A METHOD TO EVALUATE PARALELISM FOR MACHINE LOGGED POSITIONS

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Abstract. The development of machinery guidance using GNSS positioning is widely spread and used within farming fields along the world. Positioning accuracy of machines is a must in controlled traffic farming (CTF), which is strongly applied in sugarcane crop because undesired traffic on ratoons creates damages for the re-growth of the plant. Nonetheless for the adoption of such guidance systems some questions are raised of how much a guidance system can excel the operator skill guidance, or which systems provide a sufficient accuracy for the operation. A method is herein proposed that creates a relative evaluation of a positioning dataset from machine logged positions on field. The foundation of the method consists in obtaining the shortest distance from a recorded point to a reference line (given by a pair of points) in Euclidean geometry, and between the origin point and a reference point. The model was applied into an algorithm which loads a reference ground-truth measurement (like a pre-planned geographical path or a RTK measured path), obtaining its points and afterwards linking them in pairs (line segments). A second dataset is then loaded containing the recorded points for which the distance between these and the line-segments will be obtained, the shortest distance found is herein considered the offset error between the point and its reference. The implemented method showed itself capable of obtaining the distances between logged positions and reference for straight and curved tracks. Two case studies of sugarcane harvest were applied to the model, which showed the coherence of the model to retrieve offset deviations along its path; and these values were similar to the expected accuracy of the guidance systems. Also in one of the case studies the results of the model allowed to observe improvements in the manual guidance for a tractor to keep parallel to the harvester when the latter has improved auto-guidance.

Keywords: steering systems, GNSS, modeling.

1 Introduction

Agricultural guidance systems have been strongly developed in the past two decades and applied widely in field around the world. A fully automated system is capable of driving the tractor through the field in a straight line with a lateral accuracy of less than two cm. The use of the guidance systems provided more accuracy of coverage (Baio et al, 2012, Abidine et al. 2002) and reduction of operators fatigue (Holpp et al., 2013; Tillet, 1991); besides automated steering technologies allows work without visibility (night shifts) increasing the productivity of the machine.

Certain technologies of drip irrigation and controlled traffic farming (CTF) were made possible with the use of accurate guidance systems (Gan-Mor et al., 2007). CTF is an increasing trend within the farm fields in the world, with benefit found for increasing root growth and water infiltration, showing a increase of 16% in grain productivity compared to conventional systems (Vere, 2005).

In sugarcane crop, besides the damages created by soil compaction, undesired traffic on ratoons creates damages for the re-growth of the plant, reducing the following yield. A sequence of five harvests is usually expected from the same ratoon upon which compaction may reduce yield up to 20 Mg ha-1 (Norris et al., 2000). Paula and Molin (2013) also studied the impact of undesired traffic in the crop where results indicated the influence of traffic on soil, especially on clay soils; when the soil compaction increased due to traffic over the rows, a strong relationship with crop response was indicated, resulting in lower yield. According to Baio (2007), the irregularity of row spacing in sugar cane is the major cause of cane damage in the following year caused by the sugar cane harvester.

The concern to the crop damages leaded to investment in machinery guidance systems for the field operations. The sugarcane crop in Brazil covers close to 9 million hectares in the country (CONAB, 2013) and Silva et al. (2011) showed that 39% of the sugar cane mills in the country already adopted auto-guidance technology. Baio (2012) compared the positioning accuracy of a harvester upon pre-planned tracks, retrieving an increase in coverage accuracy of 0.091 m in daytime and 0.198 m in nighttime from manual to RTK auto-guidance. The data was retrieved from a few hours of measurement in a subset of a field.

Methods to evaluate satellite positioning accuracy have been studied and tested (Knight and Wang, 2009) as well as the settings were proposed for dynamic testing (Stombaugh et al.). But dynamic testing on-board agricultural machinery showed that deviations on rough surfaces are substantially higher compared to paved surfaces due to angular deviations (Gan-Mor et al., 2007).

For most practical purposes on field, lateral deviations are the most undesired. Molin et al. (2011) developed a method implemented in a spreadsheet that retrieves lateral deviations of GNSS logged data on a vehicle in a single orientation. The method was limited to straight patterns of orientation and required rotation of coordinates to a perfect north reference. The work allowed fast evaluation of field gathered data.

Nonetheless many machine working patterns are curved, in sugarcane this is a common reality in which investment occurs for defining pre-planned tracks for the machine guidance interface. These paths must consider machine time efficiency and perpendicularity towards slope (which is hardly in straight pattern).

