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Application of signal correction for *Sphenophorus levis* control and higher quality production in mechanized harvesting of sugarcane ratoon

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Abstract

Higher quality mechanized agricultural operations can be achieved with the use of the Global Navigation Satellite System (GNSS) signal positioning tools (correction signals), allowing a higher accuracy, which is extremely important to reduce operating costs and waste of inputs, in addition to allowing a more effective pest control. Thus, the aim of this study was to evaluate the behavior of the mean execution error of the positioning and pass-to-pass design in the operation of sugarcane ratoon cutting and insecticide application. Furthermore, the efficiency of controlling *Sphenophorus levis* through non-automatic steering (NS) and use of autopilot (RTX and RTK correction signals) in a sugarcane production plot of an experimental area located in the city of Motuca, SP, Brazil were evaluated for a total of 150 points by means of the statistical process control, analysis of variance, and descriptive statistics. Fipronil was the insecticide used for *S. levis* control. The evaluations consisted of the measurement of the mean execution error of the project during tractor operation in ten strides and five replications, in addition to the pass-to-pass (parallelism error) error between strides of the tractor-ratoon cutter assembly. In all strides, the mean execution error and mean error of the tractor-seeder assembly were within both the acceptable limit and the stipulated by the signal manufacturer, with values lower than 3.8 cm. The control charts were efficient to evaluate the behavior of RTX signal quality, facilitating the visualization within the limits of the project execution errors and pass-to-pass, in addition to contributing with an *S. levis* control 27.16% higher than the conventional control in the cutting operation of sugarcane ratoon.

Keywords: Automatic pilot. Precision agriculture. Statistical process control.
Abbreviations: RTX_Real Time eXtend; RTK_Real Time Kinematic; GNSS_Global Navigation Satellite System; SPC_Statistical Process Control; PTO_Power take-off; SD_Standard deviation; CV_Coefficent of variation (%); Cs_Coefficient of skewness; Kr_Kurtosis ratio; RJ test_Normality of Ryan Joiner; N_Normal distribution; A_Non-normal distribution.

Introduction

Brazil is the world's largest sugarcane producer, with an estimated production of 719.9 million tons in the 2017/2018 season, a decrease of 1.2% when compared to the previous agricultural year due to a reduction of 6.2 and 0.3%, respectively, in the area to be planted and harvested (Conab, 2017). Several biotic and abiotic problems are related to the sugarcane cultivation, standing out those biotic, especially losses caused by pests, (Manhães et al., 2013).

An infested area of *Sphenophorus levis* can reach losses from 50 to 60% of the tillers, with a mean loss of 20 to 23 tons of sugarcane per hectare each year (Almeida et al., 2011; Dinardo-Miranda and Fracasso et al., 2013). One of the most used practices in insect control, especially *S. levis*, has been the chemical control, mainly with the use of fipronil and thiamethoxam, with control levels reaching only 60 to 70% (Leite et al., 2012).

Precision agriculture techniques have been applied to sugarcane production to reduce the consumption of inputs and pesticides (Baio, 2012). The technology through auto-guidance can represent 39% of the sugarcane mills in Brazil (Silva et al., 2011). Reducing the pass-to-pass error between strides is the main advantage when compared to manual steering (Baio, 2012). Thus, higher accuracy and better operational quality using auto-guidance are needed.

The conventional mechanized application of insecticides by the sugarcane ratoon cutting is subject to the inability of the operator to keep the cutting disks constantly directed to the sugarcane ratoon rows. In this sense, precision agriculture tools and the statistical process control (SPC) are essential to evaluate the possibility of improving the operational quality by reducing potential losses through effective control of *S. levis*.

This study aimed to evaluate the efficiency of controlling *S.*

levis by means of the sugarcane ratoon cutting and insecticide application, in addition to the operational quality evaluated by the parallelism error of the tractor-ratoon cutter assembly between strides, with the use of automatic steering by RTX and RTK signals compared to the traditional method without using auto-guidance.

Results and discussion

Auto-guidance in mechanized operations to control S. levis

Table 1 shows the mean test and analysis of variance for the mean errors (m) and pass-to-pass error of the tractor-ratoon cutter assembly (m) in the mechanized operation to control *S. levis.*

The use of the RTX signal provided excellent results in the operation of ratoon cuttings, with a mean execution error of the project lower than 3.80 cm between strides using the RTX signal and lower than 3.30 cm when using the RTK signal in the mechanized sugarcane operation (Baio and Moratelli, 2011). In addition, the parallelism in autopilot treatments was close to 1.50 m (crop spacing). The mean error in these two treatments was also lower than the conventional treatment, allowing obtaining a pest control 27.16% higher.

