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Operational performance of sugarcane harvests with and without the use autopilot

Desempenho operacional de colhedoras de cana-de-açúcar com e sem o uso do piloto automático

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Abstract: Brazil is world leader in the production of sugarcane, crop that is grown in several regions of the country and responsible for the generation of sugar and ethanol. However, maintaining high productivity in the field requires that productive areas are increasingly equipped with innovative solutions that provide increased efficiency in crop management. The main focus of agricultural systematization is using georeferencing and geoprocessing to make more efficient the trafficability of agricultural machines and increase the productive area, reducing the costs with field operations and the risks of failures in cultures caused by trampling. The objective of this study was to evaluate the operational efficiency of autopilot on trafficability and reduction of trampling into a sugarcane harvesters cultivated area. Efficiency tests were carried out in an area cultivated with sugarcane divided between two treatments, using the autopilot with satellite navigation coupled in the harvester and in the other area, the harvester maintained the common working method (without use of automatic pilot). The data generated by the equipment were collected and the parameters of fuel consumption, operational time, production harvested and harvest losses were evaluated, compared and interpreted through multivariate statistical analysis. The results of this study indicated that the treatment using harvester with autopilot, there was significant field harvest efficiency (7.6 Mg h^{-1}) and a reduction in fuel consumption (on average 10%) when compared to the harvester without autopilot.

Keywords: harvest, correction, failure, positioning, *Saccharum officinarum* L.

Resumo: O Brasil é líder mundial na produção de cana-de-açúcar, cultura cultivada em diversas regiões do país e responsável pela geração de açúcar e etanol. No entanto, manter a alta produtividade no campo exige que as áreas produtivas disponham cada vez mais de soluções inovadoras que proporcionem aumento da eficiência no manejo da cultura. A sistematização agrícola utilizando-se tecnologias de georeferenciamento e geoprocessamento no cultivo da cana-de-açúcar, tem como foco principal tornar mais eficiente a trafegabilidade de máquinas e implementos agrícolas e aumentar a área produtiva, diminuindo os custos com as operações no campo e os riscos de falhas na cultura ocasionadas pelo pisoteio. Objetivou-se avaliar a eficiência operacional do uso do piloto automático na trafegabilidade e redução do pisoteio, dentro da área de plantio da cana-de-açúcar. Foram feitos testes de eficiência em uma área de cana-de-açúcar, dividida entre dois tratamentos, utilizando-se o piloto automático com navegação por satélite acoplado na colhedora e, na outra área a colhedora manteve o método comum de trabalho (sem uso de piloto automático). Os dados gerados pelo equipamento foram coletados e os parâmetros de consumo de combustível, tempo operacional, cana colhida e perdas na colheita avaliados, comparados e interpretados por meio de análise da estatística multivariada. Os resultados deste estudo indicaram que para o tratamento utilizando-se colhedora com piloto automático obteve-se significativa eficiência de colheita no campo (7,6 Mg h^{-1}) e redução do consumo de combustível (em média 10%), quando comparada com a colhedora sem piloto automático.

Palavras chave: colheita, correção, falhas, posicionamento, *Saccharum officinarum* L

Introduction

The evolution of the mechanization of sugarcane cultivation has been following its production since the colonial period, and currently places culture as one of the main agricultural powers for the Brazilian economy due to its intense technification present in all stages of the productive system. Brazil accounts for more than half of all sugar sold in the world, and is also the largest exporter of ethanol (CONAB, 2017).

The importance of sugarcane can be attributed to its diversified use for society and agriculture, and can be used since the generation of products such as sugar and ethanol, as well as cogeneration of electricity by burning the bagasse itself. Due to its high yield in the field, sugarcane is the culture that has received the most of technological investments, through research centers and companies in the sector, from which are able to promote their development at field and influence the values of national production (Ripoli and Ripoli, 2009).

In Brazil, the area cultivated with sugarcane is approximately 8,838.5 thousand hectares, with special importance for the State of São Paulo, with approximately 4,558.4 thousand hectares being cultivated and presenting the largest producing regions in the country. It is estimated that the average national productivity is around 73.0 to 80.0 Mg ha^{-1}, with a progressive increase among about the harvests (IEA, 2017; CONAB, 2017).