The work herein proposes a method that compares the lateral deviation of a machine logged data towards a reference for any type of driving pattern. Also an assessment of the method to observe its coherence and usability follows.

2 Methodology

2.1 Overview of the traffic problem in sugarcane

Harvesting is the most critical operation in sugarcane in economic and operational aspects. Decisions on row spacing are usually given by harvester limitations. Figure 1 shows a common set of harvester and tractor-carrier running on the field the sugarcane harvesting.

Fig. 1. Overview of the harvesting operation.

Driving mistakes can lead, besides the damage by overrunning on ratoon rows, reduced quality on the base cane-cutting disks and (in worse deviations) unhaversted canes outside the machine head.

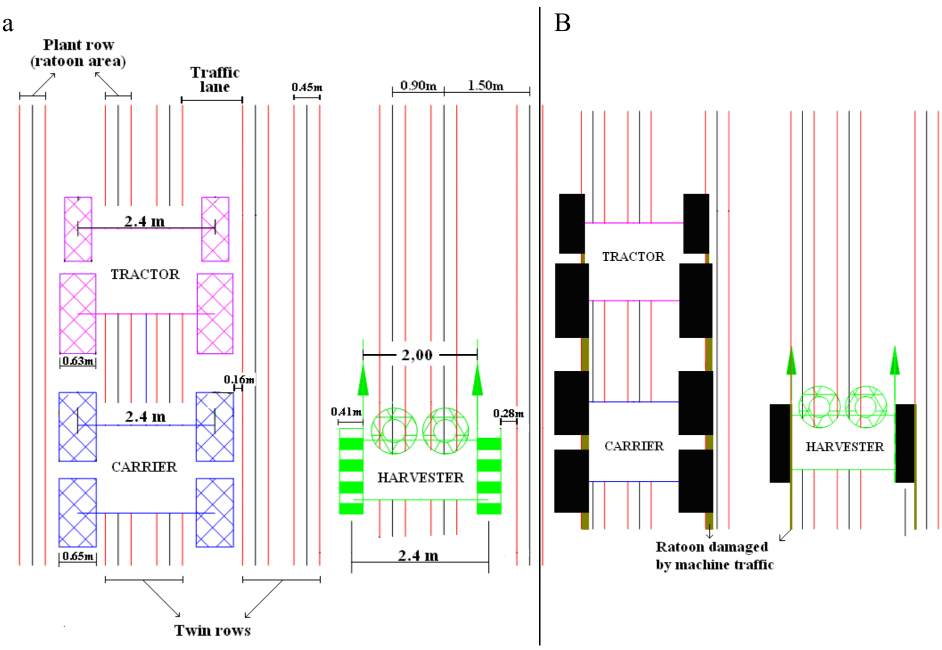

Fig. 2. Scale dimensions and of lanes and machine width properties (in “a”) and damage of sugarcane ratoon in case of the offset of the machines (in “b”).

Figure 2 shows an example of harvesting set components and traffic limitations. A room space of few centimeters is allowed to avoid ratoon damage (0.28m for the harvester caterpillar and 0.16m for the carrier tires in “a”). In “b” shows a driving offset of 0.33m to right of all machines, showing the potential damage to the ratoon (besides cane losses and harvester damages). The accuracy of positioning is required for continuous 24 hours a day of work (three shifts of 8 hours labor) for an operation that usually endures half a year. Within this scope stakeholders have been investing in auto-guidance systems for these machines as well as in creating computer predefined paths to insert in the interface of these.

2.2 Overview of the conceptual model

A post processed model was created which compares the offset between polylines (sequences of line-segments). One group of polylines is a reference-truth track (RT), which can be computer designed (pre-planned) or a sufficient accurate field measurement (RTK signal for e.g.). The other group of polylines is the logged positions (LP) of a machine while harvesting along the rows, which will be subject to positioning evaluation. Both polylines are a sequence of points given in metric coordinates.
The distance of point-to-point is retrieved through Pitagoras and the distance point-to-line is retrieved thought Euclidean-algebra, which is here described by a sequence of steps.

