COMPARISON OF PERFORMANCE IN MECHANISED AGRICULTURAL TASKS BETWEEN PRECISION AND CONVENTIONAL AGRICULTURE ON FARMS IN TOLIMA (COLOMBIA)?

Juan José Ortiz Rodríguez ¹
Juan Gonzalo Ardila Marín ²
Diana Carolina Polania Montiel ³

ABSTRACT

Purpose: Agricultural work in Colombia, particularly in small and medium-sized farms, is lagging behind in terms of technology; advances such as precision agriculture (PA) are unknown. This project managed to promote the implementation of PA technologies in the primary tasks of land adaptation, by comparing efficiency indices when conventional practices were used against the use of new technologies.

Theoretical framework: The company CasaToro SA, with its John Deere® agricultural line, allowed the implementation of StarFire TM6000®, 4240® Monitors, Auto Track 200®, and JDLink® technologies, and the use of T3RRA CUTTA® software, in tractors of its brand in different farms in Tolima, Colombia.

Method/design/approach: Measurements of time and area worked in situ were taken and the data obtained were statistically compared using Analysis of Variance (ANOVA).

Results and conclusion: Finding significant differences in tasks such as contour line drawing, which reported a decrease of up to 30% in the time needed in h ha⁻¹, and in primary tillage with discs with increases of up to 13% of the tilled area in ha h⁻¹.

Research implications: In conclusion, in Tolima, which has extensive areas of agricultural production, the implementation of PA can improve yields and reduce production costs.

Originality/value: To demonstrate the benefits of PA.

Keywords: Agricultural Engineering, Agricultural Mechanisation, Automation, Tillage.

COMPARAÇÃO DE DESEMPENHO EM TAREFAS AGRÍCOLAS MECANISADAS ENTRE AGRICULTURA DE PRECISÃO E CONVENCIONAL EM PROPRIEDADES DE TOLIMA (COLÔMBIA)

RESUMO

Objetivo: O trabalho agrícola na Colômbia, particularmente nas pequenas e médias propriedades, está atrasado em termos de tecnologia; avanços como a agricultura de precisão (AP) são desconhecidos. Este projeto conseguiu promover a implementação de tecnologias de AP nas tarefas primárias de adaptação do solo, comparando os índices de eficiência quando as práticas convencionais foram usadas contra o uso de novas tecnologias.

Referencial teórico: A empresa CasaToro SA, com sua linha agrícola John Deere®, permitiu a implantação das tecnologias StarFire TM6000®, Monitores 4240®, Auto Track 200® e JDLink®, e a utilização do software T3RRA CUTTA®, em tratores de sua marca em diferentes fazendas em Tolima, Colômbia.

¹Universidad Surcolombiana: Neiva, Huila, Colômbia. E-mail: juan.ardila@usco.edu.co
Orcid: https://orcid.org/0000-0003-4461-7195

²Universidad Surcolombiana: Neiva, Huila, Colômbia. E-mail: juan.ardila@usco.edu.co
Orcid: https://orcid.org/0000-0003-4461-7195

³Universidad Surcolombiana: Neiva, Huila, Colômbia. E-mail: carolina.polania@usco.edu.co
Orcid: https://orcid.org/0000-0001-5306-6431
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INTRODUCTION

Demand for food added to decrease in soil fertility, require agriculture sustainability, for this reason improving performance technologies have become a valuable approach to face this need (Cipriano, et al., 2022; Duarte et al., 2021). Agricultural tasks require technological updating in accordance with new developments in electronics and information systems. Precision agriculture (PA) involves technologies such as global positioning system (GPS) and geographic information system, which allow the mapping of characterised areas with different types of sensors. With the information obtained through AP, it is possible to estimate, evaluate, and understand spatial changes in soil and crop properties, and support decision-making (Marote, 2010). This entails economic and environmental benefits; for example, the use of fertilisers and pesticides is controlled by limiting their application to the amount, place, and time necessary (Fao, 2002; Zhang et al., 2002; Quevedo et al., 2006; Martino et al., 2009). However, the economic benefits of implementing PA have only been demonstrated in large, high-income generating farms, due to the cost of the technologies and investment return times, which has limited its implementation on medium and small-scale farms. Another difficulty has been the mentality of farmers who experience some opposition to change and difficulties in adapting to the use of new technologies, due to their age or academic level of training (Quevedo et al., 2006; Cullen et al., 2013; Paustian et al., 2017; Barnes et al., 2019). In Colombia, although research on PA implementation is scarce, higher education institutions such as SENA offer technical academic programmes in precision agriculture and agricultural mechanisation (SENA, 2020), and private companies such as CasaToro S.A. promote the application of PA through promotion and marketing strategies.