The growth of the sugar and alcohol industry in the state of São Paulo is mainly due to the massive use of agricultural machinery and implements in crop management, which also generates a considerable expansion of agricultural areas with problems related to high fuel costs, failures due to the trampling caused by machinery and managerial losses in the control of agricultural traffic (Souza et al., 2013; Carvalho et al., 2014).

The need to meet goals and work routines with greater operational efficiency within the sugarcane production system demands from the producer more and more technological and efficient processes in the field, from which are able to minimize damages to the crop due to the better traffic of machines and agricultural implements, generating greater confidence in the precision of equipment work and the competitiveness within the sugar and alcohol industry (Junqueira and Morabito, 2017).

The use of new technologies in the field, such as the computer science, geoprocessing and Global Navigation Satellite Systems (GNSS), are essential to the rural producer in the knowledge of the spatial variability of the soil and monitoring of agricultural operations. And the autopilot system, guided by GPS (Global Positioning System) in agricultural machinery and implements can contribute significantly to the management of areas of controlled traffic, allowing concentration to be concentrated only at specific points (using the same trace) in the sugarcane harvest. Reducing the damages caused in the structure of the soil and plants in other places of the productive area (Bernardi and Landim, 2002; Kamimura et al., 2013; Cervi et al., 2015).

The GPS tool, combined with the RTK (Real Time Kinematic) system, is capable of assisting the rural producer, since it brings benefits related to the reduction of losses in the final product, preventing failures in sugarcane cultivation lines and among other crops of importance in the Brazil (Baio and Moratelli, 2011; Santos et al., 2016; Vellar et al., 2016).

The use of non automated machines and implements, which still maintain the conventional crop management system can lead to high losses in plant production due to impacts directly related to soil use and conservation (compaction, failure and trampling) and even involving delays in harvest point (Bernardi et al., 2014; Costa et al., 2016).

The use of instrumented autopilot in agricultural vehicles such as sugarcane harvesters enables the integration of field operations, reducing rolling resistance, fuel consumption and increasing operational efficiency about the productivity of culture (Júnior et al., 2015).

Studies involving such equipment and technologies capable of bringing to the rural producers greater operational efficiency and safety in farming are of extreme importance in order to maintain the high yield of the sugar and alcohol sector and the Brazil as the main leader in the production of the sugarcane. In this way, the objective of this study was to evaluate the operational efficiency of a harvester with autopilot, in the trafficability and reduction of trampling in the sugarcane area.

Material and Methods

The conduction of the experiment occurred during the harvest of 2015/2016, in the period from 21 to 24 May 2016, in a commercial area belonging to a sugarcane power plant located in the municipality of Guatapará, State of São Paulo, at the coordinates latitude 21º15'40.2 "S, longitude 48º05'30.9" W and altitude: 691.6 meters.

According to the climatic classification of Köppen for the place, the climate is considered Aw (Tropical climate with dry season of winter), with average temperature of 22,8°C and average precipitation of 1183 mm to the year (Peel et al., 2007). The predominant type of soil is the Eutrophic Red Latosol, a clayey texture (Santos et al., 2013). Sugarcane variety RB855156 was grown throughout the área (Matsuoka et al., 1995).

The experimental area covers approximately 120 thousand hectares. With this, it was necessary to divide the total area into five equal areas, with RTK bases with a radius of 15 km (each) being installed to cover all the divided areas. The bases were installed at strategic points so that they could accurately capture and retransmit the GNSS signal to the automated sugar cane harvesters, for which the correct input frequency RX 459.0500 MHz and TX transmission were used 469.0500 MHz of each base for better utilization of the RTK signal (Cervi, et al., 2015; Almeida Júnior et al., 2015; Rodrigo et al., 2016).

The RTK base consists of a masonry construction, being surrounded by wiring and monitoring 24 hours a day whose main function is to capture the signal from the satellites and to resend the corrected information by means of radio signals specific to the sugarcane harvester or tractor in the field (having a signal receiver), where by appropriate implement positioning corrections are made in real time (Rodrigo et al., 2016).

The RTK base of real-time implement positioning corrections consisted of a TDL 450 radio frequency and a Trimble Net R9 receiver, both cooled and powered by electric power and two 12-volt batteries in case of mains failure.

An autopilot assembly was properly instrumented in the sugarcane harvester, its components subdivided into monitor, NAV or controller, GNSS receiver, radio and hydraulic system.

