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## 18. Evaluating the benefits of auto-steering on driving conditions in viticulture

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### Abstract

Mechanical weeding of vine rows using inter-vine mechanical weeders demands the tractor driver's attention to ensure that the tool weeds the vines efficiently while avoiding damage. The study aims to investigate the changes that geolocation-based auto-steering introduces to the tractor driver during that highly demanding operation. Two monitoring systems (a camera and a heart rate recording device) were used as proxies to characterize the driver's actions and quantify driver's physical and mental workload, with and without auto-steering. Additionally, the quality of the weeding was evaluated by measuring soil cover rate before and after the work, with and without auto-steering. The results showed a change in the tractor driver's habits and decreased physical and/or mental workload with auto-steering. The quality of weeding remained the same regardless of the driving condition.

**Keywords:** driver habits, mechanical weeding, row crop, workload

### Introduction

In viticulture, tractors are frequently used along vine rows for many operations such as spraying, weeding and harvesting. With the growing demand for sustainable farming practices (Pradel *et al.*, 2022) and reduced chemical weeding, mechanical weeding is becoming an increasingly viable option in viticulture. Mechanical weeding on vine rows is physically and mentally demanding and requires precise and rigorous operation (Jacquet *et al.*, 2021). This operation is usually done by a tool towed by a tractor. To correctly remove weeds without damaging vines, the tool should be correctly centred between two rows of vines, with better than 5 cm accuracy, and set at the most effective depth. Driving a tractor during mechanical weeding implies for the driver to simultaneously monitor the tractor path between the rows, monitor the tool (position, state) and check the weeding quality, while manoeuvring the tractor's movements (turning the steering wheel, accelerating, slowing down, braking) and adjusting the tool settings. Tractor auto-steering systems are expected to reduce the mental workload associated with driving and enhance the performance of the weeding operation, allowing the driver to best focus on tasks related to the quality of the work (i.e. operation settings). Auto-steering systems generally includes, among other components, a terminal device, an electronic controller which controls the tractor's steering in real time, an electric steering system, a rotation wheel angle sensor, an accelerometer, and a positioning system. When equipped with high precision positioning systems technologies such as RTK-GNSS (real time kinematic global navigation satellite system) or LIDAR (laser imaging detection and ranging), it is possible to carry out precise tasks, such as weeding on vine rows. In the specific case of France, the existence of an open RTK network called Centipède (Ancelin *et al.*, 2022; INRAE, 2019), providing RTK corrections in most of the territory, and the growing availability of affordable auto steering-systems (as retrofitted solutions or integrated into new tractors) make it easier for winegrowers to access precise auto-steering system based on RTK-GNSS positioning technologies.

This study aimed to evaluate the potential of auto-steering on a highly demanding operation like mechanical weeding in vine rows. The originality of the approach lies in evaluating the contribution of tractor auto-steering based on two aspects: (i) the quality of the work performed, specifically

verifying whether the quality of mechanical weeding is the same with and without auto-steering, and (ii) the impact on the driver, to verify whether auto-steering reduces the physical strain and the level of attention required for such precise operations and how it may change driver habits. To the authors' knowledge, no such study has ever been conducted on perennial crops. The experiment was inspired by the work of Romano *et al.* (2020), involving the instrumentation of the tractor cabin and the tractor driver to assess the impact of the required work on the driver. Work quality (weeding) was evaluated by measuring soil cover rate before and after the work.

## Materials and methods

The study occurred in a vineyard estate in the south of France, near Montpellier (Villeneuve-lès-Maguelone, WGS84: 43.532300° N, 3.864230° E). Mechanical weeding of vine rows using a mechanical inter-vine weeder was carried out with auto-steering or manual steering with a unique driver (3 years experience, 45 years old). The tractor was the Nexos 240 from Claas (Harsewinkel, Germany). A TopCon (Tokyo, Japan) high-accuracy auto-steering system equipped with an RTK-GNSS receiver was mounted on the tractor. The RTK-GNSS correction comes from a static base installed 2 km from the experimental block, part of the Centipède RTK network.