As stated above, PA uses multiple recently developed technologies to support decision-making in the agricultural sector. Numerous research studies have been carried out globally on PA. A specific scenario is the implementation of PA technologies in tractors, which are the main source of mechanical power used in agricultural production. An example of this is research such as that carried out by Lindsay et al. (2018), who measured the improvements in performance, savings, and profits obtained after implementing GPS guidance on tractors on a farm (Lindsay et al., 2018).

Paraforos et al. (2018), knowing that tractor idle time decreases its overall efficiency, managed to reduce the time spent on critical manoeuvres, such as headland turns, by implementing PA through an autopilot system (Paraforos et al., 2018). Li et al. (2019) also
implemented an autopilot system, in this case consisting of a master and a slave machine, where the master machine can, in turn, be manoeuvred on autopilot or manually, and the slave follows the master automatically with a steering wheel rotation control that receives information from GPS and a sensor installed on the front wheel through wireless communication (Li et al., 2019).

Certainly, Professors Xiongzhe Han of Kangwon National University and Chan-Woo Jeon of Seoul National University in the Republic of Korea have been among the most prolific on the subject. Han et al. (2015), knowing that the use of tractors is hampered by skidding and headland turns, developed a simulator to virtually plan tractor manoeuvres in real time in a 3D graphical environment (Han et al., 2015). Subsequently, Han et al. (2019) used the simulator to improve the performance of an autonomous tractor (Han et al., 2019). Recently, Han et al. (2021), aware that planning tractor manoeuvres in complex fields minimises time losses and downtime costs, presented a holistic manoeuvre planner that can generate routes in the field for autonomous or autopilot-equipped tractors (Han et al., 2021). Concurrently, Jeon et al. (2021) developed a route planner for an autonomous tractor that enables automatic route generation, including difficult headland turns (Jeon et al., 2021).

Agricultural Management Solutions (AMS®) are John Deere® PA technologies that can be installed on tractors and that, through GPS technology, allow the collection and recording of tractor operation data while working in the field, and even allow the tractor to be guided through routes mapped by the software through the implementation of autopilots (John Deere®, 2013). In this project, thanks to the support of CasaToro S.A., it was possible to implement the following AMS equipments: StarFire TM6000®, 4240® monitors, Auto Track 200®, and JDLink® in tractors, and the use of the T3RRA CUTTA® software. Field tests were carried out in the municipalities of Lérida (Agricola Fonseca), Ambalema (Hacienda Pajonales), Espinal (independent producer), and Ibagué (Hacienda El Escobal) in the department of Tolima, where level curve tests were carried out, measuring h ha−1 in five hectares and tillage tests with harrow measuring ha h−1 in 1 h. The aim was to encourage the implementation of PA by local producers who agreed to participate in the tests and training.

2 MATERIALS AND METHODS

Trials, demonstrations, and training of farmers implementing PA on their equipment were carried out for six months, selecting farms that had adequate machinery and sufficient time to carry out these activities.

2.1 Contour tests

The PA technologies were installed as follows: 1) StarFire TM6000® (receiver) was installed in the upper part of the cabin, and centered with respect to the axes, as can be seen in Figure 1 (a), and was set to receive the signal from another StarFire (transmitter) configured as a base. That is, once connected, the signal was configured so that it could not modify its GPS position. Moreover, its location should preferably be in a high area free of obstacles that could interfere with the signal and communication between the equipment; see Figure 1 (b). 2) In the Auto Track 200®, or autopilot, the original steering wheel was removed and replaced by fitting it into the tractor’s tiller and adjusted so that it could not turn, allowing only the steering wheel to turn, as shown in Figure 1 (c). 3) The 8.4 inch 4240® monitor was mounted on the left side of the cabin, as shown in Figure 1 (d). In addition, the JDLink® computer was discreetly mounted inside the cabin. The universal harness is the wiring harness that splices all the devices together and allows them to be powered from the battery. All these installations were done on a 125 HP 6603 tractor.

