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Field-testing of a sugar cane yield monitor in Brazil

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Abstract. *Up to date, the use of precision agriculture concepts on sugar cane is limited due to the difficulty in detecting the spatial yield variability and the effects of site specific input applications. A yield monitor, produced by Austoft® (CNH) and installed on a sugar cane harvester was evaluated during the 2002 season under field conditions. The main objectives of this work were to characterize the performance of the yield monitor, evaluate its accuracy under different setups for yield calculation and evaluate the use of a non differential correction positioning system on producing yield maps. Field testing limitations did not allow for more conclusive information regarding the accuracy of the load sensor. Even so it was possible to take some good indications, especially related to yield mapping with maps showing consistent information on yield variability in the field. The test with the use of non DGPS positioning system indicated that it is possible to use it on positioning the yield points. The difference between maps produced with GPS and DGPS did not justify the use of DGPS when considering the cost of the differential correction under local conditions.*

Keywords. Sugar cane, yield mapping, precision agriculture

Introduction

Generating yield maps for different crops has been an intriguing task for researchers and industry. Commercial products have been available for grains since 1991 (BLACKMORE, 1994) and for cotton since 1997 (KHALILIAN et al., 1999). Works on other crops have been done, as coffee (SARTORI et al., 2002), peanuts (KVIEN, 1995), forage (AUERNHAMMER et al, 1995), hay (BASHFORD et al., 1995) and others.

An initial attempt on generating sugar cane yield maps was conducted by Cox et al. (1998), but no details were provided on their system. BENJAMIN et al. (2001) designed and tested a sugar cane yield sensor based on a scale mounted on the floor of a sugar cane harvester elevator. Tests with different cane maturity, variety, flow rate and row lengths using a weigh wagon as comparison presented a prediction with slope of 0.9 and correlation of 0.966, Errors ranged from 0 to 33% and the average error of 118 tests was 11.05%.

JHOTY et al. (2002) report an experiment of precision agriculture applied to sugar cane in Mauritius using a sugar cane yield monitoring system from Australia for generating yield maps. The sensor was based on a scale mounted on the floor of a sugar cane harvester elevator. Similarly, PAGNANO and MAGALHÃES (2001) presented a yield sensor using a weighing frame with transducers on the harvester elevator and reported average error of less than 3.2%, but very low individual row accuracy on field tests.

Hernandez et al. (2003) presented a biomass flow sensor adapted to the harvester roller feeder using a displacement transmitter for measuring biomass input. Approaches of yield mapping on sugarcane using NDVI index from satellite images also have been proposed (Lamparelli et al., 2003).

A yield monitor added to a sugar cane harvester will produce sugar cane yield maps and will allows the sugar cane industry to make use of the techniques and management enhancements provided by precision agriculture. It has been widely expected in countries like Brazil where sugar cane has an important shear on the agricultural activity and with a high demand for new technologies. Sugar cane industry in Brazil is represented by approximately 260 sugar mills and about 5 million ha.

Up to date, the use of precision agriculture concepts on sugar cane is limited due to the difficulty in detecting the spatial yield variability and the effects of localized input applications. A yield monitor, produced by Austoft® (CNH) and installed on a sugar cane harvester was evaluated during the 2002 season under field conditions. The main objectives of this work were to characterize the performance of the yield monitor, evaluate its accuracy under different setups for yield calculation and evaluate the use of a non differential correction positioning system on producing sugar cane yield maps.

Material and Methods

The yield monitor under test consists on a suspended weigh pad that measures the instantaneous weigh of cane passing over the elevator using a load cell. It also measures the inclination of the elevator at the weigh pad position. A signal conditioning unit, installed under the weigh pad, receives the signals from the elevator speed sensor and the load cell and sends it to the monitor on the cab through a CANBUS connection. The monitor unit consists on a data logger and display that collects positioning information from a GPS receiver without differential correction and records position and yield data into a memory storage card and displays the information to the operator.

During the tests the data collection program had four configuration options: 1. mass-flow-rate - uses all the sensor to calculate yield; 2. mass (no speed) - calculates the yield without considering the signal from the elevator speed sensor; 3. mass (no acceleration) - calculates the yield without considering the inclination of the elevator; 4. instant weigh - uses only the instant weigh of cane on the elevator to calculate the yield.