The tractor towed the Clemens Technologies (Wittlich, Germany) inter-vine mechanical weeder. This tool is made up of lateral blades driven into the ground which should disappear as they approach the vines in order to not damage the plants. The driver can set the width of the tool, the working depth and the angle of the blades manually before the operation. During weeding, if necessary, he can manually press a button to cut the hydraulic pressure that holds the blades in the weeding position, to avoid damaging the vines.

The experiments were spread over two days, on the mornings of 30 May 2024 and 31 May 2024 (Figure 1). Each day, two passes were made, one with auto-steering and one with manual steering.

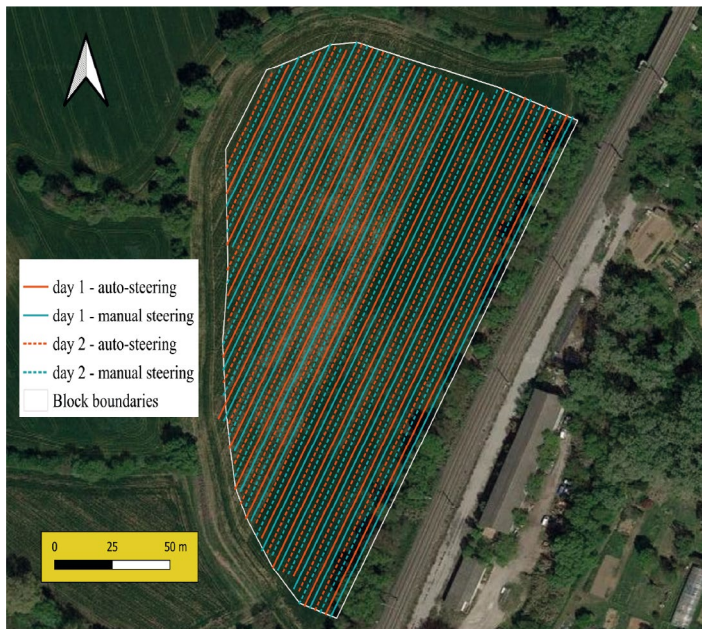


Figure 1. Tractor passes in inter-rows during the mechanical weeding experiment.

Each pass lasted approximately one hour and corresponded to 13 inter-rows. Fig. 1 illustrates the spatial distribution of vine rows over the 4 different passes. The 2.7 ha study block is flat, and the vine rows are planted in a straight line with RTK technology. The driver was instructed to drive at 4 km/h.

#### Quality of the weed control

The efficiency of mechanical weeding was assessed by the soil cover rate one day before weeding and six days after. Soil cover rate was defined as the proportion of ground surface covered by the weeds. Its measurement was performed from images of 50 cm×50 cm (0.25 m<sup>2</sup>) quadrats using the Canopeo application (Patrignani *et al.*, 2015). The quadrats were positioned on the vine row next to the plants (Figure 2). 60 soil cover rate measurements were made on 60 different quadrats, 30 with and 30 without auto-steering.

#### Heart rate measurement of the driver

The driver was equipped with the Kalenji DUAL ANT+ chest strap heart monitor manufactured by Décathlon (Villeneuve-d'Ascq, France) to measure its heart rate (HR). HR and time of acquisition were directly sent and saved to a server via a smartphone in the tractor. Chest strap heart monitors were supposed to have an absolute error equal to 0.7% (Parak *et al.*, 2021) (i.e. 0.4 beats per minute (bpm) of error for a measurement of 60 bpm). Sampling time varies between 5 s and 30 s. In addition, a dual-frequency GNSS receiver embedded in a commercial tracking device manufactured by Samsys (Lille, France) was mounted on the tractor to measure its geolocation. The tracking device had a sampling time between 1 and 3 s and a location accuracy of 1 m. Any HR values were then associated to spatial coordinates using time values of both measurements, HR and positioning. Points associated with turning at the ends of the rows were then removed from the dataset, using the spatial block boundary and points positioning, in order to keep only points associated to weeding inside the block. The data was treated and analysed using Python (Van Rossum and Drake, 2009).

#### Tracking driver movements and gazes

The tractor cab was equipped with a camera mounted in the front of the tractor's windscreen. The entire experiment was recorded.