For the initial land survey, the field and contour lines function was configured on the monitor. Moreover, the lot started to be delimited by going along the limit, recording the route;
then, the survey activity was configured and the lot traveled from end to end. Two points were taken (initial and final) and a straight line was drawn, and the software generated several equidistant lines according to the configuration. The tractor travelled the lines marked on the monitor, taking altimetry points throughout the lot. The information was extracted for transformation into an elevation map using the T3RRA CUTTA® program. In the computer, contour lines were made according to the topography of the terrain and the distances between the curves or the slopes. The software proposal was then modified and used to determine the best curve design, as shown in Figure 2 (left). In non-uniform lots, contour design was done by dividing the lots into sub-lots for better water management. Once the level curves were designed, the program data was taken by USB to the monitor and these were carried out with the Taipa ridging machine, as shown in Figure 2 (right).

Figure 1. (a) StarFire TM6000® Receiver, (b) StarFire TM6000® Transmitter, (c) Auto Track 200®, and (d) Monitor 4240®.

Fonte: Own source.

Figure 2. Terrain survey and contour plotting in T3RRA CUTTA® (left), and its realisation with Taipa ridging machine (right).

Fonte: Own source.

The contour line tracing tests consisted of measuring the time on five hectares and calculating the h ha\(^{-1}\) indicator with three replications, for a total of 15 ha per farm, on three farms: Agrícola Fonseca in Lérida, Hacienda Pajonales in Ambalema, and an independent farmer in Espinal. Subsequently, a comparative statistical analysis was performed using the SISVAR® software, using the conventional tracing procedure with a satellite flagger as a
witness. Through the analysis, the percentage of time saved was calculated and analysis of variance (ANOVA) was performed to establish whether the difference between the use of PA and conventional agriculture was significant.

### 2.2 Harrow tillage trials

Performance tests were conducted with the autopilot to perform primary tillage tasks with disc plows on three different farms, ensuring that the implement used for this task was the same. The test time was one hour, calculating the tilled area simultaneously, using the autopilot and comparing it with the tilled area without the pilot simultaneously. Figure 3 allows comparing scenario (a) with autopilot and no overlap and scenario (b) without autopilot and overlap. Figure 3 (c) shows the conventional procedure, the tractor with implement, but without the StarFire TM6000® or Auto Track 200® PA technologies.

The area was measured for 1 h and the ha h⁻¹ indicator was calculated, with three replications, for a total of 3 h per farm, on three farms: Hacienda Pajonales in Ambalema, Hacienda El Escobal in Ibagué, and an independent farm in Espinal.

![Figure 3. Harrowing activity (a) with autopilot and no overlap, (b) without autopilot and overlap, and (c) conventional tillage.](image)

**Fonte:** Own source.

### 3 RESULTS

Subsequently, a comparative statistical analysis was performed using the SISVAR® software, using the conventional tillage method without PA as a control. Through the analysis, the percentage increase in yield was calculated for each farm and ANOVA was performed to establish whether the difference between the use of PA and conventional tillage was significant.
3.1 Contour tests

The time to make contour lines was reduced by up to 30% with PA, depending on the micro-relief of the terrain, temperature, and operating speed of the tractor when making the curves. The times measured during the tests are recorded in Table 1, as well as the calculation of the average per farm and treatment, and the percentage of time saved using PA.

Table 1 – Tracing time per hectare, contour lines test.

<table>
<thead>
<tr>
<th>FARM</th>
<th>TIME [h ha⁻¹]</th>
<th>AVERAGE</th>
<th>% TIME SAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flagger</td>
<td>John Deere AMS</td>
<td>Flagger</td>
</tr>
<tr>
<td>Agricola Fonseca</td>
<td>7</td>
<td>6,8</td>
<td>5</td>
</tr>
<tr>
<td>Hacienda Pajonales</td>
<td>6</td>
<td>5,5</td>
<td>6</td>
</tr>
<tr>
<td>Independent</td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Fonte: Own source.