The treatments were conducted in a randomized block design with 5 replicates each (6 ha per plot), totaling 10 plots, with a mean slope the terrain of 2%.

For both treatments was used a harvester, Case® 8800 (CASE, 2014), since, for Treatment A, the autopilot was activated at the time of harvest and in Treatment B, the autopilot (GPS and RTK) was switched off, keeping only the controller to store the data collected in the field (consumption rate fuel efficiency, operational efficiency, harvested cane and trampling) during the sugarcane harvest, totalizing 60 hectares with both treatments, Figure 1.

To determine the mass harvested in megagrams per hectare (Mg ha^{-1}) a load cell was used in the infield wagon (digital scale). Fuel consumption rate data, in liters per hour (L h^{-1}), and the operational efficiency of the harvester (ratio of mass harvested by the area in ha h^{-1}), and the operating time in megagrams per hour (Mg h^{-1}) (Baio et al., 2011), were collected from the vehicle by the AFS® software (CASE, 2017) installed in the on-board computer.

After the data collection, data analysis was performed in the AgroCad® software (TECGRAF, 2017), by means of the t test ($p < 0.05$), to estimate the trampling rate of sugarcane plants in the field, by means of a correlation between cultivated and harvested area using autopilot and the same correlation without the use of autopilot.

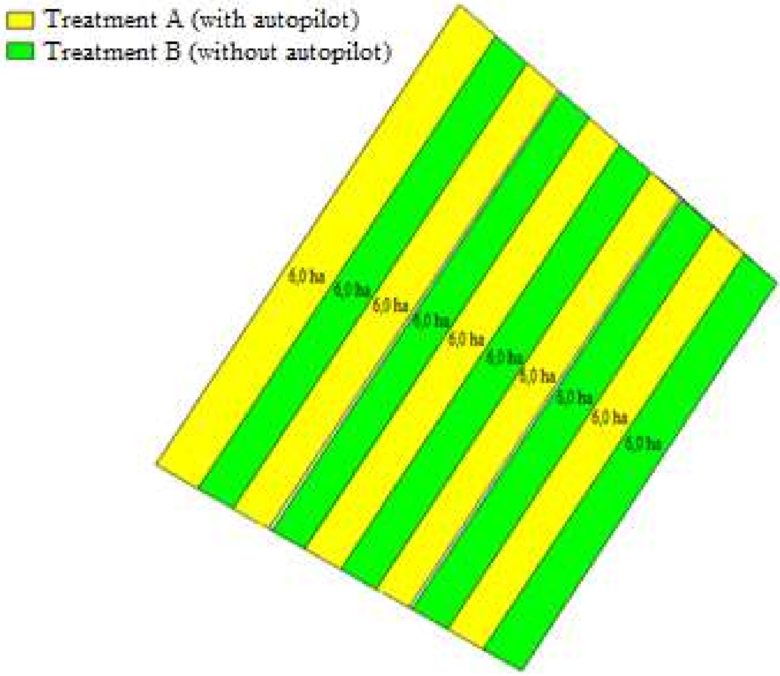


Figure 1. Experimental design for the treatments with autopilot (A) and without autopilot (B)

Results and Discussion

Observing the map of the fuel consumption rate, in liter per hour (L h^{-1}), for treatments A and B (Figure 2), we could verify that using the autopilot system in the harvester, the fuel rate presented an average variation of 45.0 L h^{-1} according to the results of the AFS® software, while without autopilot the fuel rate was 49.5 L. h^{-1}, approximately 10% lower than with autopilot (Table 1).

For the t-Student test ($p < 0.05$), the null hypothesis was rejected, indicating statistical difference with 95% confidence level for operating time and fuel consumption and null hypothesis for the amount of sugarcane mass harvested (Table 1).

Ripoli and Ripoli (2009) and Martins et al. (2017), indicate that among the management factors that involve the cultivation and production of the sugarcane crop (fertilizers, skilled labor, phytosanitary products, etc.), the mechanized harvesting process can present values higher than 10% in the total costs of the field operations, reaching up to 30%, due to the high consumption of fuels for the harvesters, with rates higher than 55 L h^{-1}. This, when not used technologies capable of increasing operational effectiveness in the field. This fact corroborates the values recorded by treatment A (Figure 2 and Table 1), demonstrating that the use of autopilot is an essential technology to reduce the rate of fuel consumption in the sugarcane harvesting process.