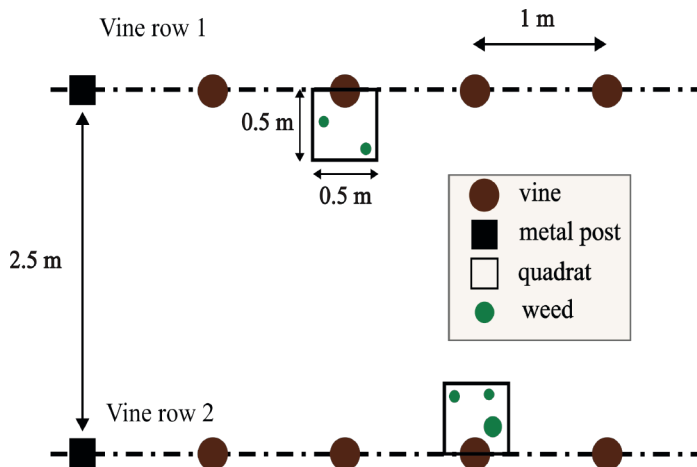


Figure 2. Example of quadrats positioning on vine rows for soil cover rate measurements.



Figure 3. Example of an image grabbed from the camera located inside the tractor cab during the weeding operation. It shows the case of the driver's backward gaze to verify that the rear-mounted tool is correctly aligned between the vine rows, preventing potential damage to the plants, and that the weeding quality is good enough.

Gaze direction analysis was used to accurately allocate the time spent by the driver on each monitoring task (Figure 3). Gaze directions were categorized into three primary tasks: (i) tool monitoring and weeding quality monitoring, which refers to the times when the tractor driver checks that the tool attached to the rear of the tractor is correctly centred between the rows (Figure 3), avoids hitting the vines and performs a proper mechanical weeding operation. For the driver, it corresponds to a backward gaze (when he is turned to check behind the tractor) or gaze towards one of the three rear-view mirrors (two exterior side-view mirrors, one interior rear-view mirror). (ii) Tractor monitoring which refers to the time when the tractor driver is checking the tractor path between the rows. For the driver, it corresponds to forward gaze or gaze towards the terminal device when auto-steering is on, (iii) other tasks, which encompasses all activities performed by the driver that are not directly related to driving, they may indicate how comfortable the driver feels. It corresponds to activities like adjusting in-cab controls, visually inspecting the canopy or the trellising system, checking the smartphone, etc. Manual image analysis was conducted to quantify the time spent on each visual gaze direction (backward, rear-view mirrors, forward, terminal device, and others) during weeding work, either with or without auto-steering. The image analysis also quantifies each steering modality's weeding work duration. The weeding work was associated with the tractor moving between the vine rows within the block boundary, and then does not take into account tractor stops or tasks associated with manoeuvring at the ends of the rows. For each steering modality, the time ratio (TR) associated to a gaze direction was defined by Equation (1):

$$TR (\%) = \frac{dt}{\Delta t} \times 100 \quad (1)$$

Where  $dt$  is the time spent on a gaze direction for a specific steering modality and  $\Delta t$  is the weeding work duration associated to that steering modality. This image analysis was made using the VGG image annotator (Dutta and Zisserman 2019).

## Results

### *Quality of weed control*

The mean speed of the tractor during the experiment, derived from geolocation data, is equal to 3.9 km/h with manual steering and 3.8 km/h with auto-steering. The difference was not significant, and, in both cases, the speed was very close to 4 km/h, which is the optimal working speed for mechanical weeding.

In both cases, auto-steering and manual steering, the use of the inter-vine mechanical weeders enables high-quality weed control and permits a significant decrease in the soil cover rate 6 days after the passes (Figure 4). In the case of auto-steering, the mean soil cover decreases from 8.2% to 1.2%, the median soil cover decreases from 5.0% to 0.0%. In the case of manual steering, the mean soil cover decreases from 7.3% to 1.5% and the median soil cover decreases from 3.2% to 0.7%.