The monitor was installed on a Brastoft 7700® (CNH) sugar cane harvester. The weigh pad, elevator speed sensor and signal conditioning unit were installed on the top of the elevator. The data logger and display were installed into the harvester cab and the GPS antenna was placed on the cab's roof.

The work was done at the Guaira Sugar and Alcohol Mill, in Guaira (approximately 20.40 degrees South and 48.25 degrees West), State of São Paulo, Brazil. All four configurations of the data collecting program were tested in four testing phases. Each phase (Table 1) consisted on a calibration process and a period of time to produce at least a yield map from one field of about 3 to 5 ha.

Table 1 – Description of the configuration setups of the sugar cane yield monitor tests.

Phase	Description
1	Configuration set to "mass-flow-rate"
2	Configuration set to "mass (no accelerometer)"
3	Configuration set to "mass (no speed)"
4	Configuration set to "instant weigh"

Two tractors with three haul out bins each support the harvester. The mill considers the weigh of 18 t for each set of three haul out bins as an average weigh. This value was used as an initial steep of the calibration process. The value accrued for the monitor was set to match this average weigh using the calibration page on the display. After the accrued weigh was approximately close to the average weigh, the haul out bins were weighted in the scale at the industry and the scaling factor was adjusted so the actual and the accrued weigh were monitored to check the stability of the data collection.

Raw yield data normally presents errors, so a filtering process was performed according to MOLIN & MENEGATTI (2002). Once the dataset for a field was considered clean of errors, a dedicated GIS (SSToolbox® - SST Development Group) was used to generate the yield maps.

To validate the use of a non differential correction positioning system, the data acquired with the monitor was compared to the same data, but with the position given by a DGPS, based on the methodology used by MOLIN & GIMENEZ (2002). An OmniStar 3000L® DGPS receiver, with satellite differential signal provided by OmniStar (OmniStar – Fugro), was used. The GPS and DGPS antennas were installed on the cab's roof and a palmtop was used to collect the position and the GPS time at each position was acquired. The time was used to match the yield values to the DGPS Position System. DGPS positioning was acquired in a frequency of 1 Hz and the monitor operated gathering points at 0.5 Hz. Once both data sets, the monitor with the GPS and the DGPS, had the column of yield on it, the yield map was interpolated in 5 m cells using the inverse distance method in an area of 2.6 ha. A linear correlation analysis was performed to characterize the likeness of the maps to show the practical effect of the use of a non differential correction system.

Results and Discussion

The results from the calibration of the yield monitor on phase 1 are presented on Table 2. The first steep of the calibration resulted on a scaling factor of 51.013 t/h. During the second step of the calibration routine, the scaling factor increased to 61.000 t/h. The average error during the calibration and monitoring was –1.94 % and with a variance of 149.94. If the worst two results were removed from the data, the variance would reduce to 68.00 and the error to –2.70 %. Figure 1 shows the scatter plot of the data.

Table 2 – Results from the calibration routine and monitoring of the actual weighs during phase 1.

Date	Time (h)	Scaling Factor (t/h)	Monitor weigh (t)	Scale weigh (t)	Error (%)
07/out	14:46	51.130	13.19	16.57	-20.40
	15:07		14.19	16.91	-16.09
	15:27	57.959	15.41	15.74	-2.10
	16:38		15.40	15.04	2.39
	16:55		14.37	15.87	-9.45
09/out	15:59	59.000	16.95	14.75	14.92
	16:32		17.99	14.30	25.80
	16:44		14.73	13.92	5.82
	17:15		13.49	14.75	-8.54
	17:59		13.63	14.41	-5.41
	18:22		13.39	13.99	-4.29
	18:51		14.42	15.03	-4.06
	19:50	61.000	14.37	14.94	-3.82
Average			14.73	15.09	-1.94