For Ramos et al. (2016), estimate the fuel consumption rate of the machines and implements in the field, becomes a tool of extreme importance in the evaluation of the yield of an engine and decision making by the producer in the operations of the cultivated area.

The efficiency in the use of fuel by the harvesters in the field can generate to the sugar and alcohol sector, economic gains and less emission of gases of greenhouse effect to the atmosphere. As seen in treatment A (Figure 2), the use of autopilot is able to optimize the energy used in crop harvesting operation with sufficient fuel economy to evidence GNSS and RTK technology as essential devices in the field when compared to treatment B, without the use of these instruments.

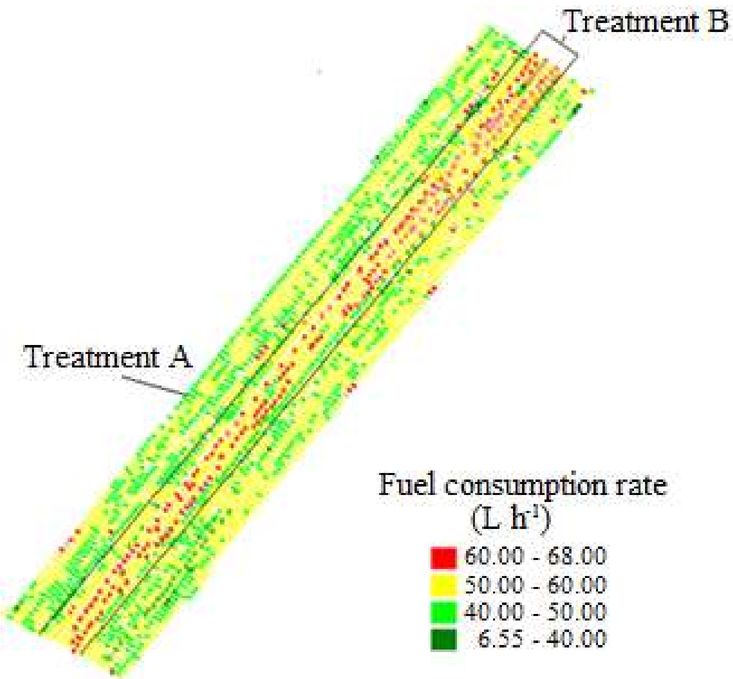


Figure 2. Spatialization of the fuel consumption rate, L h^{-1}, of the sugarcane harvester for treatment A and B

Table 1. Average values of sugarcane mass harvested (ton ha^{-1}), operating time (min) and fuel consumption (L), for treatments A (with autopilot) and B (without autopilot) respectively

Treatments	Sugarcane mass harvested (Mg ha^{-1})	Operational time (min)	Fuel consumption (L)
A	656.6 a	492.4 a	336.5 a
B	655.0 b	542.7 b	370.8 b
Test t	Hypothesis 0	Hypothesis 1	Hypothesis 1
P(T<=t)	0.7952	8.0381E-06	8.0381E-06

*distinct letters differ from each other, by the t-test ($p < 0.05$).

Benedini et al. (2013) observed that the management of the mechanized harvest in the sugar cane crop is a direct systematization between machine, soil and plant, and losses are directly linked to these three factors. Thus, poor performance of a harvester in the field as observed for treatment B without the use of autopilot (Figure 2 and Table 1) may result in poor quality of the final feedstock and reduction in the operational efficiency of the harvesting process, for example, the decrease in the number of crop cuts.

According to Figure 3, in the operational efficiency spatialization, it was verified that, using the autopilot system in the sugarcane harvester, the operational efficiency in productivity was 3.1 ha^{-1}. While for treatment B without the use of autopilot, it was on average 1.5 ha h^{-1}, characterizing a relevant decrease (Table 1) by about 50% in operational efficiency for the conventional harvesting method (without use of automatic pilot).