### *Heart rate*

Figure 5 illustrates the effect of steering modality on the driver's heart rate (HR). The HR data consisted of 1276 points, 659 points corresponding to auto-steering and 617 to manual steering. For auto-steering, the range of heart rate data varies from 50.0 to 64.0 bpm, while for manual steering, it varies from 51 to 66.0 bpm. For auto-steering, the mean heart rate ( $\bar{x}$ ) is 56 bpm, and the standard deviation is 2.5 bpm. For manual steering,  $\bar{x}$  is equal to 58.1 bpm, and the standard deviation equals 2.7 bpm. The  $p$ -value ( $=0.2$ ) of the Levene statistic test (Brown and Forsythe, 1974) is superior to the threshold level of 0.05, then indicates that the two samples come from populations with the same variance. The  $p$ -value ( $=2.2 \times 10^{-16}$ ) of the Wilcoxon-Mann-Whitney test (Wilcoxon, 1945) is inferior to the significant threshold of 0.05, then indicates that the difference between the two heart rate data samples (auto-steering and manual steering data) was statistically significant. The magnitude of difference between the two samples is moderate with a size effect equal to 0.4. In conclusion, heart rate was significantly lower with auto-steering ( $\overline{HR} = 56$  bpm) compared with manual driving ( $\overline{HR} = 58.1$  bpm).

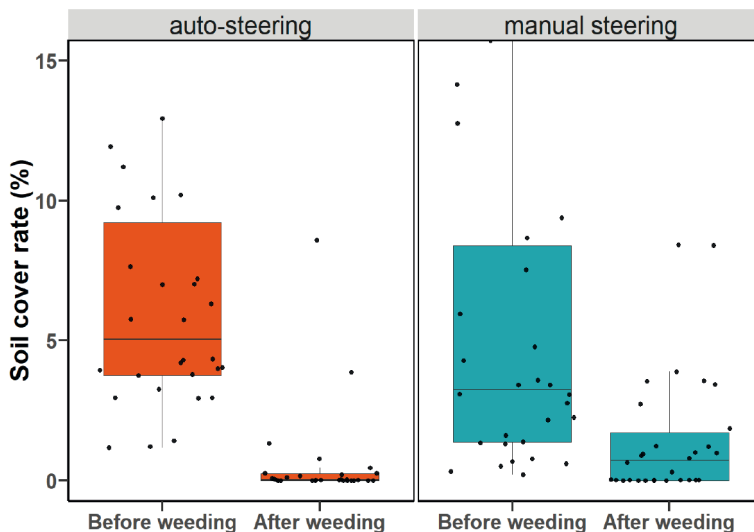


Figure 4. Soil cover rate one day before and six days after mechanical weeding with and without auto-steering.

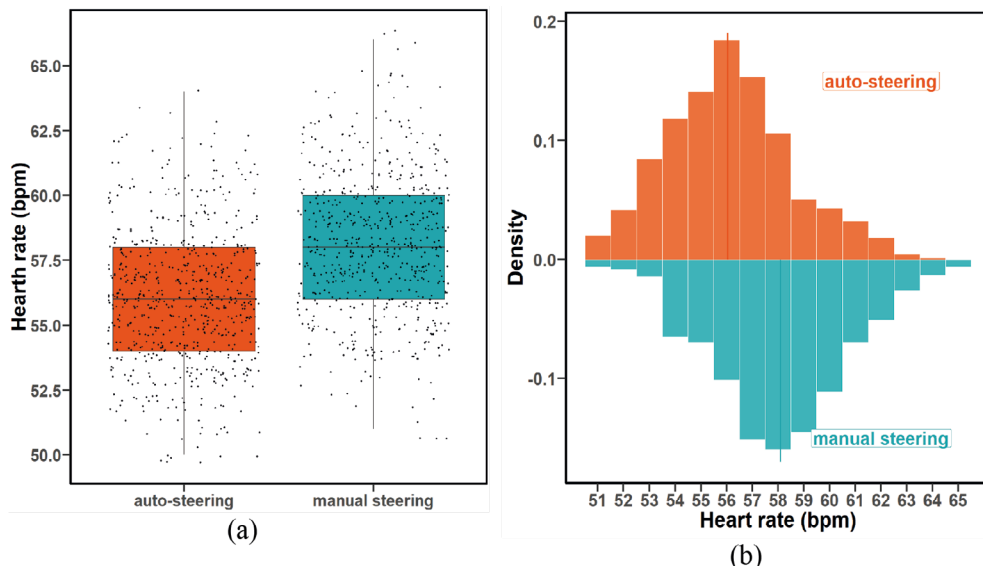


Figure 5. Distribution of heart rate values measured with and without auto-steering system, visualized through (a) boxplots illustrating the median and interquartile range and (b) histograms showing the distribution of measurements for each driving mode.