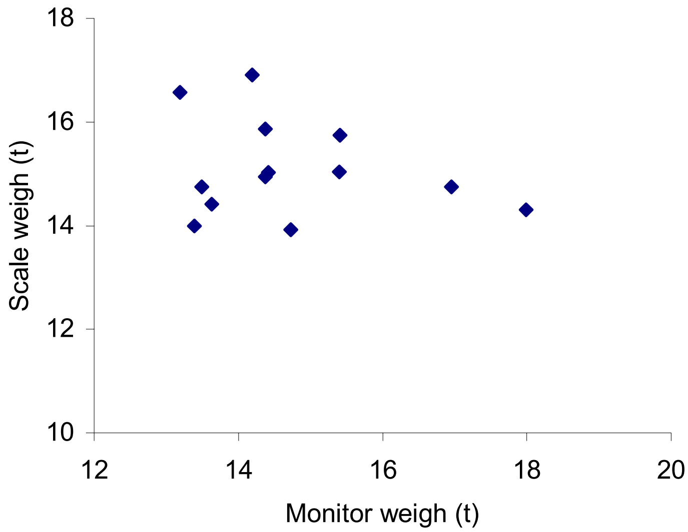

Figure 1 – Scatter plot of the data collected during phase 1

After the scaling factor was set to 59.000 t/h, two sequenced measurements resulted on high errors (14.92% and 25.80%), with no reasonable explanation. The next measurement resulted on error of 5.82% and no adjustment was done between these measurements.

Except on the first two measurements done with the scaling factor of 59.000, the errors showed a negative trend, suggesting that the scaling factor was too low. So a new adjustment was done and the scaling factor was manually set to 61.000. After that just one measurement was taken, with an error of -3.82 %.

On phase 2, even with no information available about the rule of the accelerometer signal on the calculation of yield, it is supposed to inform the inclination of the elevator to correct the vertical load. Table 3 shows the results from the phase 2. Just a few measurements could be done on this phase due to operation problems at the industry, but the data allowed a good calibration of the yield monitor. The weigh monitoring was not done in this phase and the monitor was set to work with scaling factor of 63.000 t/h. The average error during the calibrations was –0.50 %. Figure 2 presents a scatter plot of the data.

Table 3 – Results from the calibration routine during phase 2.

Date	Time (h)	Scaling Factor (t/h)	Monitor weigh (t)	Scale weigh (t)	Error (%)
27/05	09:10	42.000	16.03	18.81	-14.8
	10:48	68.400	19.47	19.82	-1.8
	12:39	68.407	18.57	19.41	-4.3
	14:40	68.407	18.69	17.54	6.6
	16:50	69.000	22.64	20.21	12.0
Average			19.08	19.16	-0.5

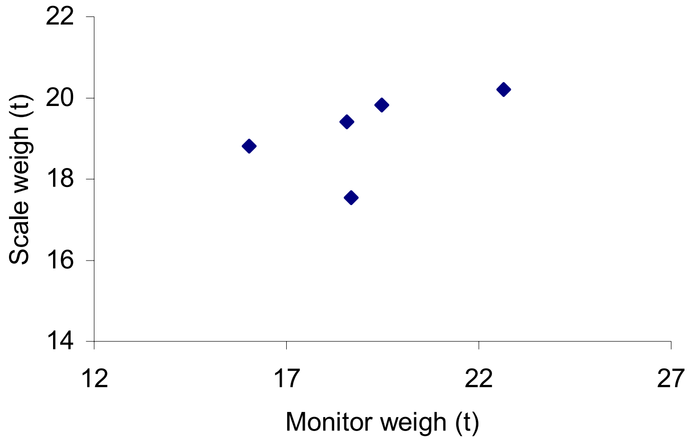

Figure 2 – Scatter plot of the data collected during the calibration process of phase 2.

During phase 3, according to the options available on the setup, the elevator speed sensor may be ignored on the yield calculation. After doing so, a new set of data was collected and the results from the calibration and weigh monitoring on phase 3 are presented on Table 4 and Figure 3.

The initial scaling factor was set to 68.300 t/h and in the first weigh it was adjusted to 106.111 t/h. This significant change was due to the scaling factor which was set up for the previous configuration. The new scaling factor resulted in high errors (up to 36.80%), and during the rest of the calibration, the factor was adjusted to 85.000 t/h. The results were not very consistent. With a scaling factor of 85.000 t/h, errors ranged from -12.30 to 32.80 %. A bug in the internal program of the monitor was the probable cause of the inconsistency. Figure 3 shows the scatter plot of the data collected during the calibration routine.