The high coefficient of variation found can be attributed to the operator experience, who does not have access to the correction signals to improve the steering quality during the operation.

Control efficiency of S. levis

Figure 1 shows the results for the population of *S. levis* at two moments: at the initial evaluation of sugarcane ratoon and after ratoon cutting operation for insecticide application. The use of automatic steering allowed better control of larvae and 100% control of adults since it presented a lower mean error and more correct parallelism, allowing the cutting disk to remain correctly directed in the crop rows and that the insecticide to reach the target. All biological variables (larvae and adults) were higher when compared to those found by Pavlu and Molin (2016), who randomly sampled the total area. In our study, sampling was carried out in the center of the infestation spot for better reliability of the results obtained in the experiment.

Quality control for RTX and RTK signals

Table 2 shows the high accuracy for the RTX signal obtained through the descriptive analysis of mean errors and pass-to-pass of the tractor-ratoon cutter assembly and also of the percentage of control in the quality of the ratoon cutting operation process. This is in accordance with Carballido et al. (2014), who performed dynamic tests exploring the potential of autonomous tractors in agriculture with 610 points and obtained similar values of standard deviation in real-time corrections by both base station (RTK = 1.43 cm) and satellite (RTX = 2.55 cm). Figure 2 shows graphs of distribution frequency of the mean execution errors of the project (m) and pass-to-pass error of the tractor-ratoon cutter assembly (m) obtained in the ratoon cutting operation for *S. levis* control, in which the acceptable points were between 1.462 and 1.538 m for RTX and between 1.475 and 1.525 m for RTK. Thus, Figure 2B, C, E, and F present 100% of points within the acceptable values by using the autopilot. This result is in accordance with Santos et al. (2016), who obtained success for the mean execution error of the project and pass-to-pass error of the tractor-ratoon cutter assembly when using RTX, contrasting with the non-use of autopilot (Figure 2A and D), which presented only 24% (12 of 50) of points within the acceptable maximum limit (0.038 m).

Regarding the variables used to characterize the ratoon cutting operation for *S. levis* control, the analysis with sequential graphs and control charts was used only with the purpose of studying the variability process. For quality indicators (mean error and parallelism error of the tractor-ratoon cutter assembly), this analysis also sought to evaluate the stability of this process performed without and with autopilot.

Figures 3 and 4 show the stable and low-variability behavior of the variables mean execution error of the project and pass-to-pass error of the tractor-ratoon cutter assembly with the use of the RTX and RTK signals in the operational process of ratoon cutting. Specifically, Figure 4 contrasts with the pass-to-pass error of 4.88 cm in the mechanized planting operation with RTK signal found by Voltarelli et al. (2013). Despite being stable, the treatment without autopilot has much higher variability when compared to the use of the autopilot. This higher variability is due to a lower capacity of the operator to maintain the correct parallelism without the assistance of correction signals, i.e. using only the personal ability. The correct parallelism has extreme importance for this operation and, consequently, for pest control.

The control chart presented in Figure 4 shows a high variability of the ratoon cutting process when there is no use of the autopilot. There is a point out of the control limits, indicating instability of the process, which is probably due to the 6 M factor, especially the manpower factor, since often only the operator experience is not enough to avoid positioning errors. In this context, the RTX and RTK correction signals are alternative tools to improve the operational quality, being in accordance with Rizos et al. (2012) regarding the real-time horizontal positioning error by means of satellites in orbits and clock corrections. The control charts in Figure 5 show that the behavior of ratoon attack control was similar between automatic steering systems, in addition to high variability in the treatment without autopilot due to the difference between the minimum and maximum values found in the experiment (Montgomery, 2009; Pavlu and Molin, 2016). This high variability is closely related to the mean and pass-to-pass errors, factors in which it was also higher for the treatment without autopilot, with a consequent lower pest control quality when compared to the other two treatments, which have real-time correction signals with a superior accuracy than that of the operator abilities, allowing the implement to be directed correctly on the crop rows and resulting in a more consistent control.