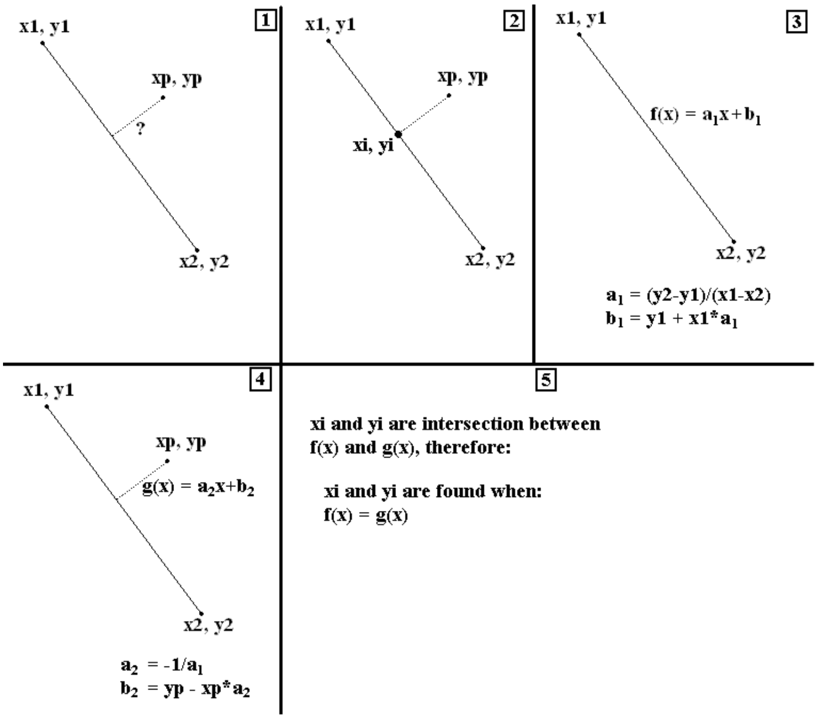

Fig. 3. Steps used to retrieve the distance between a line and a point.

The steps illustrated in Figure 3 are described:

1. A point P is defined by coordinates [xp,yp] coordinates near a line La defined by [x1,y1;x2,y2];
2. The minimum distance between the point and the line is given by a line Lb perpendicular to La, which intersect La in [xi,yi].
3. An algebraic function is extracted from La;
4. A function of opposing direction is found from Lb;
5. The point [xi,yi] is found by the intersection of both functions, and its Lb distance to [xp,yp] is found through Pitagoras.

The model loops along the LP points retrieving its point-coordinates. This point will have its distance retrieved from all the points of the RT group (point-to-point distance) and from all line-segments, sequenced pairs of points, of the RT group (point-to-line distance). The minimum distance retrieved from either of these two distances will be taken as the deviation of the LP point to the RT reference.

A conditional statement is used to check if the point is within the perpendicular range of the line (La), because by algebraic functions, infinite lines are always in the range of a point.

Another conditional statement is used to check the orientation of La and the position of [xi,yi] in relation to [xp,yp] to determine if the point is offset to the right or left side of the line.

This process is repeated for all the points of the LP group.

2.3 Implementation of the model

The model was implemented in a computer algorithm. It was written in Pascal language and built and compiled in the software Lazarus 1.0 (free Pascal Lazarus Project) into an application.

The proposed method is simple in retrieving geometric distances, but its implementation requires a more elaborated work with data-arrays in order to make an exhaustive search between the two base datasets.

The data is loaded in a specific text-file format with its coordinates in metric format (usually in UTM coordinates), and loaded into record-type arrays.

Figure 4 provides a view of the implemented application with a dataset classified (numbers in the table represent deviations in meters). The harvest logged positions are the black dots and the red line is the path that is supposed to be followed by the machine. The algorithm allows the classified data (deviation range and side) to be exported in a file in the CSV (comma separated value) format along with the coordinates of each point. This data can be loaded into a GIS (Geographical information system) for enhanced display and analysis.