Working under the configuration “mass, no speed”, the monitor uses all sensors except the signal from the elevator speed sensor, to calculate yield. Even if the monitor does not use the elevator speed it is not aware if the elevator is running or not. The consequence is that when there is cane over the weigh pad, the monitor keeps accumulating weigh, with the harvester running or not.

Field shape interferers on the quality of the yield maps, resulting in a predicted weigh higher than the actual weigh. When the problem was noticed, the operator was told to turn the monitor off every time the harvester reached the headland. This solution should be implemented in the program to prevent further errors. This problem affects only the data collected in the headlands and the accrued load, but does not affect the points collected during the harvest, when the harvester is running and only dynamic measurements are being collected.

Table 4 – Results from the calibration routine and monitoring of the actual weighs during phase 3.

Date	Time (h)	Scaling Factor (t/h)	Monitor weigh (t)	Scale weigh (t)	Error (%)
13/jun	16:55	68.300	14.9	16.19	-8.0
	18:35	106.111	16.03	15.63	2.6
14/jun	10:05		20.17	14.74	36.8
	11:40		19.6	16.03	22.3
18/jun	11:15	94.950	20.02	17.09	17.1
	15:10		21.61	17.82	21.3
	17:04	82.069	18.62	17.96	3.7
19/jun	10:55		16.46	17.47	-5.8
	12:00		12.42	14.49	-14.3
	17:50		14.86	16.25	-8.6
	18:25		15.61	15.58	0.2
20/jun	11:20	87.000	19.96	20.33	-1.8
	12:25	85.000	21.93	18.91	16.0
	12:54		21.55	18.73	15.1
	13:34		25.23	21.3	18.5
	14:04		18.45	21.04	-12.3
	14:43		22.26	21.89	1.7
	15:51		20.4	17.63	15.7
	16:25		25.45	19.17	32.8
	17:05	85.000	21.14	18.92	11.7
Average			19.33	17.86	8.23

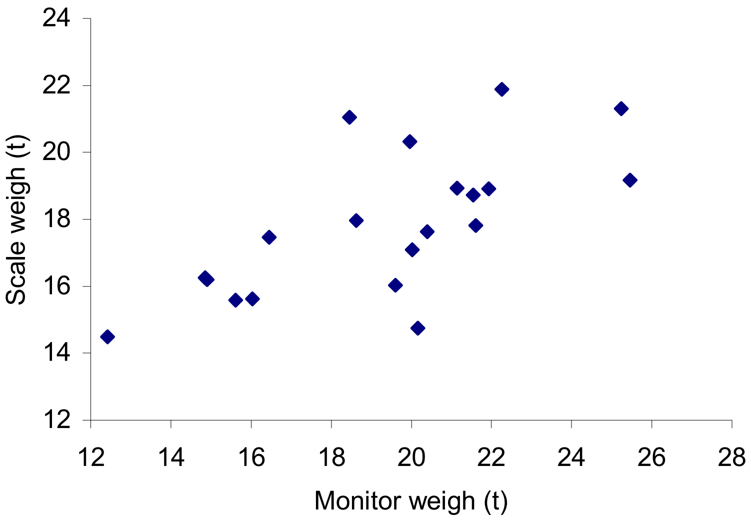

Figure 3 – Scatter plot of the data collected during the calibration process of phase 3.

Table 5 and Figure 4 shows the results obtained during the calibration of the yield monitor, working under configuration of instant weigh measurements. The fourth phase is the one with more data collected during the calibration routine, due to good conditions evolving from the mill and transportation system. Under this configuration, the yield monitor worked using only the