Material and methods

Description of the area: location, soil, climate, and plant

The experiment was carried out at Santa Terezinha Farm, located in the municipality of Motuca, SP, Brazil, near the geographical coordinates 21°27′ S and 48°07′ W in the WGS84 geodetic reference system, with an altitude of 604 m, mean slope of 1.5%, and climate Aw according to the Koppen classification.

The used sugarcane variety was CTC 4, which has excellent

Table 1. Mean errors (m) and pass-to-pass error of the tractor-ratoon cutter assembly (m) between strides in the operation of sugarcane ratoon cutting (insecticide application) and control (%) with non-automatic steering (NS) and autopilot (RTX and RTK).

Signal	Mean error (m)	Pass-to-pass error (m)	Control (%)
NS	0.091 a	1.479 b	66.89 b
RTX	0.017 b	1.504 ab	85.06 a
RTK	0.011 b	1.512 a	86.00 a
F-test	74.24**	9.44*	13.13**
sd (5%)	0.017	0.030	10.02
CV (%)	90.76	4.25	20.52

Means followed by the same letter do not differ significantly from each other by the Tukey's test ($p \leq 0.05$). sd – significant difference.

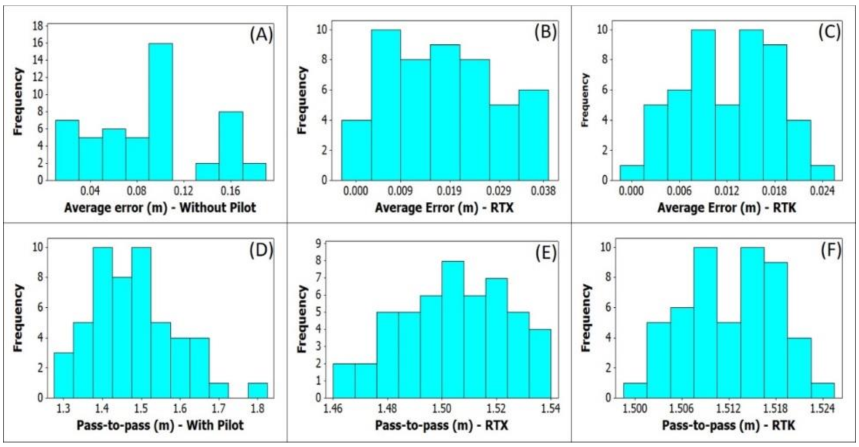
(A) (B)

Fig 1. Mean values of larvae (A) and adults (B) found per trench (0.5 × 0.5 × 0.3 m) during the period before (pre) and after (post) ratoon cutting operation for insecticide application. Means followed by the same letter do not differ significantly from each other by the Tukey's test ($p \leq 0.05$). Pre-control; Post-control.

Table 2. Descriptive statistics for quality indicators of the sugarcane ratoon cutting process (mean execution error of the project, pass-to-pass error of the tractor-ratoon cutter, and percentage of attack control).

Variable	Treat.	Mean	SD	CV	Min	Max	Cs	Kr	RJ test
Mean error (m)	*SP*	0.091	0.06	67.67	0.010	0.280	0.73	0.43	0.986^{N}
	RTX	0.017	0.01	65.62	0.000	0.049	0.25	−0.92	0.984^{N}
	RTK	0.011	0.01	51.29	0.000	0.025	−0.08	−0.81	0.993^{N}
Pass-to-pass (m)	*SP*	1.479	0.11	7.33	1.30	1.780	0.59	0.00	0.987^{N}
	RTX	1.504	0.02	1.31	1.46	1.538	−0.18	−0.76	0.993^{N}
	RTK	1.512	0.01	0.40	1.50	1.525	−0.08	−0.81	0.983^{N}
Attack control (%)	*SP*	66.89	21.00	31.39	20.00	100.00	−0.24	0.02	0.987^{N}
	RTX	85.06	13.67	16.07	66.70	100.00	0.10	−1.86	0.993^{N}
	RTK	86.00	12.94	15.04	66.70	100.00	0.03	−1.76	0.983^{N}

SD: Standard deviation; CV: Coefficient of variation (%); Cs: Coefficient of skewness; Kr: Kurtosis ratio; RJ test: Normality of Ryan Joiner (N: Normal distribution; A: Non-normal distribution).



Mean error (m).

