# MEASURING AND MAPPING SUGARCANE GAPS

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## ABSTRACT

Sugarcane is an important semi perennial crop in tropical regions of the world as the principal source of sugar and bioenergy. A sugarcane important parameter is the gaps caused by problems during planting and harvesting. Distances above 0.5 m between two stalks along the sugarcane row are considered gaps and it is usually defined manually by a team measuring gaps in field samples, and expressing results as a percentage of gaps in relationship with the total sugarcane row distance. We developed a technique to measure and locate gaps in the field by using a photoelectric sensor horizontally positioned underneath a vehicle. This sensor was connected to an encoder and a GNSS receiver to compute gaps measure and the distance between these gaps. Initial tests were run under controlled conditions and field tests were conducted on newly planted and first ratoon areas. Sample plots were established to compare manual and sensors readings. Statistical tests showed no statistical difference between manual and sensor measuring methods and the correlation were 0.80 on a planted field and 0.66 to the first ratoon comparison. With this method it is possible to georeference the measurements allowing the generation of maps representing the spatial distribution of gaps, giving to the user an information about gaps occurrences and their locations.

**Key words**: sensor, automation, crop failures

## INTRODUCTION

Sugarcane is responsible for 80% of the sugar produced in the World (calculated from FAO). It is cultivated in approximately 26.1 mi ha (FAO) and Brazil is the largest producer with 9.8 mi ha, where it is also important as raw material to produce ethanol, which is used especially in flex-fuel cars reducing fossil fuel use and offsetting carbon, presenting itself as a cleaner and renewable source of energy (Goldemberg, 2007; Goldemberg et al., 2008; Pacca and Moreira, 2009).

As any other crop it demands a constant practical innovation aiming higher yields, better quality and lower costs (Bramley, 2009). Site specific management practices have been adopted by sugarcane growers (Silva et al., 2011) as an important tool to reach higher yields and minimize environmental impacts.

Sugarcane fields are planted each five years, in average, and an important parameter that is monitored to indicate the quality of the planting is the gaps caused by problems during planting operation (e.g. absence of stalks, pests, dry weather, erosion, etc). In the same way, the economic return of plantations greatly depends of a good stand along the years. Especially during harvesting rhizomes can be pulled off by the base cut disks of the harvester if the sugarcane root system is too shallow. Trailers and tractor may cause damages to the ratoon by traffic over the harvested rows causing injuries and soil compaction as the tractor and the harvester sequentially cross the area (Freitas, 1987; Farina and Ziberstain, 1998; Raper, 2005). As observed by Paula and Molin (2013), soil compaction, especially on clay soil, increased due to traffic over the rows and has a strong relationship with sugarcane production and crop longevity which means that it may have to be replanted sooner than expected.

Gap on sugarcane plantations are considered as the distance projection larger than 0.5 m between two consecutive stalks along the sugarcane row and measured at the soil level from stalks centers (Stolf, 1986). It is usually taken manually by a team witch walks through the fields measuring gaps in predetermined points (field samples) and expressing results as a percentage of gaps in relationship with the total sugarcane row distance.

Measurement of plant´s gaps has been extensively studied on annual crops and especially on grains the planter monitors that senses the fall of seeds in the row have been widely adopted. For maize it is also possible to detect individual plants by a mechanical sensor on the combine head rows (Sudduth et al., 2000) or by a photoelectric sensor (Plattner and Hummel, 1996). On perennial crops and cultivated forests the most used techniques are related to image processing and canopy height measurements to detect the nonexistence of individual plants (Tesfamichael et al., 2009).

Optical sensors that measure crop reflectance have been used in estimating sugarcane gaps (Frasson et al., 2007) and, associated with geographic coordinates obtained from a GNSS receiver, lead to very useful information that allows locating where there are gaps inducing a quick action to correct it by replanting. As this work can be done associated with routine operations it can cover larger areas than the manual measuring. It is possible to have massive information about the whole field and not only from sampling locations. Images offer almost the same solution but both have limitations regarding resolution as the data is collected from the top and leaves at the time of monitoring will cover and create confusion for the detection of individual plants. In this way, detecting individual plants close to the ground may have more effectiveness, so in this work we evaluated a photoelectric sensor as tool to measure sugarcane gaps after planting and consecutive ratoons, comparing it with manual measurements and analyzing how similar they are.

## MATERIAL AND METHODS

A photoelectric sensor BA2M-DDT (Autonics, Yangsan, Si, Korea) was used, horizontally positioned, to detect stalks. It uses a LED infrared light source with an adjusted sensitivity to up to 2.0 m of distance to the target, working at 4 Hz with 1 ms approximate response time. It was integrated to a data logger CR1000 (Campbell Scientific, Logan, Utah, USA) together with a 240 cycles per revolution encoder (Hohner, Artur Nogueira, SP, Brazil) installed on a tractor non activated front wheel, composing the gap measuring system. It also comprised a L1 GPS receiver (AG 132, Trimble, Sunnyvale, California, USA) to provide geographic coordinates and to georeference the generated data. A dedicated code on the data logger established the communication and the calculations of spacing between stalks intervals.