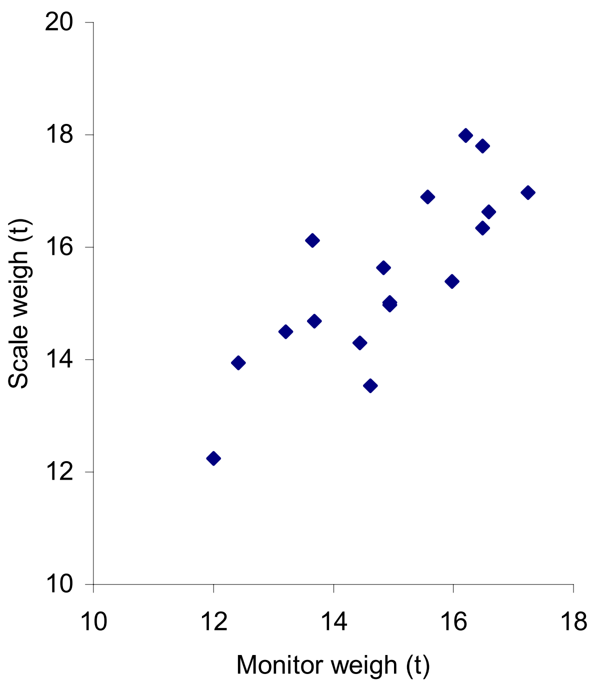

Figure 4 – Scatter plot to the data collected during the calibration process of phase 4.

signal from the load cell under the weighpad to calculate yield. The final average error was –3.5 %, underestimating the total load harvested, which is still a good result. If only the data gathered after the end of the calibration period would be used to calculate the error, it would be of –2.30 %.

Table 5 – Results from the calibration routine of the actual weighs during phase 4.

Date	Time (h)	Scaling Factor (t/h)	*Monitor weigh* (t)	*Scale weigh* (t)	Error (%)
18/jul	14:00	95.4865	14.62	13.54	8.0
	14:31	95.4865	12.42	13.94	-10.9
	14:56	95.4865	12.00	12.24	-2.0
	15:30	95.4865	14.94	15.02	-0.5
	17:25	95.4865	13.68	14.68	-6.8
	18:24	95.4865	13.21	14.50	-8.9
19/jul	09:40	95.4865	13.65	16.12	-15.3
	10:03	100.4865	15.98	15.39	3.8
	10:31	100.4865	16.59	16.63	-0.2
	11:20	100.4865	16.49	17.80	-7.4
	11:45	100.4865	15.57	16.90	-7.9
	12:10	100.4865	17.24	16.97	1.6
	12:40	100.4865	14.84	15.63	-5.1
	13:01	100.4865	14.44	14.30	1.0
	13:20	100.4865	14.94	14.97	-0.2
	13:45	100.4865	16.48	16.34	0.9
	14:10	100.4865	16.21	17.99	-9.9
Average			14.90	15.47	-3.5

The reliability of the data is affected by the same problem noted on phase 3, where the yield monitor did not consider the signal from the elevator speed sensor to shut of the data collection. So, the yield monitor kept increasing load even when the elevator or the machine was not moving.

Some characteristics were shown in all maps. For example, some points with high yield were artificially created under effect of the field operating system. The operator keeps running the harvester until the area between the chopper knives and the elevator is full of cane, after the haul out bin is loaded. This amount of cane stays there until another haul out bin arrives and take it and all accumulated mass flow through the elevator in a short period of time. Even with the harvester running, the area covered in 2 or 3 seconds is too small, resulting in points with high yields. The filtering process applied to the data solved part of this problem. Very high yields, such as 500 t/ha or more were easily removed from the data, but points with yield close to 130 t/ha may be generated from normal field conditions or from situations like those considered here. This problem may be attenuated using some interpolation technique or moving average.

Most of the yield maps represent more than one field because the harvester crosses it during harvesting for improving field efficiency. The maps show clearly the zones of low, medium and high yield, and show the difference of yield across the fields. Figure 5 shows two fields, evidencing yield differences. Maps do not show a standard pattern of variation influenced by the yield monitor. In the same row, low, medium or high yields may be found, showing that the spatial distributions correspond to the natural yield variability, in zones. For field managers the presence of yield variability and its location is the major information.