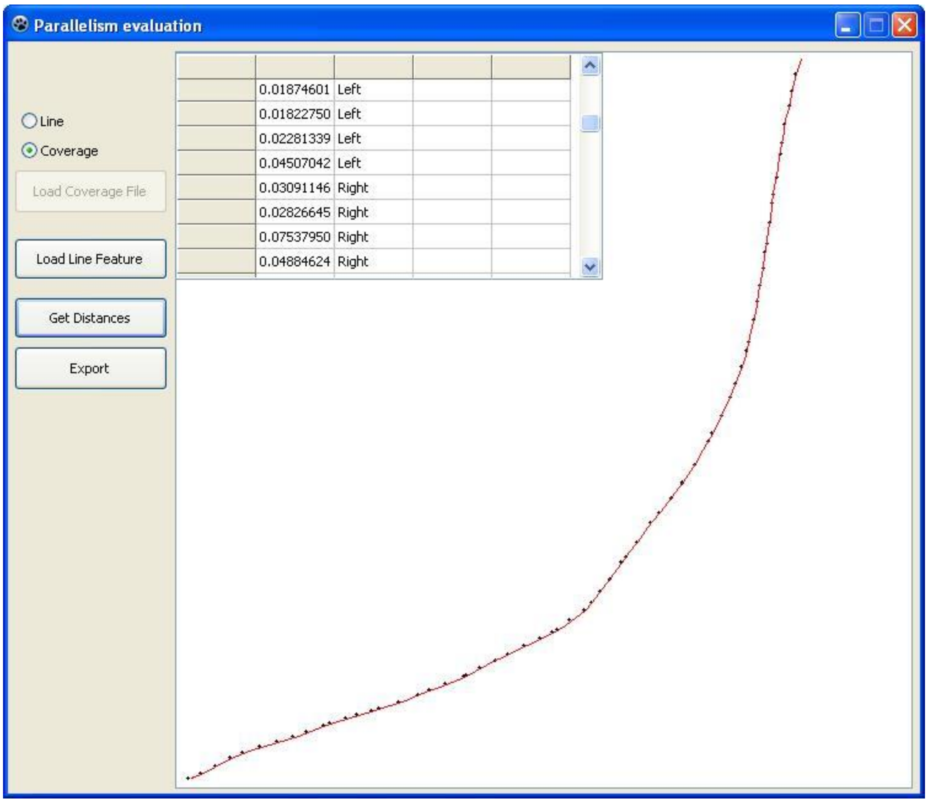

Fig. 4. View of the developed application for parallelism evaluation.

An index system was implemented to narrow the number of points of the reference line, in order to speed the process of evaluation. This index system divides the reference line data into a 10 by 10 matrix, into squares separated by their coordinates. In each square a significantly lower number of points can be located and every point to be evaluated can be directly located into its square.

3 Case studies and discussion

3.1 Evaluation of an accurate auto-guidance steering

In a case study site, data collected from 8 ha field located in the municipality of Assis (Sao Paulo state, 22°20'28.37"S; 50°40'35.71"W) were submitted to evaluation by the model for a sugarcane harvester (John Deere model 3522), in a twin row configuration of (0.9m and 1.5m alternated as in Figure 2a). The harvester was equipped with auto-steering system with RTK correction logging the points (LP) in a 1.2 m s^{-1} speed. A line reference (LR) was provided by the planter operation also guided by the RTK auto-steering. Both polylines (LR and LP) were logged in a frequency of 1Hz.

A total of 4134 points were logged by the harvester (average of 516.75 points per hectare). The data collected and submitted to parallelism evaluation by the algorithm.

Table 1. Descriptive statistics of the deviation error of the harvester on the field.

Number of points logged	Mean (m)	Standard deviation (m)	Minimum (m)	Maximum (m)	Coeficient of variation (%)
4134	0.0215	0.0296	0.0000	0.8498	137.82

The values (for both datasets) were coherent with the expected positioning accuracy of the RTK with more than 90% of the data with deviations lower than 0.05m however three uncertainties must be considered in this case study: the positioning errors of the planter (reference) and the harvester (evaluated), and it only considers errors off-path and not along the path.

The evaluated dataset was imported in the form of map (Figure 5), making visible three locations with concentration of higher path deviations (three red circles on the map). Within these regions there is a concentration of points with deviations higher than 0.06m, which is a critic value that may limit the quality of the base cutting disk of the harvester. It is suggested that these regions are related to a localized steeper slope or harsh curve steering along the path.

Fig. 5. Map view of the deviation error of the harvester on the field.

3.2 Evaluation of a harvester and tractor-carrier parallelism

In another case study, data was collected in 9 hectare field located in the municipality of São Carlos (São Paulo state, 22°01'52.9"S; 47°51'46.63"W). The sugarcane row settings are the same as in the first case study. This study aimed to evaluate driving accuracy of manual and two types of auto-guided systems. A harvester was equipped with integrated hydraulic steering with RTK signal, and a tractor-carrier was equipped with electric engine acting on the steer bar of the operator with RTX signal. The full delineation of the test is described in Table 2.

Table 2. Test settings for analysis of the machines on harvest.