For the system validation a test was established using regular obstacles simulating stalks (Fig. 1). Wood stakes with varying widths (0.05, 0.10 and 0.20 m) were put stand in the ground with distances of 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 m between each other. The sensor was mounted in the front of a tractor running at speeds of 1.3, 1.8 and 3.0 m $s^{-1}$ with six replications corresponding to the successive passes of the sensor laterally to the stakes. Analysis of variance tested the influence of forward speed and stake widths as a function of the interval distance between obstacles.

**Fig. 1. Test using regular obstacles simulating stalks (left) and photoelectric sensor positioned underneath in front of the tractor (right)**

Data collected were processed to calculate gaps as a percentage of a total scanned row distance (equation 1) and manual gap percentage was calculated as proposed by Stolf (1986), on equation 2.

$$G = \frac{d}{DFs} x100 \quad (1)$$

$$G = \frac{\sum d}{\sum DF} x\ 100 \quad (2)$$

where:
G – gaps (%)
d - absence of stalks distance (m)
DFs – distance between starting gaps (m)
∑d – sum of gaps (m)
∑DF – total row measured.

On the first field test the photoelectric sensor was directly measuring absence of stalks in six 60 m long sugarcane rows. Gaps were also manually measured in the total extent of each row to evaluate the capability of the sensing system on detecting stalks gaps.

Field tests were performed in new planted areas and after harvesting (regrowth conditions). Tests were run initially in three fields summing 17.2 ha with sugarcane planted around 90 days before, at 1.5 m row spacing, in a sugar mill area around Piracicaba, SP, Brazil (22°33'27"; 47°28'0"). Plots of 6.0 x 6.0 m (four crop rows) were allocated in the field in a grid of approximately four plots per hectare (Figure 2). The sensor data values where extracted from each plot by graphically delimiting them on a GIS (SSToolBox®, SST Software, Stillwater, OK, USA).

Sugarcane gaps were manually measured on each plot considering the maximum stalk distance of 0.5 m as the limit for non-gaps. The sensing system was installed on a tractor performing the row leveling operation, normally conducted around 90 days after planting, at speed of 1.7 m $s^{-1}$, taking two rows each pass and measuring gaps at 50% of the rows.

Ratoon sugarcane gaps evaluations were performed in the same region (22°33'22"; 47°28'0") at a first ratoon sugarcane field with 1.5 m of row spacing, 90 days after harvest. The sampled area of approximately 20 ha was also evaluated at 50% of the rows, with manual evaluation performed in samplings of 6.0 x 6.0 m with a density of one sample for each two ha.

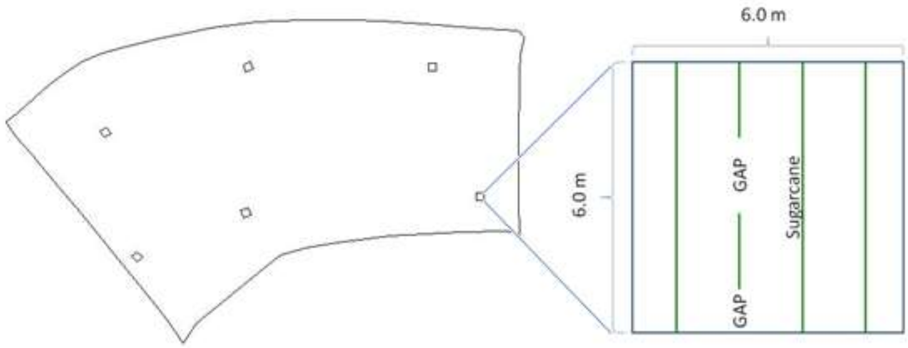


**Fig. 2. Example of individual plots location in field**

All data were analyzed by a *t*-test to compare samples by pair and a correlation to explain how much the sensor was capable to recover from the manual measures. Correlation coefficient (r) was used to express the correlation between sensor and manually measured gaps.

## RESULTS AND DISCUSSION

Preliminary tests in laboratory indicated that the sensor can take up to four readings per second and the minimum distance reading between obstacles was 5 pulses, corresponding to 0.07 m. It may be increased with changes on the encoder, increasing its sensitivity. Validation tests, using regular obstacles simulating stalks, showed the photoelectric measurements accuracy presenting errors between 0.02 and 0.03 m under speeds varying from 1.3 to 3.0 m $s^{-1}$ and obstacles ranging from 0.1 to 1.0 m of gap (**Erro! Fonte de referência não encontrada.**3). At this stage correlation between stakes arrangement and sensor measured distances was close to 1 demonstrating good measurement accuracy.