#### Driver movements and gazes

Table 1 summarises the observations based on video recordings made by the tractor cab on the tractor driver during weeding operations with or without auto-steering. The auto-steering work duration and the manual steering work duration were almost similar.

Tool monitoring and weeding quality monitoring accounts for 73% of the work duration with auto-steering and 54% with manual steering. It is also observed that tractor monitoring represents 25% of the total time with auto-steering and 43% with manual steering. The driver spent more time looking at terminal devices using auto-steering than manual driving. The terminal device is rarely checked (TR=1%) in manual driving since it is only used as a guide bar indicating how centred the tractor is on the reference line. It is observed that other tasks represent 2% of the total time with auto-steering and 3% with manual steering. These values are very small and quite similar for both steering modalities.

Task	Gaze direction	TR (%) auto-steering	TR (%) manual steering
Tool monitoring and weeding quality monitoring	Backward	12	6
	Rear-view mirrors	61	48
Tractor monitoring	Forward	20	42
	Terminal device	5	1
Others	Canopy, smartphone	2	3

Table 1. Distribution of time ratio (TR) associated to each gaze direction (rear-view mirrors, forward, backward, terminal device, others), with and without auto-steering during weeding operation.

## Discussion

Auto-steering significantly decreased the time ratio allocated to tractor monitoring and increased the time ratio associated to tool monitoring and weeding quality monitoring. It is also noted that time ratio associated to other tasks are almost similar with or without auto-steering. These results support our hypothesis that auto-steering can alleviate the mental workload associated with checking the path of the tractor during mechanical weeding. The liberated time is substantively redistributed to focus more effectively on tool monitoring and potentially improving operational performance but isn't employed for other tasks not related to the weeding operation. However, although the driver paid greater attention to the weeding operation, this did not increase weeding efficacy. Indeed, the study demonstrated that weeding effectiveness was the same with and without auto-steering. One potential benefit of increased tool monitoring is a reduction in vine injuries. However, the experimental data is insufficient to confirm this hypothesis.

The lower heart rate (HR) observed with auto-steering indicates that the driver has a lower physical and mental workload when using auto-steering. Indeed, HR positively correlates with physical and/or mental workload (Bashiri and Manh, 2014, Brookhuis and De Waard, 2010; Mulder *et al.*, 2004). A significant difference of 2 bpm over the whole period of the experimentation (approx. 3 h) allows us to conclude that there is a significant difference in working conditions for the driver with or without auto-steering. While this study cannot quantify the specific level of difference due to mental or physical workload, it demonstrates a discernible difference between the two steering methods. The results obtained in this study should be validated in a broader range of situations.

First and foremost, it is important to ensure the reproducibility of the results with more tractor drivers. It is believed that driver age and experience are factors to consider, as auto-steering may be more reassuring for inexperienced drivers. This aspect is crucial in a shortage of experienced labour, particularly tractor drivers. In addition, it should be kept in mind that these results were obtained in flat vineyard blocks with straight vine rows planted with RTK, which represent ideal blocks for auto-steering technologies.

## Conclusion

Precise auto-steering based on RTK-GNSS offers an opportunity to facilitate highly demanding operations such as mechanical weeding on vine rows. In ideal conditions (flat and RTK planted vine rows), the quality of weeding is the same as that of manual steering, but the impact on the driver is significant since auto-steering reduces the physical strain and the level of attention required for such precise operations. This study highlights that auto-steering can alleviate the physical demands of mechanical weeding, providing a potential pathway towards reducing or eliminating the need for chemical herbicides. This study remains the first experiment that needs to be consolidated on a more extensive and heterogeneous sample of conditions and drivers.

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