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Performance evaluation of a non-chemical weed control machine for vineyards and orchards operating with high pressure cold water

M. Varani[1a], G. Molari[1], M. Mattetti[1], A. Ferrari[1]
[1]Department of Agricultural and Food Sciences – Bologna University, viale G. Fanin, 50, 40127, Italy

Abstract

In the last decades, environmental pollution problems due to the extensive use of chemical herbicides caused the introduction of alternative methods to protect the crop. Moreover, a further boost to the introduction of these new methods has been given by the market, where organic products are increasingly requested by the consumers. Regarding vineyards and orchards, one of the most widely used methods of non-chemical weed control is through the mechanical action of appropriate agricultural implements. Commonly these implements are characterized by rotating blades operating inter-row, but this typology of machines could damage plant roots and are subjected to failures in stony soils. To overcome these problems some manufacturers developed flame or steam weeder, but the limited operating speed leads to an increment of management costs. An innovative solution was designed by Caffini S.p.a (Italy) with the implement "Grass Killer" that perform the weed control with high-pressure cold water. The high-pressure water stream (around 1000 bar) is obtained with a piston pump connected to the PTO of the tractor and it is applied on the weed through a rotating inter row disc with nozzles. The objective of this study was to evaluate the performances in terms of weed control efficiency and energy consumption of this implement. Tests have been performed in an orchard connecting the "Grass Killer" to a New Holland T4.110LP equipped with a CAN Logger and a GPS. Moreover, in order to measure the energy required by the piston pump of the implement a torque-meter was installed on the PTO of the tractor. Furthermore, the weed control efficiency was monitored with a flying drone equipped with an NDVI camera. The results show that the implement removes the majority of the weed with only one treatment. In addition, the power required by the piston pump of the implement is about 27 kW, that is roughly the 60% of the total power needed by the tractor to run the operation.

Keywords: mechanical weed control, organic farming, agricultural tractor

INTRODUCTION

Starting from the early days of agriculture weeds has always been a main issue for farmers. The main effect caused by the presence of weeds are yield losses, that could approach 100% (Lacey, 1985). The reason of this losses is due to direct competition with crop for light, water and nutrients. Other important problems caused by weeds are the interference with crop management, the reduction of crop quality and it could be a reservoir for pest and diseases (Naylor and J. Lutman, 2002).

The first studies on chemical herbicides started at the beginning of the 20th century, but they became widely adopted after the second World War because military research boosted their development. In fact dichlorophenoxyacetic acid (2,4-D), considered the first modern herbicide, was synthesized in 1941 by W. G. Templeman and R. Pokorny (Zimdahl, 2010).

[a] E-mail: massimiliano.varani@unibo.it

In the last decades, the extensive use of chemical herbicides showed many disadvantages such as residues in plant materials (Hatzios and Penner, 1982), pollution of ground water (Smith and Stephenson, 1984) and shift in weed population because of continuous use of certain chemicals (Owen, 2008). Moreover, a further boost to a less intensive use of chemicals has been given by the market, where organic products are increasingly requested by the consumers (Qasem, 2011).

Regarding vineyards and orchards, one of the most widely used methods of non-chemical weed control is through the mechanical action of appropriate agricultural implements. A commonly used implements are grass mulchers operating inter row, but this typology of machines could damage plant roots and are subjected to failures in stony soils. Nowadays there are other widespread implements for mechanical weed control such as flame, steam or foam weeders but all these tools have low operating speeds and the initial investments are high (Wei et al., 2010).

An alternative solution is performing the weed control with high-pressure cold water, a principle adopted by the implement "Grass Killer" designed by Caffini S.p.a (Italy). The high-pressure water stream (around 1000 bar) is obtained with a piston pump connected to the Power Take Off (PTO) of the tractor and it is applied on the weeds through a rotating inter row disc with nozzles. The task of the high-pressure water stream is to penetrate the topsoil and cut the weeds roots in order to slow down their regrowth. All the cited implements must have at the same time a good herbicide efficacy and they should be optimized in order to reduce fuel consumption (Mattetti et al., 2017). The objective of this study was to evaluate the efficiency in terms of energy consumption of the Grass KIller measuring important performance parameters such as torque at the PTO and fuel consumption of the tractor. Moreover, the performances in terms of weed control efficiency were evaluated through the usage of a flying drone equipped with an NDVI camera.

MATERIALS AND METHODS

Materials used for the test

Test were carried out in an apricot orchard owned by Martorano 5 farm located in Martorano di Cesena (Cesena, Italy). The tested Grass Killer (Caffini S.p.a, Italy) was the 1000 l water tank version with only one rotating inter row disc with nozzles. The implement was mounted on a New Holland T4.110LP tractor with a maximum engine power of 79 kW and a weight of 2900 kg (Figure 1).

