogorov-Smirnov tests, the average and standard deviation. The TCH values that met with a normal distribution were those for 6 and 8 bundles. Figure 4 shows the different statistical treatments carried out with the data.

**Table 2**—Tests for determining normality of the data in accordance with the number of bundles.

Quantities of bundle	Indicator (1)	Indicator (2)	Average (TCH)	SD
1	<0.01	<0.01	133.8	53.79
2	<0.01	>0.15	125.4	30.75
4	<0.01	<0.01	123.5	23.57
6	>0.1	>0.15	121.8	18.78
8	>0.1	>0.05	122.2	18.15

(1) Shapiro-Wilks, (2) Kolmogorov-Smirnov.

If the P-value is >0.05, there is not sufficient evidence for suggesting that the data do not follow a normal distribution.

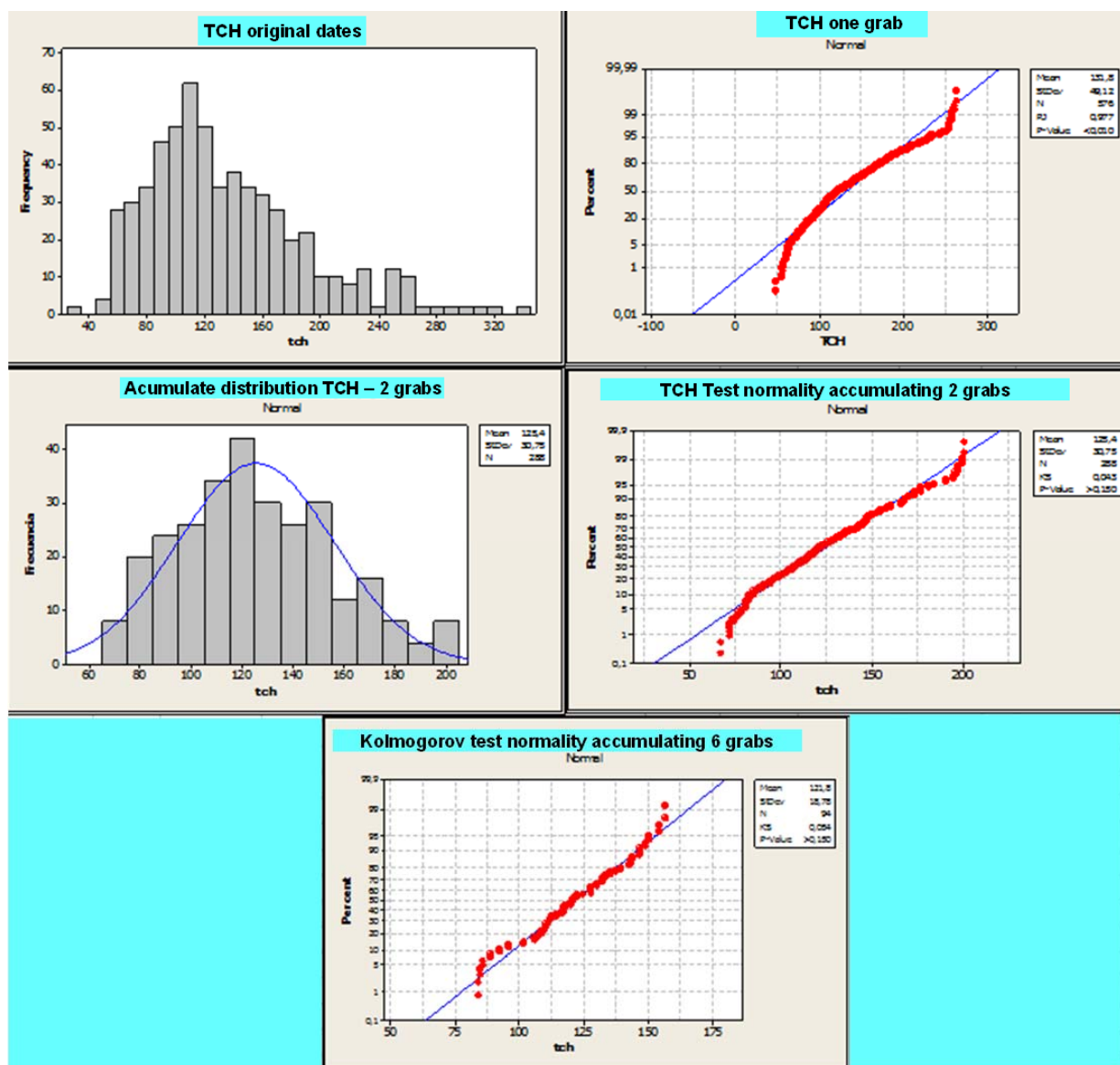


Fig. 4—Examples of statistical analyses applied to the data with different bundles (grabs).