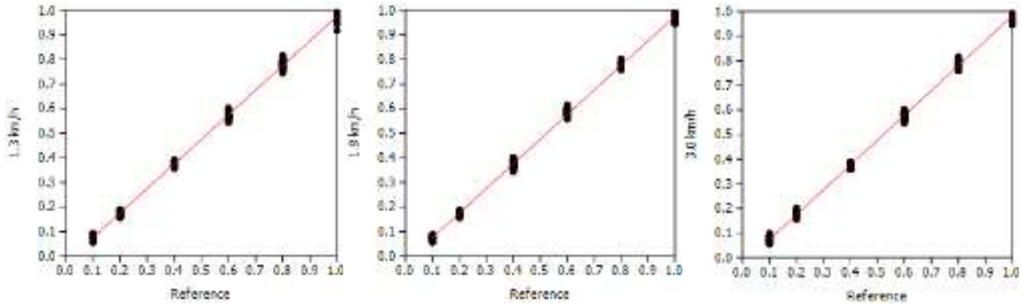

**Fig. 3. Correlation between photoelectric measurements and stakes distances, from obstacles ranging from 0.1 to 1.0 m of gaps, obstacles widths of 0.05, 0.10 and 0.20 m and under forward speeds varying from 1.3 (left), 1.8 (center) and 3.0 m s$^{-1}$ (right)**

Results of first test performed at a sugar cane field are shown at

Table 1 and the percentage of photoelectric sensor gaps were close to those manually measured. It gave an indication that the system was able to work fine under field conditions.

**Table 1. Distances without stalks measured by the photoelectric sensor in the test area of six 60 m sugarcane rows**

| Row | Failures (%) | | Corelation (r) |
|---|---|---|---|
| | Mannually measured | Sensor measured | |
| 1 | 41.3 | 46.3 | 0.99* |
| 2 | 46.3 | 50.7 | |
| 3 | 23.8 | 21.8 | |
| 4 | 31.3 | 28.1 | |
| 5 | 26.2 | 24.8 | |
| 6 | 46.3 | 54.8 | |

* *p* value = 0,05

Results obtained from the statistical tests shown that there are not statistical differences between manual or sensor measuring methods (t-test) and the r (

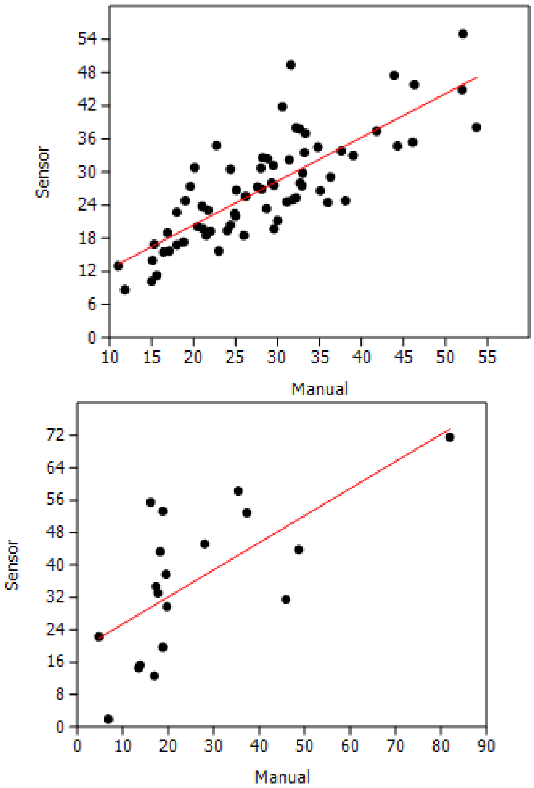


Fig. 4) were 0.80 on the planted fields and 0.66 on the regrown area (first ratoon). Table 2 resumes the statistics of planted and first ratoon areas.