Fig 2. Histogram of the distribution of values obtained for the mean execution error of the project (A, B, and C) and pass-to-pass error of the tractor-ratoon cutter assembly (D, E, and F) between strides for the treatments non-automatic steering (NS) and autopilot (RTX and RTK).

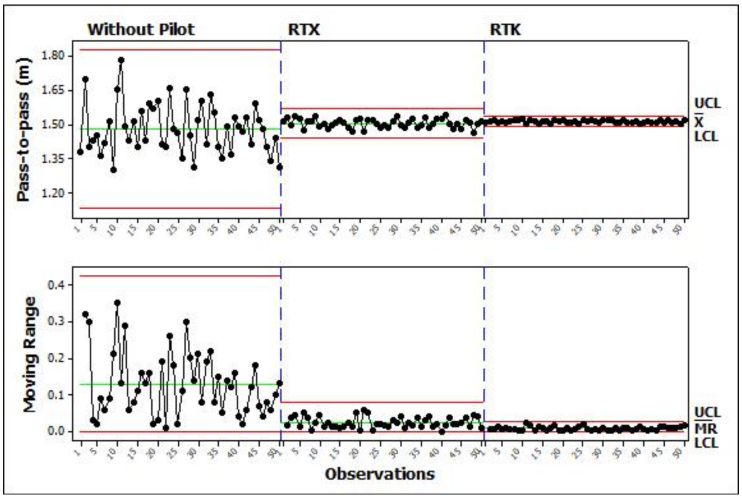
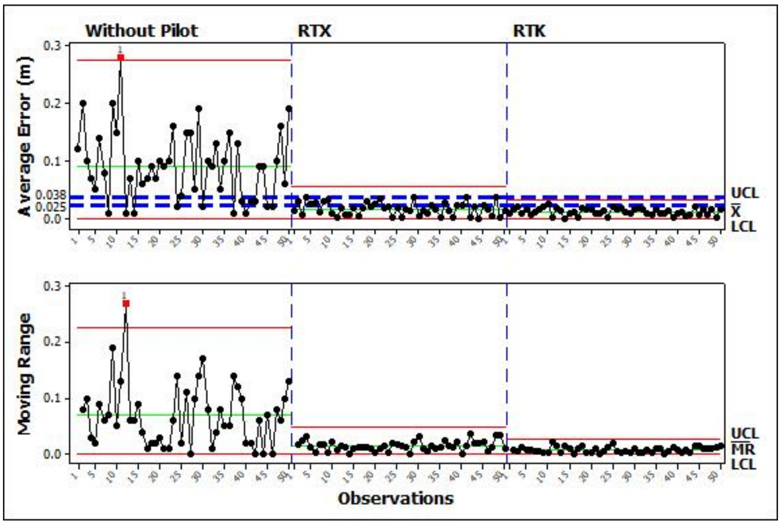


Fig 3. Control charts for analyzing the pass-to-pass error of the tractor-ratoon cutter assembly (m) between strides in three different treatments: non-automatic steering (NS) and autopilot (RTX and RTK).



Mean error (m)

Fig 4. Control charts for analyzing of the mean execution error of the project (m) between strides in three different treatments: non-automatic steering (NS) and autopilot (RTX and RTK).

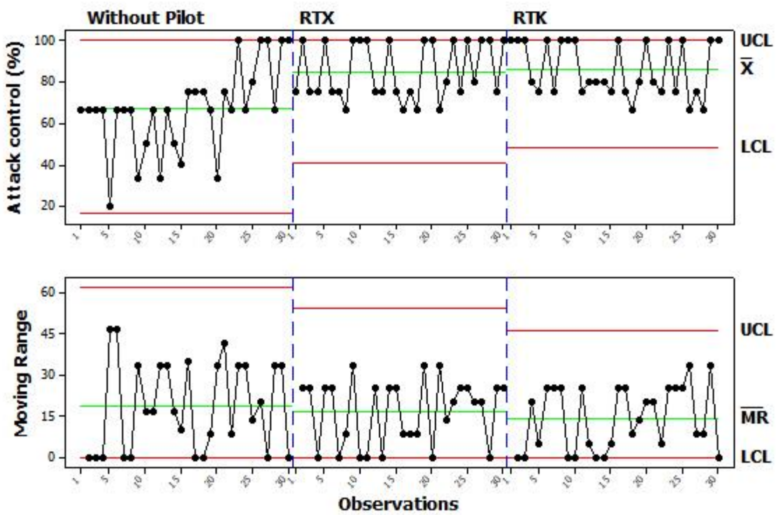


Fig 5. Control charts for the attack control behavior of *Sphenophorus levis* per trench (0.5 × 0.5 × 0.3 m) in the treatments non-automatic steering (NS) and autopilot (RTX and RTK).