For carrying out the geostatistical analyses, work was done using the TCH data, grouping the different quantities of bundles and using the one that described a normal performance in order to guarantee greater precision in the analyses (Rey and Ovalles, 2001).

The geostatistical analysis concluded that when using six bundles, a theoretical exponential model and an anisotropic at  $303^\circ$ , which corresponds to the direction of the bundles in the field, the best spatial dependence was found, using the ratio  $C/(C_0+C)$  100%; a  $C_0$  of 0.00 nugget effect (sampling error); a spatial relation (sill) of 407.56; a range of 52.16 and a mean square error for the cross-validation of 0.94.

It was also found that, by increasing the number of grabs in the cluster, the proportion that measures spatial dependence  $C/(C_0+C)$  increased 14% with 2 bundles to 78% with 4 bundles, and 100% with 6 and 8 bundles. Although the spatial dependence was high with 4 bundles, there are doubts as to the normality of the data; thus it was not selected.

Figure 5 is the result of the data analyses and shows the yield maps (TCH) based on the ranges of production quartiles that correspond to the yield map as is presented in real time and the result of using the method of interpolation found (exponential).

Both maps show the particular condition of the field having an unfertilised area, where the production was different but where there were spatial variations along each windrow.

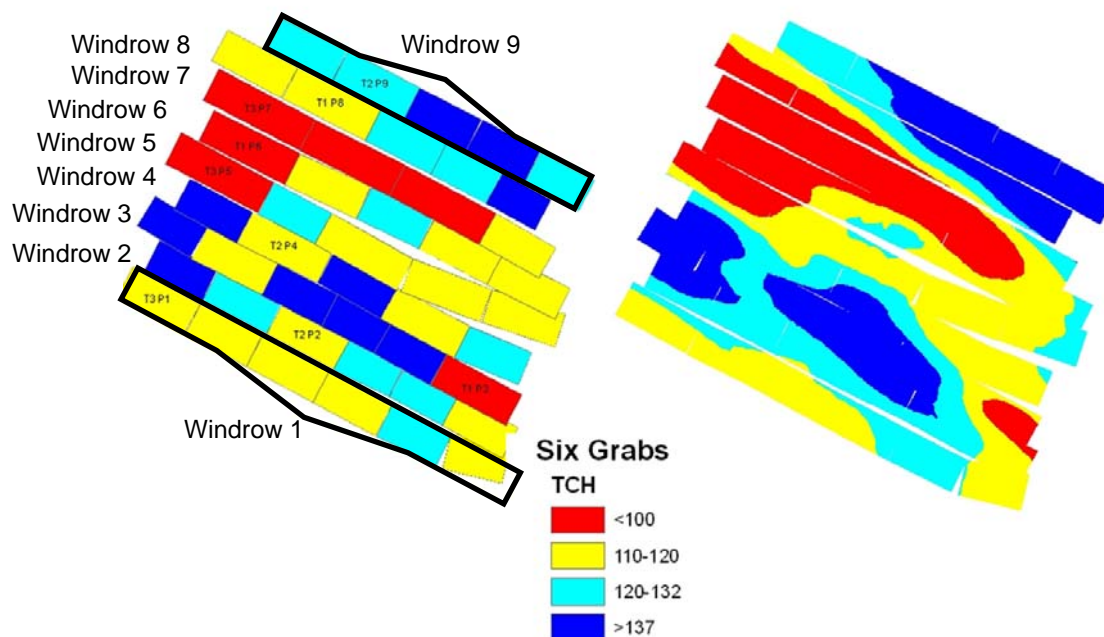


Fig. 5—Spatial distribution of the TCH in a lot, by windrows (left) and continuously (right).