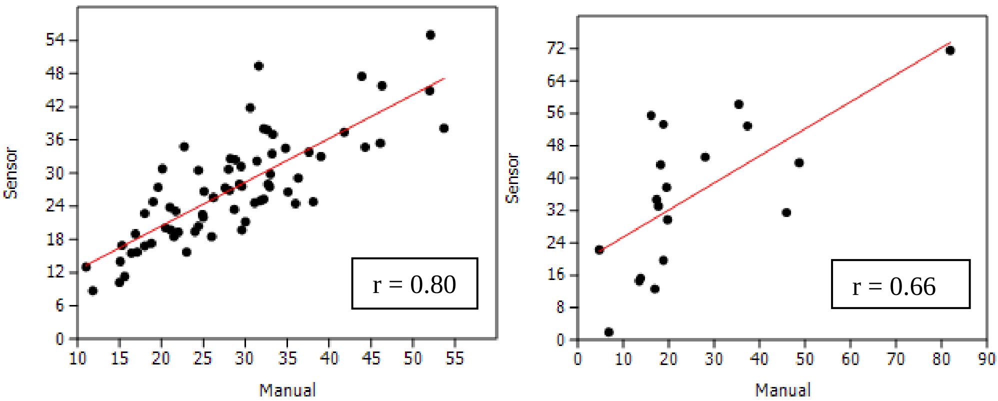


**Fig. 4. Correlation between gaps measured manually and by the sensor system on plant crops (left) and first ratoon crops (right)**

On both cases test-t had *p* values higher than 5% showing we cannot reject the hypothesis of the same means for both measures on planted and first ratoon areas.

Newly planted areas showed a better results than on the first ratoon area but in both we had good correlation between manual and sensor methods of measure gaps at sugarcane crop. The height from the ground that the sensor is located may cause some noise as sometimes it senses sugarcane leaves and not only stalks. The arrangement of leaves on planted and on regrowth areas is different so care must be taken on positioning the sensor relative to the ground.

**Table 2. Statistical summary of results from planted and first ratoon areas (%)**

| Statistics | Planted areas | | First ratoon area | |
|---|---|---|---|---|
| | Manual | Sensor | Manual | Sensor |
| N | 70 | 70 | 19 | 19 |
| Min | 11.0 | 8.7 | 4.7 | 1.9 |
| Max | 53.7 | 55.0 | 81.9 | 71.6 |
| Mean | 28.4 | 27.1 | 25.2 | 35.6 |
| Std. error | 1.1 | 1.1 | 4.1 | 4.2 |
| Stand. dev | 9.6 | 9.5 | 18.1 | 18.3 |
| 25 prcntil | 21.0 | 19.7 | 16.1 | 19.7 |
| 75 prcntil | 33.0 | 33.1 | 35.4 | 52.9 |
| Kurtosis | 0.18 | 0.31 | 4.40 | -0.59 |

The photoelectric sensor has the capacity of collecting continuous data and with the processing and georeferencing the starting point of each gap can be shown in a map (Figure 5). In the manual measurements only portions of sampling rows are monitored and the result is an average number from local readings. A detailed resolution obtained from photoelectric sensors allows a better way to decide which area has to be replanted in fields that were just planted or renovated if injuries compromise the crop economical threshold.

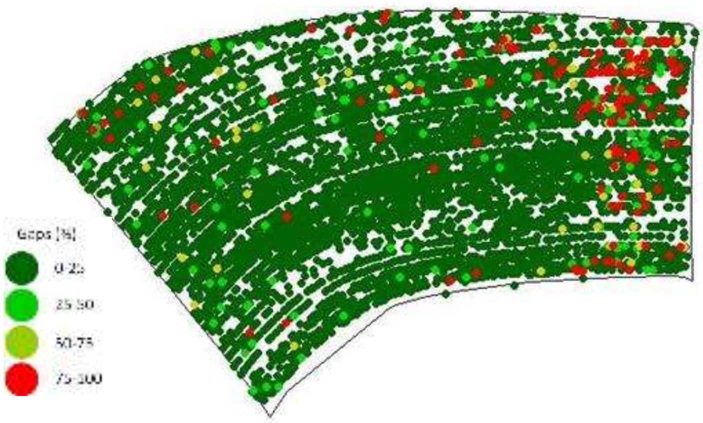


**Fig. 5. Illustration of a field of 20 ha showing an area on the right-hand with larger gaps (points in red represent locations with more than 75% of gap)**

Usually, replanting is done based on yield drop (Keerthipala and Dharmawardene, 2000) and there is not much in the literature relating gaps and yield. Certainly, georeferencing gaps, their intensity and extension, displaying them in a map, allows a useful tool which can lead a better management by acquiring complementary information about the field like problems related to erosion, pests and others, showing more precisely where to act, saving labor and time.

## CONCLUSION

The photoelectric sensor system developed and tested did not show statistical difference on gaps measurements from the current manual method, and it explains up to 66% of gaps encountered by manual monitoring with the advantage of intensive sampling and higher data density. It can be mounted in any vehicle that is traveling on the field during the growing season for any other operation. With the help of maps of gaps it is possible to identify their intensity and extension indicating areas that show concentrations of gaps.


## ACKNOWLEDGEMENTS

To Grupo São Martinho for the field work support and to the Research and Projects Financing (FINEP) from the Ministry of Science and Technology through the PROSENSAP project and the National Council for Scientific and Technological Development (CNPq) for their financial support.


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