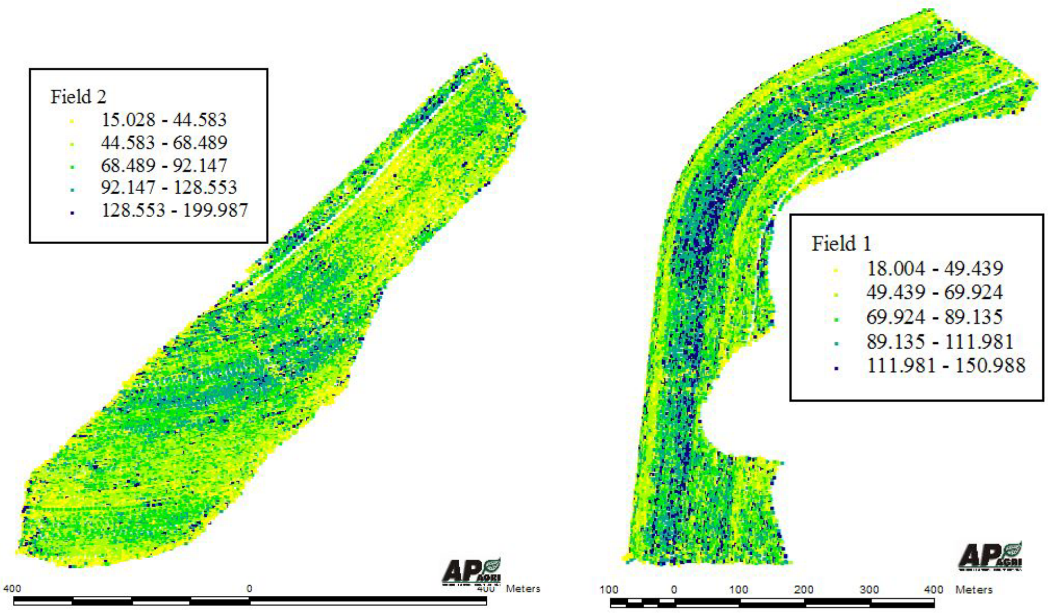

Figure 5 – Sugar cane yield maps showing yield differences within a field

The test of validation of the non-DGPS system was performed in a part of a field of 2.6 ha and the total number of points collected from the DGPS system was 5801; with the yield monitor they were 2900. Due to limitations on time synchronization, not all of the yield data points matched the points collected with the DGPS system and only 952 points could be used on the analysis. The points collected with the DGPS are displaced to north of those collected with GPS. This effect appears on the interpolated maps, where the yield cells were displaced to north (Figure 6).

The correlation between the two yield maps was 0.69. This correlation means that even using a non DGPS positioning system, 69% of the data was repeated and the practical effect were small changes in the location of the management zones created from the yield maps. The use of management zones is quite complex, as well as its creation. The idea behind the management zone is to provide information to manage inputs and the technology behind it does not require accuracy better than 30 m (STAFFORD, 1996). Usually, the limiting condition for the positioning system accuracy is the size of the cell and under this concept, the displacement of the yield points produced from GPS only are not critical to the complete cycle of precision farming.

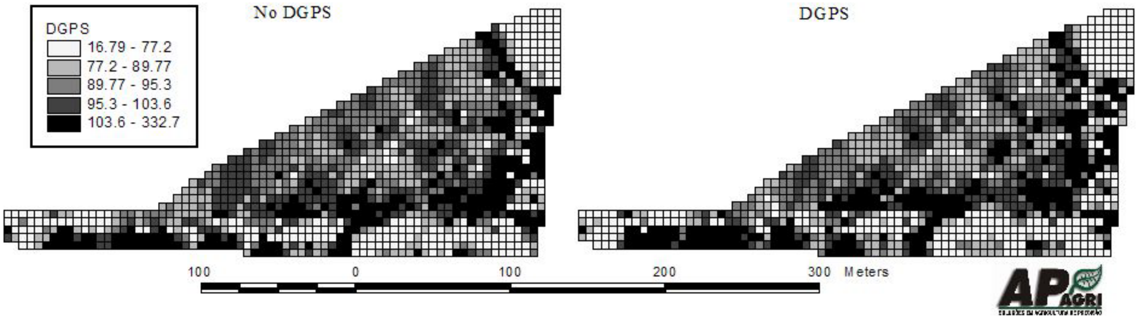

Figure 6 – Interpolated maps showing small difference between the yield map with GPS and with DGPS evidencing the displacement of the points between the two systems.

Conclusions

A series of field tests with a sugar cane yield monitor was conducted and it was possible to characterize its performance on all possible configurations. Field testing limitations did not allow for more conclusive information regarding the accuracy of the load sensor. Even so it was possible to take some good indications, especially related to yield mapping with maps showing consistent information on yield variability in the field.