## Conclusions

Currently, the system is used to weigh all experimental plots in Cenicaña.

Some sugar mills are beginning to incorporate the system in their harvesting process (cane loaders and computers)

The system can be used when the harvesting is done with self-dumping equipment unlike other systems.

With the system developed, yield maps can be generated in real time based on weight values and their coordinates.

By means of a computer connected to the Internet, those who are interested in monitoring the harvesting can learn about its progress and the within-lot variability of yield in any place.

It's necessary to analyse all dates of each lot or field because continuous data do not necessarily mean that they comply with the criterion of normality. In the analysis of the case in this document, which grouped 2, 6 and 8 bundles, there was sufficient evidence to suggest that the data followed a normal distribution.

The system can be employed for analysing production in other agricultural systems such as fruits, oil palm, rice, potatoes or similar crops.

The system is being patented initially in Colombia.

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## SUIVI DE LA RECOLTE DE CANNE A SUCRE ET GENERATION DE CARTES DE RENDEMENT EN TEMPS REEL

Par

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**MOTS CLÉS: Canne à Sucre, Agriculture de Précision, Cartographie de Rendement, Système de Pesage de Cannes, Entières pour Suivi de Récolte.**

### Résumé

DANS UNE région donnée ou une plantation, il est courant de déterminer la variabilité de production entre les différents champs ou parcelles récoltés. Le secteur agro-industriel de la vallée de la rivière Cauca de Colombie a des moyens appropriés pour mesurer et gérer la variabilité de production entre les parcelles de canne, mais n'a pas de méthode alternative pour mesurer leur variabilité intrinsèque. Actuellement, la récolte de la canne est manuelle dans la presque totalité de la zone, alors que le chargement est effectué avec des chargeuses automotrices. CENICAÑA a développé un système installé sur les chargeurs qui permet d'enregistrer le poids de canne dans chaque grappin ainsi que sa position géographique. Les données sont stockées et transmises par téléphone portable vers un ordinateur qui permet de les visualiser pour un suivi précis de la récolte et pour générer des cartes de rendement. Ce papier décrit la structure du système développé, la méthodologie pour l'obtention et la transmission des données, ainsi que la façon d'analyser et d'interpréter les cartes de rendement. L'analyse de la récolte d'un champ où les zones fertilisées ou non sont connues montre la valeur de chaque poids enregistré. Dans ce cas, la meilleure estimation de la production du champ est obtenue en moyennant les données de six grappins successifs. Le système pour obtenir les données, la méthodologie pour leur analyse et la génération des cartes de rendement peuvent tous être implémentés dans d'autres secteurs agricoles.



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**PALABRAS CLAVE: Caña de Azúcar, Agricultura de Precision,  
Yield Mapping, Wholestalk Weigh System, Harvest Monitoring.**

### Resumen

EN UNA zona determinada o de plantación es común determinar la variabilidad de la producción que existe entre los campos de caña de azúcar cosechada o lotes. El sector azucarero agroindustrial en el valle del río Cauca, Colombia cuenta con los mecanismos adecuados para determinar y manejar la variabilidad de la producción entre lotes de caña, pero no ha tenido suficientes alternativas para determinar la variabilidad dentro de ellos. En la actualidad, la labor de corte antes de la cosecha de la caña se realiza manualmente en la mayoría de la zona, mientras que el alce de los tallos cortados se hace con equipos autopropulsados. CENICANA ha desarrollado un sistema que puede ser instalado en las alzadoras de caña, este registra el peso de cada ñada y su posición geográfica. Los datos son almacenados y transmitidos por teléfono celular a una computadora donde se puede visualizar para llevar un monitoreo preciso de la cosecha y adicionalmente generar mapas de rendimiento. Este trabajo describe la estructura del sistema desarrollado, la metodología para la obtención y transmisión de los datos, y cómo interpretar y analizar los mapas de rendimiento. Un análisis de la cosecha de un campo, del cual se sabe donde hubo fertilización y donde no, muestra el valor de cada peso registrado. En este caso, la mejor estimación de la producción en el campo se obtuvo promediando los datos de seis ñadas consecutivas. Tanto el sistema de obtención de los datos y la metodología para análisis y generación de mapas de rendimiento pueden ser aplicadas en otros sectores agrícolas.

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