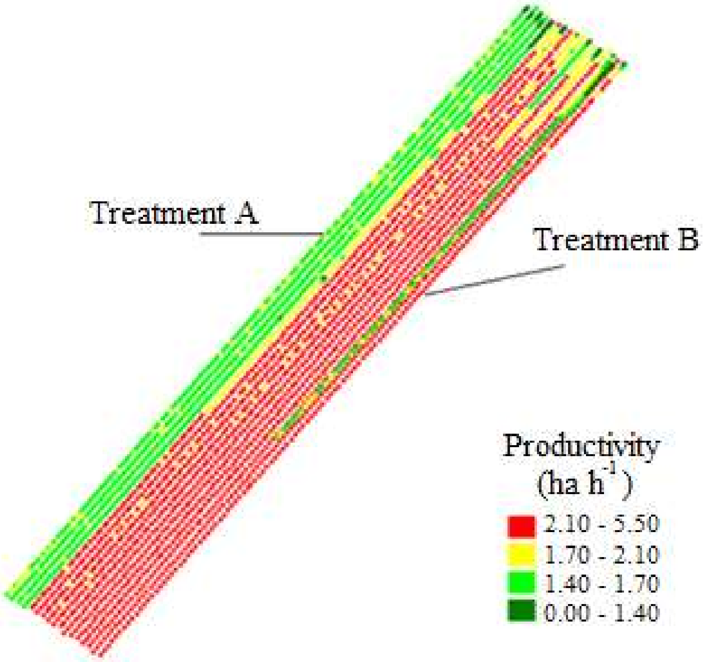


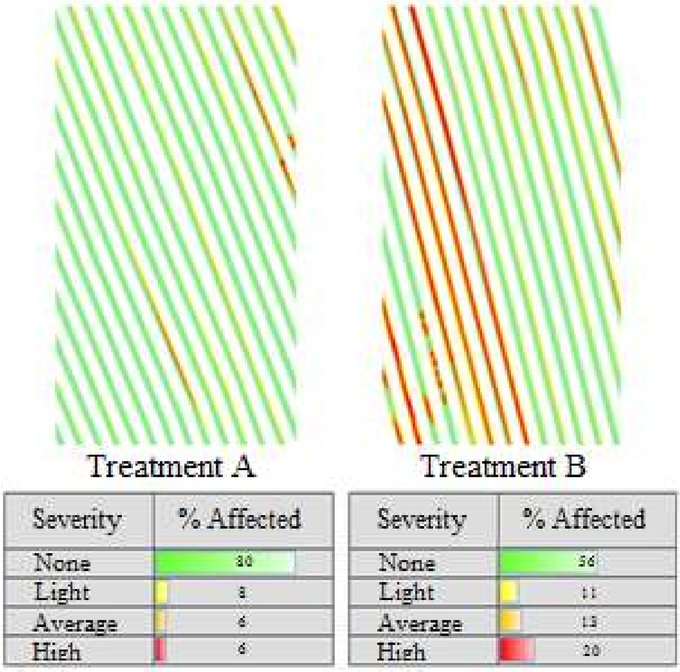
Figure 3. Spatialization of operational efficiency in productivity (ha h^{-1}) for treatment A (with the use of autopilot), and the treatment B (without use of autopilot)

Silva et al. (2008) statistically evaluated the harvesting process for sugarcane, identifying that the operational productivity losses caused in the field are directly related to the type of technology used in the process. This fact agrees with the values found for treatment B (Figure 3 and Table 1), since the absence of technologies capable of guaranteeing the best operational efficiency of the harvester in the field, such as autopilot, can lead to sugarcane sugar losses, classified as visible (losses likely to be measured in the field by the producer or operator) and invisible (they can be measured only with the aid of operating systems and technologies, such as autopilot) (Silva et al., 2008; De Lima et al., 2015).

With the configuration of the route, using the planting lines performed by the harvester, in the two treatments (Figure 4), it was observed that in the use of autopilot (treatment A), there was a 44% reduction in trampling of the sugarcane when compared to the treatment B.

According to the data obtained by the trampling map of the plants (Figure 4), it was possible to assume that the useful life of the sugar cane in treatment B was impaired due to trampling damage in the lines. Since the absence of autopilot in the sugarcane, harvesting operation generated intense failures in the order of 56% and classified as high severity 20%, for the plants. Confirming that GNSS and RTK technologies duly instrumented in the sugarcane harvester, treatment A, are capable of significantly reducing damages of high severity and contribute to the longevity of the cane field due to the better trafficability of the vehicles in the field. For Vani et al. (2013) and Oliveira Filho et al. (2016), the correct positioning of the machine by means of the autopilot and RTK, is able to direct the equipment in the cutting lines and planting lines correctly and benefiting the operator with an increasingly accurate trafficability in the field.