A variation was observed in the results obtained, which can vary depending on the micro-relief of the lots; if the terrain is very broken, the yield with the satellite flagger and the percentage of error in the precision of the contour lines increase. This 30% time saving obtained in Agricola Fonseca is reflected in the difficulty in the design of the curves, as these were too aggressive and, in some cases, the tractor made an 8-shape turn to resume the curve, wasting time. Due to this problem, when the curves were designed, they were smoothed in such a way that the very tight curves were even smoother, and no time was wasted in performing extra manoeuvres to resume the curve. In the fields of Hacienda Pajonales and the independent one, the realisation of the curves did not require much effort; therefore, the time saved with automatic guidance decreased compared to the result obtained in Agricola Fonseca.

After analysing each of the times obtained per client using the SISVAR® software, it was observed that there are significant differences in the Agricola Fonseca and Hacienda Pajonales clients, where the P values of the ANOVA were 0.00054 and 0.00232, respectively, against an Alpha value of 0.05; as they were lower than the Alpha value, they supported the alternative hypothesis with 95% confidence; the average of the times was different. While in the independent farm there were no significant differences in the recorded times, the P value was 0.15919, higher than the Alpha value, rejecting the null hypothesis. This fact may be due to the micro-relief of the terrain, as explained above.

3.2 Harrow tillage trials

Table 2 shows the results obtained in the dragging tests with their respective areas, implementing conventional mechanisation, comparing these times with those obtained by applying PA. There was an increase in the hectares worked when automatic guidance was implemented, compared to the area worked without it. The averages of the three tests carried out are presented, evidencing a higher yield in the area worked with PA technology. Comparing the areas worked with and without guidance, the client of El Espinal obtained a yield of 13%, followed by Hacienda Pajonales with 12% and, lastly, Hacienda El Escobal with the lowest percentage of 6%.
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Table 2 – Area tilled per hour, harrow tillage test.

<table>
<thead>
<tr>
<th>FARM</th>
<th>PERFORMANCE [ha h⁻¹]</th>
<th>AVERAGE</th>
<th>% OF PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With AutoTrack</td>
<td>Without AutoTrack</td>
<td>With AutoTrack</td>
</tr>
<tr>
<td>Pajonales</td>
<td>2.2 2.3 2.2</td>
<td>2.5 2.5 2.7</td>
<td>2.2</td>
</tr>
<tr>
<td>El Escobal</td>
<td>2.3 2.2 2.2</td>
<td>2.4 2.5 2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Independent</td>
<td>2 2.2 2.1</td>
<td>2.4 2.5 2.4</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Fonte: Own source.

Significant differences were observed using the SISVAR® software in the Hacienda Pajonales and independent clients, which in the ANOVA yielded P-values of 0.01770 and 0.00749, respectively, lower than the Alpha value of 0.05, which is interpreted as the affirmation of the null hypothesis of difference between treatments with 95% confidence. While at Hacienda El Escobal, there were no significant differences in the registered hectares, with a P value of 0.07048 greater than the Alpha value. This result reflects the experience of the operators, which is important in the results of this test, which differ depending on the overlap required or executed by the tractor driver operating without the guidance of the autopilot.

4 DISCUSSION

Shockley et al. (2012a) evaluated yield increases in spraying, fertilisation, and seeding operations comparing the use of autopilot on tractors versus the conventional scenario, reporting increases of 17.2% measured in acres worked with sprayer per hour, 14.95% with fertilisation and 8.27% with seeder (Shockley et al., 2012a). The present work reports yield increases of 6 to 13% in hectares per hour during adaptation operations with disc harrows. The yield increases reported by Shockley et al. translate into chemical and fertiliser reductions of up to 10.96% and seed reductions of up to 4.84%, with consequent environmental and economic benefits. Lindsay et al. (2018) reported a 1% increase in yield in spraying, fertilisation, and seeding operations on several farms using a tractor guidance system, and from this increase they calculate a large increase in profitability when including the savings associated with decreased consumption of seeds, fertilisers, herbicides, and other chemical products (Lindsay et al., 2018). However, they stated that yield is difficult to measure for multiple farms because data collection is expensive, so they assumed an arbitrary standard yield increase of 1%; whereas the present work reports and details the methodology for measuring and assessing yield, finding values much higher than the 1% standard as reported by Shockley et al. (2012).