(A)


(B)

Fig 6. Implement used for the insecticide application operation in the sugarcane crop (A) by means of ratoon cutting (B).

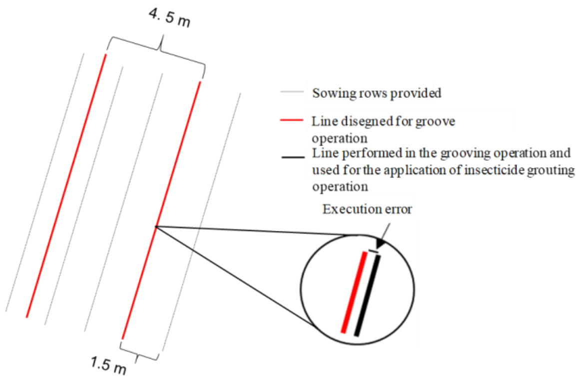


Fig 7. Model of the AgroCAD® project for auto-guidance. Planned sowing rows; Line designed for furrowing operation; Lined performed during the furrowing operation and used for insecticide application.

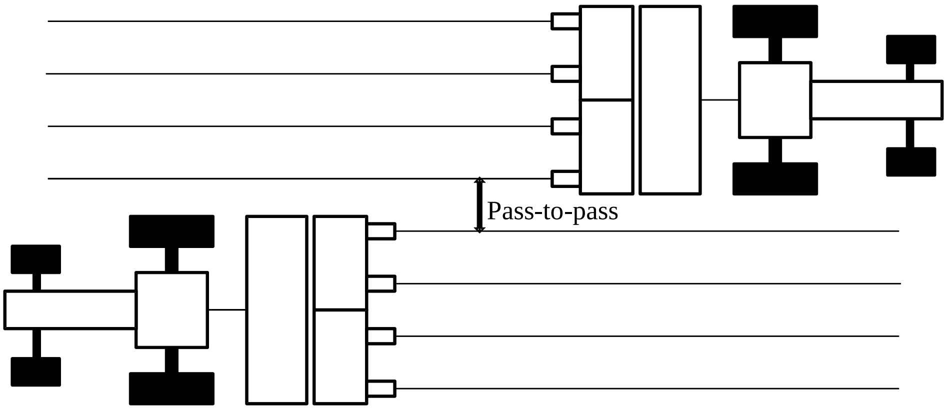


Fig 8. Evaluation of the pass-to-pass between strides of the tractor-sprayer assembly.

tillering, aptitude for mechanization, and tolerance to drought. Planting was carried out in 2015 in a clay-loam soil (EMBRAPA, 2013) with an interrow spacing of 1.50 m, being in the first cut when the experiment was setup.

Experimental design and treatments

The total experimental area (30 hectares) was furrowed with the assistance of the RTK autopilot (Real Time Kinematic) in order to standardize the parallelism of the planting rows, allowing a uniform stand for ratoon resprouting.

The following treatments were used: non-automatic steering (NS), automatic pilot with RTX signal correction (Real Time eXtend) and automatic pilot with RTK signal correction in the ratoon cutting operation, during insecticide application for *S. levis* control.

Mechanization methods

Sugarcane ratoon cutting operation for insecticide application in all treatments was carried out by the same mechanized set. This set consisted of a Case Farmall IH tractor (95 hp) operated in 2nd gear at 1700 rpm and speed of 11 $km.h^{-1}$ and a DMB ratoon insecticide sprayer (Figure 6A) adjusted to a spacing of 1.50 m between three 26-inch discs. This implement has compression springs that cut the straw layer and ratoons at a depth of 0.10 m. Fixed just behind the cutting disks (Figure 6B) there is a device with a nozzle (orifice of 0.003 m) for a deep application.

Insecticides

This implement has a tank with capacity for 600 liters of spray solution, equipped with a level display and piston pump driven by a tractor power take-off (PTO) system for spraying the insecticide Fipronil (Regente 800 WG) at a dose of 250 g ha^{-1} and a spray solution volume of 120 L ha^{-1}.