This situation is consistent with that observed in Figure 4, for the treatment with the use of autopilot allied to the RTK system. Highlighted for the Treatment A with a significant increase in the efficiency of the machine, harvesting the same amount of sugarcane in less time with was a mass of 3.283 tons of sugarcane collected in 2.462.25 minutes, and generating yield of 80 ton h^{-1} (Figure 5 and Table 1).



Severity	% Affected
None	80
Light	8
Average	6
High	6

Severity	% Affected
None	56
Light	11
Average	13
High	20

Figure 4. Spatialization of trampling of plants, sugarcane and severity level, in %, for treatments A (with autopilot) and B (without pilot use)

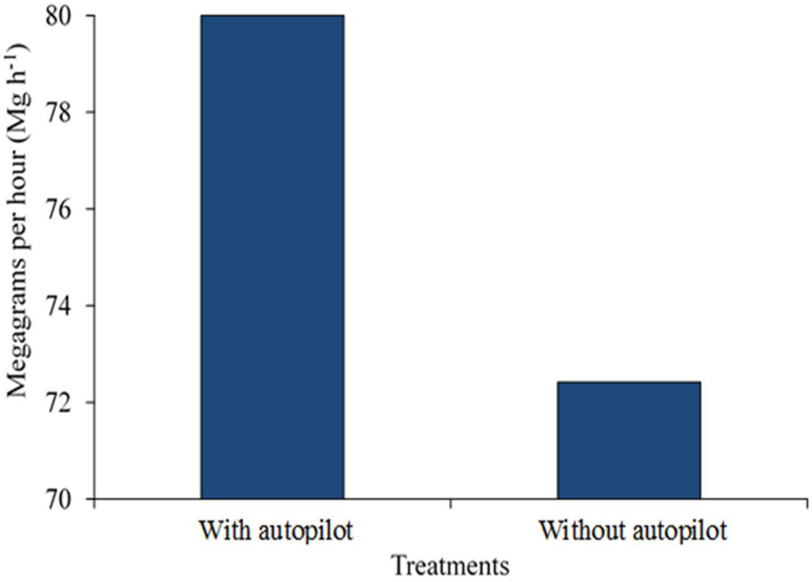


Figure 5. Efficiency of the harvester, in Mg h^{-1}, for treatments A (with autopilot use) and B (without use of autopilot)

For treatment B (without pilot) using the same harvester under the same working conditions, the amount of sugarcane harvested was 3.275 tons in 2.713.44 minutes, yielding a yield of 72 tons h^{-1} and 10% significant loss in machine efficiency (Figure 5 and Table 1).

These data observed for harvester efficiency in treatment A (Figure 5 and Table 1), were close to the work conducted by Segato and Daher (2011), who evaluated the efficiency of sugarcane harvesters without using technologies such as GPS and RTK, and found losses of 10% of the final raw material harvested, a fact considered by the authors as a concern for the sector because the producers end up having a deficit in the order of millions of dollars per year. This can be avoided by using technologies linked to the GPS and RTK (autopilot) tools instrumented in agricultural machinery and equipment for the production of sugarcane.

For Ripoli and Ripoli (2009) and Faulin et al. (2012) in addition to the benefits of automatic positioning, the use of this technology in mechanized harvesting reduces visible losses by approximately 42%, besides providing operator comfort and assisting of managers with the monitoring of the operation related to fuel consumption, hours worked and optimization of the equipment.

Based on the information collected, the use of autopilot in the mechanized harvesting of sugarcane, when used correctly in all its components of operation, offers several benefits to the rural producer, as it considerably reduces the human error in the conduced of the harvester, avoiding the trampling, improving the efficiency of the machine in trafficability and consequently reducing fuel consumption.

Conclusion

The use of autopilot in the sugarcane harvester machine, significantly increased its operating income in tons per hour with values close to 10%.

The autopilot was able to reduce trampling in the sugarcane harvester by 56% and increased fuel efficiency by about 10.2%.

The correct use of autopilot ensures better trafficability of the vehicles in the field, guaranteeing benefits for producers in the sugar and alcohol sector, such as economy, less soil compaction and greater longevity for the sugarcane cultivation.

References

BAIO, F. H. R.; MORATELLI, R. F. Avaliação da acurácia no direcionamento com piloto automático e contraste da capacidade de campo operacional no plantio mecanizado da cana-de-açúcar. **Engenharia Agrícola**, v. 31, n. 2, p. 367-375, 2011.