Figure 1. New Holland T4.110LP and Caffini Grass Killer

In order to measure the PTO torque, a NCTE 7000 torquemeter (NCTE AG, Germany) with a full scale of 3000 Nm was installed between the tractor PTO and the implement. Moreover, the tractor was equipped with a CANcaseXL CAN logger (Vector Informatik GmbH, Germany) in order to acquire actual engine power and fuel consumption. The speed of the tractor was measured with an IPESpeed GPS receiver (IPETronik GmbH, Germany) connected to the previously presented CAN logger. A Landini Trekker 55F (Argo tractor S.p.A., Italy) with a maximum power of 39 kW and a weight of 2830 kg equipped with a grass mulcher operating inter-row were used to compare the weed control efficiency. A custom built flying drone equipped with a Mapir Survey 3N NDVI camera (Mapir Camera,USA) was used to capture aerial images of the orchard before and after the treatments (Figure 2).

Figure 2. a) Grass mulcher that operates inter row; b) Custom built drone equipped with MApir Survey 3N NDVI camera

All the obtained data were elaborated and analysed with the software MATLAB (Mathworks, USA).

Energy consumption evaluation method

First of all, the Field Capacity (FC) of the implement was calculated by dividing the total amount of tilled hectares with the time required for the operation. The implement water consumption was evaluated observing the tank water level before and after the treatment.

The parameters considered for the test were the tractor speed (S_t), the engine power (P_t) and speed (S_e), fuel consumption (F_{Con}) and the torque at the PTO (T_{pto}). Other important parameters such as PTO Speed (S_{pto}) and power absorption (P_{pto}) were calculated by the following equations:

$$S_{pto} = \frac{S_e}{\tau} \qquad \tau\text{: transmission ratio between the engine and PTO shaft} \qquad (1)$$

$$P_{pto} = S_{pto} * T_{pto} \qquad (2)$$

The performances of the tractor in terms of energy consumption were evaluated only during the actual operation without considering turning manoeuvres. For this purpose, data were selected during data analysis process excluding all the conditions were the implement was not working or it was operating outside of the designed conditions (Figure 3).

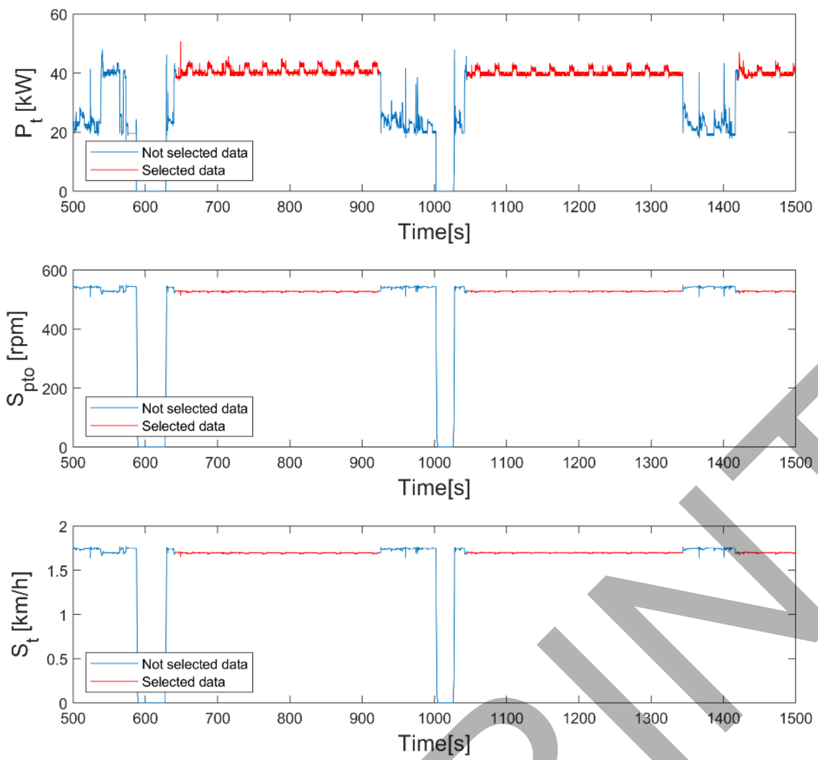

Figure 3. Example of the data selection process for the energy consumption analysis.

After this selection process, the mean values of the considered performance parameters were calculated.

Weed control evaluation method

In order to compare the weed control efficiency of the Grass Killer, one side of the apricot orchard rows was treated with a traditional grass mulcher operating inter row. Then NDVI images were taken with the flying drone the day of the test (27th September 2018) before the two implements performed the weed control operation. Afterwards, the 10th October 2018 other images were taken to observe the weeds growth.

The obtained images were processed with an NDVI analysis and the selected image portion of every inter row was calculated considering the distance between two trees and the diameters of the two implements discs. NDVI indices were assigned to every pixel inside the inter rows, these indices could have a minimum value of -1 (total absence of infra-red radiation, thus no vegetation) and a maximum of +1 (total absence of red radiation).

The mean values of the inter rows NDVI indices were calculated, then a One-Way Anova test between the two sides of the orchard inter rows was performed for both 27th September 2018 and 10th October 2018 NDVI mean values.