Conduction of the study

The operation of insecticide application in the sugarcane ratoon using correction signals was carried out using a furrowing project, which was elaborated in the software AgroCAD® and executed by a set of tractor and 3-furrow ridger. The project did not need to be adapted to carry out the insecticide application since the sprayer also had three rows.

Figure 7 shows the working width of the implement, as well as the crop spacing, with the lines for the autopilot orientation spaced at 4.50 m since each stride had three cutting lines and spacing of 1.50 m. In the insecticide application by means of the ratoon cutting, the treatments were arranged considering the use of the correction signals (RTX and RTK) or not (conventional operation). Fifty points with a spacing of 50 m from each other were collected in a completely randomized design, totaling 150 sample points.

The pass-to-pass between strides of the tractor-sprayer assembly was evaluated by measuring the spacing between them with Trimble GN6 receiver (semi-kinematic relative positioning method) (Figure 8).

The operation without the use of autopilot (NS) used only the vision and the 15-year experience of the tractor operator to drive the tractor on the sugarcane crop rows.

The RTX autopilot was equipped with a Trimble AG25 antenna, which has multi-band receivers (L1 and L2) and works with GPS, SBAS, GLONASS, RTK, RTX, and OMNISTAR signals, as well as a Trimble FmX on-board monitor.

Ratoon cutting operation by means of the autopilot with RTK signal was performed using a mobile base station located near the area in which this study was developed. This mobile base used a Trimble R6 receptor and HPB-PDL450 Radio.

Samplings of *S. levis* infestation were performed by opening trenches with dimensions of 0.25 m^2 and 0.30 m depth in the sugarcane rows, counting the biological forms (larvae and adults), and calculating the threshold level to stems due to the pest attack. These samplings were carried out in the center of the infestation spot in order to ensure the presence of the past, totaling 60 sampling points (30 pre-application and 30 post-application).

At each sampling point, the total number of stumps in the clumps, attacked stumps, larvae, pupa (none found), and adults were counted. The percentage of attacked stumps is the relationship between the number of attacked stumps and the number of total stumps. The percentage of attack control was calculated by the relationship between the pre- and post-percentage of attacked stumps.

$$\%\,Control = \frac{\%\ \text{Ratoon attacked after control}}{\%\ \text{Ratoon attacked before control}}$$

Statistical analysis

The variability and stability of the pass-to-pass error of the tractor-ratoon cutter assembly and the mean execution error of the project of the processes of cutting and insecticide application in the sugarcane ratoon were analyzed by means of the statistical process control (SCP) with the software Minitab®.

Control charts were used as tools of SCP using variables from run charts. The selected chart model was the individual-moving range (I-MR), which has an upper graph, which corresponds to individual values sampled at each point, and a lower graph, which is obtained by the calculated amplitude between two successive observations.

Control limits were established when considering the data variation due to special or uncontrolled causes in the process (Montgomery, 2009).

In the charts of mean execution error of the project and pass-to-pass error of the tractor-ratoon cutter, the specific control limit (UCL and LCL) was established based on the information by the signal manufacturer, which emphasizes a precision of 0.038 m for the RTX signal and 0.025 m for the RTK signal.

The analysis of variance and descriptive analysis were performed with the aim of verifying the data behavior, the analysis of normality was carried out by the Ryan-Joiner test ($p \leq 0.05$), and the comparison of the mean errors in treatments was performed by the Tukey's test ($p \leq 0.05$).

Conclusion

Auto-guidance by the RTX and RTK correction signals is an excellent alternative for the insecticide application operation by means of ratoon cutting, as observed in the control

charts, being more stable and within the limits of the execution error of the project and pass-to-pass error.
The use of auto-guidance provided an increase of 27.16% in relation to the conventional mechanized control of *S. levis* in the sugarcane ratoon cutting operation. This was a result already expected since the quality in pass-to-pass and low mean error are essential for this operation. Correction signals allowed an improvement in these two aspects, in addition to higher stability in the process, resulting in more effective pest control.
The use of correction signals leads to better pest control, reduced production losses, more efficient use of inputs, reduced operator stress, better fuel use, and better operational efficiency. Moreover, in general, correction signals make the operation more sustainable, a factor for which precision agriculture has increasingly contributed.

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