Group set	Harvester (guidance type)	Tractor-carrier (guidance type)
a	Manual	Manual
b	Auto-guidance RTK signal	Manual
c	Auto-guidance RTK signal	Auto-guidance RTX signal

As in the first case study, the reference line was obtained from logging the positioning of the planters (also with RTK signal guidance). Both polylines were obtained with a logged frequency of 1 Hz and the harvesting speed was also within 1.2 m s^{-1}.
For each machine, a minimum of 790 positions were recorded for evaluation (above 3000 logged positions for the manual set). The results are displayed in the graphs of Figure 6.
The results show (Figure 6) the suitability and coherence of the model to retrieve the offset distances. In "a" the graph shows higher deviations for the manual guidance system, average errors were of 0.193m and 0.197m for the harvester and tractor carrier respectively. A fraction of 27% and 50.8% of the harvester and tractor-carrier logged positions respectively entered the sugarcane ratoon area.
In "b" an expected accuracy of the harvester positioning was found, averaging 0.021m and 0.118m of deviation error (harvester and tractor). Remarkably the better positioning of the harvest leaded to a better guidance work of the operator in relation to the manual guidance in "a", it may be explained by less steering corrections that the tractor operator has to make to keep parallel to the harvester.
In "c" there is a comparison between two distinct signal positioning systems located each in a distinct machine, the average errors were of 0.037m and 0.045m respectively for the harvester and the tractor. The values found are coherent with the RTX signal provider (0.038m in controlled conditions) aggravated by a poorer steering actuator in comparison to the harvester.