In contrast to the very comprehensive study by Lindsay et al., Parafóros et al. (2018) limited themselves to measuring the manoeuvring time near field limits (headland turns) for a tractor with an automatic driving system, demonstrating the minimisation of time thanks to the implementation of PA (Parafóros et al., 2018). In the present study, the T3RRRA CUTTA® software was not used in the optimisation of headland turns, as these were executed by the machinists, but it did allow the design of optimal trajectories for the tractor with autopilot; even so, the planning of these critical manoeuvres in automation enabled by the software needs to be explored in the future. Shockley et al. (2012b) measured the percentage overlap of spraying and seeding operations, comparing the use of automatic control on the tractor versus a conventional management scheme on four experimental farms, finding differences of up to 12.83% in seeding time without control versus 0.8% in seeding time with control in an irregular plot and 7.27% versus 0.47% in a regular plot, and up to 16.96% overlap in fertilisation without control versus 1.73% with control in an irregular plot and 12.62% versus 1.3% in a regular plot (Shockley et al., 2012b). Similarly, Velandia et al. (2013) found that the percentage of double-seeded area could range from 0.1% to 15.5%, depending on the size and shape of the experimental plots, and that the adoption of an automatic control system in seeding tractors resulted in savings of between 4 and 26 $ ha⁻¹ (Velandia et al., 2013). Notably, Shockley et al.
found that automatic control increased net yields by up to 36 $ ha\(^{-1}\) in relation to these marked differences in overlap control [19]. In this work, the overlap difference was not measured, but it was verified as shown in Figure 3.

Vellidis et al. (2014) established the economic gains of planting and harvesting peanuts with autopilot versus conventional management and, although they did not report a difference in operational performance, they found that auto-steer outperformed conventional steering by 579 kg ha\(^{-1}\) in 2010 and 451 kg ha\(^{-1}\) in 2011, and stated that in many cases, auto-steering can pay for itself within a year (Vellidis et al., 2014).

5 CONCLUSIONS

A methodology for the implementation of PA in medium and large-scale crops where it is economically viable was established for crops such as rice, maize, fodder, and sugar cane.

PA implementation was promoted in some of the municipalities of Tolima and practices are being carried out in other departments for the same purpose.

In the statistical results carried out for the tests of percentage of time saved and percentage increase in performance with PA, it was observed that, at least in one group, there were no significant differences in these tests, but these groups were a minority in which the results were analysed and justified.

The implementation of PA technology in Colombia is necessary, in search of competitiveness in quantity, quality, and price in international markets. Colombia has extensive areas of agricultural production; therefore, PA will maximise yields and minimise production costs and negative environmental impacts.

Through training, demonstrations and field tests, operators are learning that the technology will not completely replace their work, but they need to know how to operate this equipment, as in the future it will be an extension of tractors and a fundamental tool for their work.

The decrease in fuel consumption when implementing PA compared to conventional agriculture is achieved by considering that the tractor will run for less time, so the operator’s time on the tractor and the wear and tear of the implements will be less, thus being more efficient, in turn minimising costs.

The lack of data acquired in the tests, due to economic, time, and labour availability issues, does not allow generalising conclusions about the benefit of implementing PA, so it is suggested that the study should be carried out in greater depth to collect more data.

Another limitation was that the handling of the equipment was slow in some cases, as the advanced age of some operators was a limiting factor in capturing the information provided. Some of them had never handled a touch-screen device before and it took a while for them to become familiar with some of the equipment. Moreover, there was an attitude from some operators that these devices were going to replace them, so it took time to make them understand that without their participation, these devices would not work and these tasks would not be efficient.

ACKNOWLEDGEMENT

The authors thank CasaToro S.A. for allowing the use of John Deere® AMS technologies and providing the human talent of experts in their implementation. We also thank the farmers of Agrícola Fonseca, Hacienda Pajonales, the independent producer of Espinal, and Hacienda El Escobal for allowing the use of their tractors and tillage of their fields, and to the Surcolombiana University for providing the human talent of its researchers for the realisation of this project.
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