BENEDINI, M. S.; BROD, F. P. R.; PERTICARRARI, J. G. Perdas de cana e impurezas vegetais e minerais na colheita. 1ª Edição. Boletim Coplana, Jaboticabal, 2013. 7p.

BERNARDI, J. V. E.; LANDIM, P. M. B. Aplicação do sistema de posicionamento global (GPS) na coleta de dados. 1ª Edição. Rio Claro: UNESP, 2002. 31p.

BERNARDI, A. D. C.; NAIME, J. D. M.; RESENDE, A. D.; BASSOI, L.; INAMASU, R. Agricultura de precisão: resultados de um novo olhar. 1ª Edição. Embrapa Brasília, DF: Editora Cubo, 2014. 596p.

CARVALHO, L. A.; REZENDE, I. S.; PANACHUKI, E.; SILVA JUNIOR, C. A., NOVAK, E.; SILVA, G. F. C. Variáveis físicas do solo e produtividade de cana-de-açúcar sob sistemas de preparo na reforma de canavial. **Agrarian Academy**, v.1, n.1, p.259-74, 2014.

CASE IH Brasil. Manual Case colhedora de cana A8800 Multi-Row. 2014, 8p. Disponível em: <https://d3u1quraki94yp.cloudfront.net/caseih/LATAM/LATAMASSETS/Folhetos/Colhedoras%20e%20Colheitadoras/a8800-multi-row-folheto.pdf>. Acesso em 21/04/2017.

CASE IH Brasil. AFS Software. 2017. Disponível em: <https://www.caseih.com/latam/pt-br/products/afs/afs-software>. Acesso em 20/04/2017.

CERVI, R. G.; ESPERANCINI, M. S. T.; SILVA, H. D. O. F.; ISLER, P. R.; DE OLIVEIRA, P. A. Avaliação do desempenho operacional da colheita e transbordo de cana-de-açúcar (*Saccharum* spp.). **Energia na agricultura**, v.30, n.3, p.232-241, 2015.

CONAB - Companhia Nacional do Abastecimento. Acompanhamento da safra brasileira: cana-de-açúcar safra 2017/2018. **Conab**, v.4, n.1, p.1-57, 2017.

COSTA, A. S. J.; COLLINS, D. C. S. D.; FERRARI, T. D. R. L.; BERTAGNA, R.; WAGNER, L. R. Avaliação do impacto ambiental causado pelas alterações espaço temporal do uso do solo e da cobertura vegetal utilizando o modelo das cadeias de Markov. **Ciência e Natura**, v.38, n.1, p.115-124, 2016.

DE LIMA, R. P.; DE LEÓN, M. J.; DA SILVA, A. R. Compactação do solo de diferentes classes texturais em áreas de produção de cana-de-açúcar. **Revista Ceres**, v.60, n.1, p.016-020, 2015.

SANTOS, H. G. D; JACOMINE, P. K. T.; ANJOS, L. H. C. D.; OLIVEIRA, V. A. D.; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A. D.; CUNHA, T. J. F.; OLIVEIRA, J. B. D. Sistema brasileiro de classificação de solos. 3.ed. rev. e ampl. Brasília: Embrapa, 2013. 353p.

FAULIN, M. R.; SALVI, J. V.; AZEVEDO, F. R.; BARRADO, M. J. Qualidade da colheita mecanizada na cultura da cana-de-açúcar com e sem direcionamento automático. 3° EncMap. Pompéia: Bless, 2012, 8p.
IEA - Instituto de Economia Agrícola. Índice de Mecanização na Colheita da Cana-de-açúcar no Estado de São Paulo e nas Regiões Produtoras Paulistas. **Análises e Indicadores do Agronegócio**, v.12, n.6, p.1-6, 2017.

ALMEIDA JÚNIOR, J. J.; PEROZINI, A. C.; THOMAS, P. C. Utilização do piloto automático no plantio mecanizado da cultura da cana-de-açúcar (*Saccharum* spp), Alto Taquari-MT. **Nucleus**, v.12, n.2, p.211-220, 2015.

JUNQUEIRA, R. Á. R.; MORABITO, R. Optimization approaches for sugarcane harvest front programming and scheduling. **Gestão & Produção**, v.1, n.1, p.1-16, 2017.