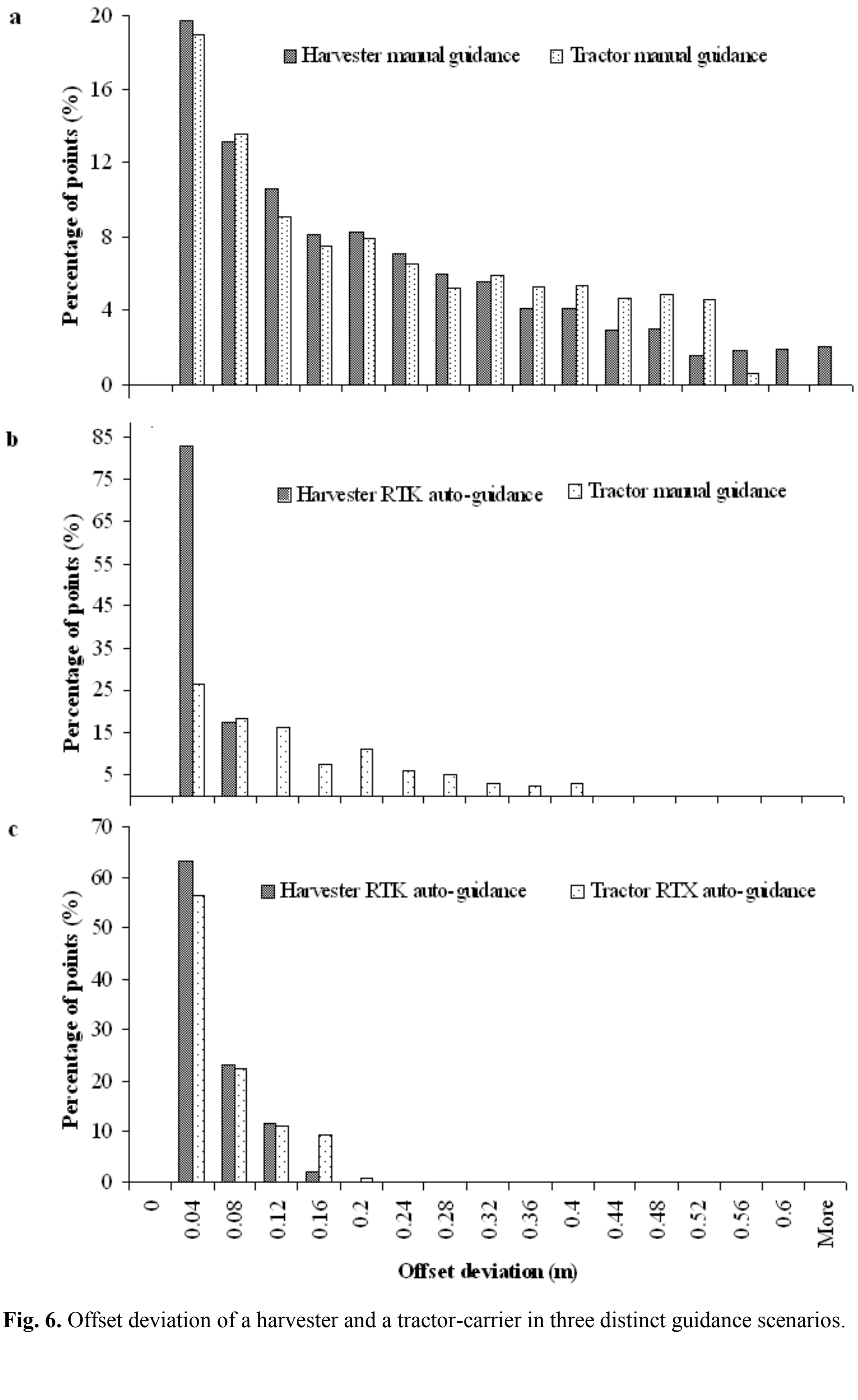

Fig. 6. Offset deviation of a harvester and a tractor-carrier in three distinct guidance scenarios.

4 Conclusion

In this work a model to evaluate relative driving deviations of machinery was proposed and implemented in a computer algorithm. The model is capable of retrieving offset distances of machine logged points towards a reference in for any shape of machine track (straight or curved). The results can be exported and submitted to spatial and quantitative evaluation. Two case studies were submitted into the model-algorithm and its results discussed and analyzed. The results were coherent with the expected accuracy of positioning for the guidance systems, and allow user evaluation of field-working aspects of these.

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References

Abidine, A. Z., Heidman, B. C., Upadhyaya, S. K., Hills, D. J.: Application of RTK GPS based auto-guidance system in agricultural production. ASAE Paper Nº 021152–ASAE. St Joseph MI (2002).

Baio, F. H. R.: Aplicacação de AP no plantio (Application of PA in the planting). In T. C. C. Ripoli, M. L. C. Ripoli, D. V. Casagrandi, & B. Y. Ide (Eds.), Plantio de cana-de-açúcar: estado da arte (Sugar cane planting: State of the art). 2 (pp. 92–101). Piracicaba (2007).

Baio, F. H. R.: Evaluation of an auto-guidance system operating on a sugar cane harvester. Precision Agriculture, 13(1), 141-147 (2012).

CONAB – Companhia Nacional de Abastecimento. Sugarcane production 2013/2014. Available in: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/13_08_08_09_39_29_boletim_cana_portugues_-_abril_2013_1o_lev.pdf (2013 - in Portuguese).

Gan-Mor, S., Clark, R. L., Upchurch, B. L.: Implement lateral position accuracy under RTK-GPS tractor guidance. Computers and Electronics in Agriculture, 59(1), 31-38. (2007).

Holpp, M., Kroulik, M., Kviz, Z., Anken, T., Sauter, M., & Hensel, O.: Large-scale field evaluation of driving performance and ergonomic effects of satellite-based guidance systems. Biosystems Engineering, 116(2), 190-197 (2013).

Knight, N.L., Wang J.: A comparison of outlier detection procedures and robust estimation methods in GPS positioning. Journal of Navigation 62.4: 699 (2009).

Norris, C. P., B. G. Robotham, T. A. Bull.: High density planting as an economic production strategy: c) A farming system and equipment requirements. In Proc. Aust. Soc. Sugar Cane Technologists, 113-118 Bundaberg, Qld/Australia: Australian Society of Sugar Cane Technologists, Brisbane, Qld (Australia). 2000.

Paula, V. R., Molin, J. P.: Assessing damage caused by accidental vehicle traffic on sugarcane ratoon. Applied Engineering in Agriculture, 29(2), 161-169 (2013).

Silva, C.B., Moraes, M.A.F.D., Molin, J.P.: Adoption and use of precision agriculture technologies in the sugarcane industry of Sao Paulo state, Brazil. Precision Agriculture, 12(1), 67–81. (2011).

Stombaugh, T. S., Sama, M. P., Zandonadi, R. S., Shearer, S. A., Koostra, B. K.: Implications of standardized GNSS accuracy testing. In Precision agriculture, Proceedings of the 9th international conference on precision agriculture. Denver: Colorado State University (CD Publication) (2008).

Tillet, N.D.: Automatic guidance sensors for agricultural field machines: a review. J. Agric. Eng. Res. 50 (3), 167–187 (1991).

Vere D. Research into conservation tillage for dryland cropping in Australia and China. ACIAR - Australian Centre for International Agricultural Research. Impact Assessment Series Report No. 33 (2005).