The test with the use of non DGPS positioning system indicated that it is possible to use it on positioning the yield points. The difference between maps produced with GPS and DGPS did not justify the use of DGPS when considering the cost of the differential correction under local conditions.

References

AUERNHAMMER, H., DEMMEL, M., PIRRO, P. J. M. Yield measurement on self propelled forage harvesters. St. Joseph, ASAE Paper 95-1757, 5p. 1995.

BASHFORD, L. L., WEDERGREN, C. R., KOCHER, M. F. Site specific yield with a big roll baler. In: AGRICULTURAL EQUIPMENT TECHNOLOGY CONFERENCE, 1995, Chicago. *Abstracts*... ASAE, 1995. p.7.

BENJAMIN, C.E., MAILANDER, M.P., PRICE, R.R., 2001. Sugar cane yield monitoring system. Paper No. 011189. ASAE, St. Joseph. 9p.

BLACKMORE, S. Precision farming: an overview. Agricultural Engineer, St. Joseph, Autum 1994, p.86-88. 1994.

COX, G., HARRIS, H., COX, D., 1998. Application of precision agriculture to sugar cane. p. 753-765. In: P.C. ROBERTS et al. (ed) 4th International Conference on Precision Agriculture, July 19-22, 1998. St. Paul: ASA-CSSA-SSSA.

HERNANDEZ, B., FERNANDEZ, F., PONCE, E., QUINTANA, L., ESQUIVEL, M., and RODRIGUEZ, J.J. 2003. Sugarcane yield mapping from the harvester biomass input flux. p. 433-4. In: WERNER, A. and JAEFE, A. (ed.) Programme book of the joint conference of ECPA-ECPLF. Wageningen Academic Publishers, Amstelveen.

JHOTY, I., RAMASAMY, S., AUTREY, L.J.C. 2002. Yield variability in sugar cane. p. 61-70. In: Robert, P.C. (ed) 6th International Conference on Precision Agriculture, July 14-17, 2002. Minneapolis: ASA-CSSA-SSSA.

KHALILIAN, A., WOLAK, F.J., DODD, R.B., and HAN, Y.J. 1999. Improved sensor mounting technology for cotton yield monitors. Paper No. 991052. ASAE, St. Joseph, 11p.

KVIEN, C., WATERS, D. and USERY, L. Farming in the information age. *GPS World,* “Precision Farming” suplement, Eugene, p.10-19, December 1995.

LAMPARELLI, R.A.C., ROCHA, J.V., MACHADO, H.M., and ZULLO JR, J. 2003. Using NDVI as a support to sugar cane yield estimates. p. 471-2. In: WERNER, A. and JAEFE, A. (ed.) Programme book of the joint conference of ECPA-ECPLF. Wageningen Academic Publishers, Amstelveen.

MOLIN, J.P. and MENEGATTI, L.A.A. 2002. A. Methodology for identification, characterization and removal of errors on yield maps. Paper ASAE 021168. ASAE, St. Joseph, 17p.

MOLIN, J.P. and GIMENEZ, L.M. 2002. Use of gps without differential correction on yield mapping. p. 1073-79. In: ROBERT, P.C. (ed) 6th International Conference on Precision Agriculture, July 14-17, 2002. Minneapolis: ASA-CSSA-SSSA.

PAGNANO, N.B., and MAGALHÃES, P. S. G. 2001. Sugarcane yield measurement. p.839-3. In: BLACKMORE, S. and GRENIER, G. (ed.) 3th European Conference on Precision Agriculture, June, 18-20, 2001. Montpellier: AgroMontpellier-ENITAdeBordeaux,.

SARTORI, S., FAVA, J.F.M., DOMINGUES, E.L., RIBEIRO FILHO, A.C., SHIRAISI. L.E. 2002. Mapping the spatial variability of coffee yield with mechanical harvester. Proceedings of the World Congress on Computers in Agriculture and Natural Resources, p.196-205. ASAE, St. Joseph.

STAFFORD, J.V. 1996. Essential technology for precision agriculture. p. 595-604. In: ROBERT, P.C., RUST, R.H., and LARSON, W.E. (ed) 3rd International Conference on Precision Agriculture, June 23-26, 1996. Minneapolis: ASA-CSSA-SSSA.