KAMIMURA, K. M.; SANTOS, G. R. D.; OLIVEIRA, M. S. D.; JUNIOR, D.; DE SOUZA, M.; GUIMARÃES, P. T. G. Spatial variability of the physical properties of a Red Yellow Latosol under coffee. **Revista Brasileira de Ciência do Solo**, v.37, n.4, p.877-888, 2013.

MARTINS, M. B.; RAMOS, C. R. G.; SOUZA, F. L.; SARTORI, M. M. P.; LANÇAS, K. P. Relação entre velocidade de deslocamento, rendimento da cana-de-açúcar e o consumo de combustível da colhedora. **Revista de Agricultura Neotropical**, v.4, n.1, p. 88–91, 2017.

MATSUOKA, S.; ARIZONO, H.; BASSINELLO, A. I.; GHELLER, A. C. A.; HOFFMANN, H. P.; MASUDA, Y. Variedades superprecoces de cana-de-açúcar. **Álcool e Açúcar**, n. 78, p. 22-30, 1995.

OLIVEIRA FILHO, F. X. D.; MIRANDA, N. D. O.; MEDEIROS, J. F. D.; SILVA, P. C. M. D.; MESQUITA, F. D. O.; COSTA, T. K. G. Soil compaction in a sugarcane field at Baía Formosa, Rio Grande do Norte, Brazil. **Revista Ceres**, v.63, n.5, p.715-723, 2016.

PEEL, M. C.; FINLAYSON, B. L.; MCMAHON, T. A. Updated world map of the Köppen-Geiger climate classification. **Hydrology and Earth System Sciences Discussion**, Europe Geoscience Union, v.11, n.5, p.1633-1644, 2007.

RAMOS, C. R. G.; LANÇAS, K. P.; DE SOUZA SANTOS, R.; MARTINS, M. B.; SANDI, J. Eficiência e demanda energética de uma colhedora de cana-de-açúcar em talhões de diferentes comprimentos. **Energia na agricultura**, v.31, n.2, p.121-128, 2016

RIPOLI, T. C. C.; RIPOLI, M. L. C. **Biomassa de cana-de-açúcar: colheita, energia e ambiente**. 1ª Edição. Piracicaba, SP: PLD, 2009. 333p.

BALDO, RODRIGO F. G. et al. “Automatic Steering Systems Based on Relative Position”. **International Journal of Engineering and Technical Research**, v.6, n.1, p.2454-4698, 2016.

SANTOS, A. F.; KAZAMA, E. H.; ORMOND, A. T. S.; TAVARES, T. O.; SILVA, R. P. Quality of mechanized peanut digging in function of the auto guidance. **African Journal of Agricultural Research**, v.11, n.48, p.4894-4901, 2016.

SEGATO, S. V.; DAHER, F. Perdas Visíveis na Colheita Mecanizada de cana-de-açúcar crua sob velocidades de deslocamento da colhedora, **Nucleus**, v.8, n.1, p.315-325, 2011.

SILVA, R. P. D.; CORRÊA, C. F.; CORTEZ, J. W.; FURLANI, C. E. Controle Estatístico Aplicado ao Processo de Colheita Mecanizada da Cana-de-açúcar. **Engenharia Agrícola**, v.28, n.2, p.292-304, 2008.

SOUZA, Z. M.; MARQUES JUNIOR, J.; PEREIRA, G. T. Variabilidade espacial de atributos físicos do solo em diferentes formas de relevo sob cultivo da cana–de–açúcar. **Revista Brasileira de Ciência do Solo**, v.28, n.6, p.937-944, 2013.

TECGRAF. Software AgroCAD. 2017. Disponível em: <http://agrocad.com.br/site/>. Acesso em 20/04/2017.

VANI, B. C.; MONICO, J. F. G.; SHIMABUKURO, M. H. Fundamentos e aspectos computacionais para posicionamento computacionais para posicionamento por ponto GPS. **Revista Brasileira de Geomática**, v.2, n.1, p.8-19, 2013.

VELLAR, R.; GADOTTI, G. I.; LUZ, M. L. G. S. Diagnóstico sobre a agricultura de precisão na região sul do Rio Grande do Sul. **Revista Brasileira de Engenharia e Sustentabilidade**, v.2, n.2, p.67-73, 2016.