RESULTS

Energy consumption

The measured FC of the Grass Killer was 0.3 ha/h and the water consumption was around 914 l/ha. In Table 1 are reported the mean values of the measured parameters.

Table 1. Mean values of the measured parameters during actual operation

	Mean Value
S_t	1.72 km/h
F_{Con}	9.12 l/h
P_t	41.42 kW
P_{pto}	27.17 kW

One can note that the operating speed was quite low, this was due to the fact that the weeds in the orchard were very high, so the implements needed to remain more time in the same spot. The percentage of power absorbed by the PTO compared with the actual engine power is 65.63%.

Weed control

In Figure 4, the aerial images taken with the NDVI camera are reported, while in Tables 2 and Table 3, the measured NDVI values are reported.

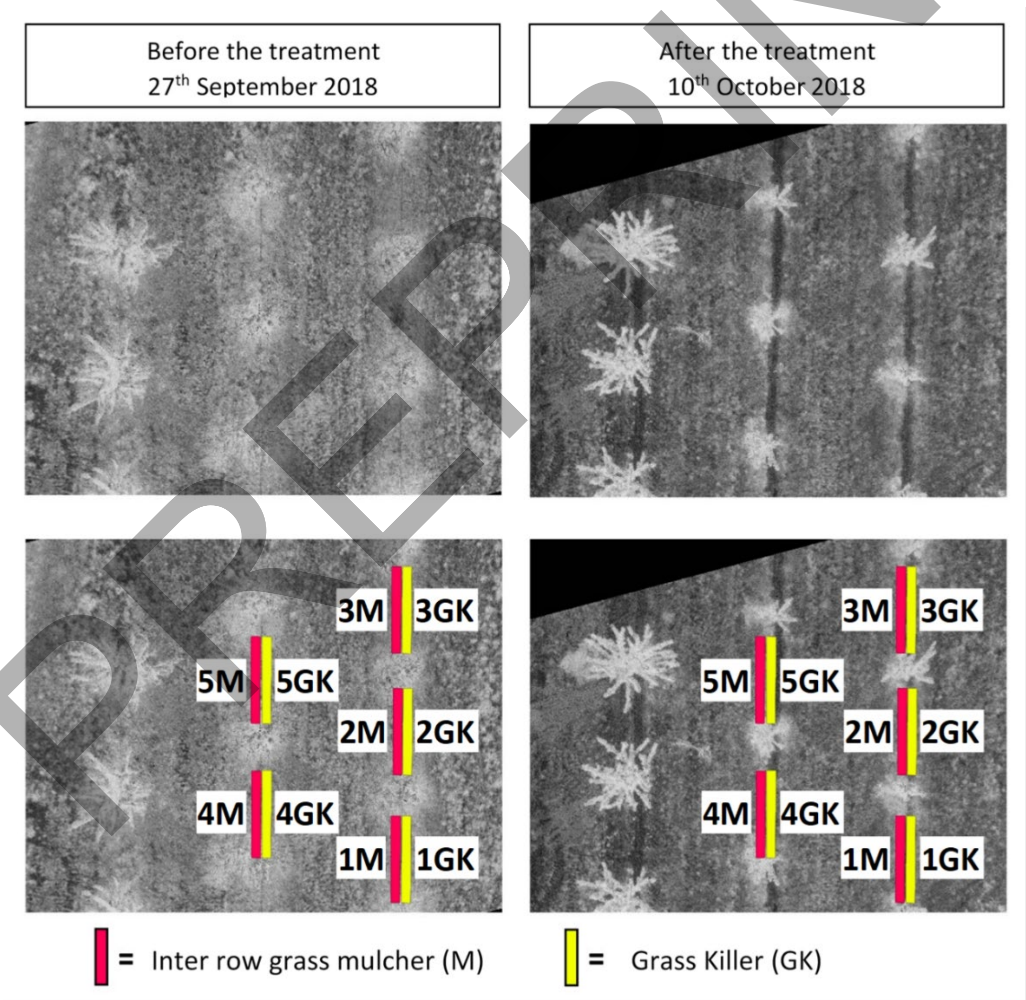

Figure 4. NDVI camera aerial images before and after the treatment with Grass Killer (GK) and an inter row grass mulcher (M). The alphanumeric characters showed in the picture are the inter row Identification Numbers (ID)

Table 2. NDVI values before the treatments (27th September 2018).

Inter row ID	NDVI maximum value	NDVI mean value
1GK	0.586	0.375
1M	0.630	0.349
2GK	0.583	0.395
2M	0.607	0.387
3GK	0.589	0.340
3M	0.612	0.346
4GK	0.633	0.388
4M	0.733	0.415
5GK	0.656	0.373
5M	0.626	0.384

Table 3. NDVI values after the treatments (10th October 2018).

Inter row ID	NDVI maximum value	NDVI mean value
1GK	0.532	0.239
1M	0.521	0.305
2GK	0.576	0.248
2M	0.586	0.307
3GK	0.521	0.221
3M	0.533	0.292
4GK	0.568	0.285
4M	0.600	0.321
5GK	0.672	0.228
5M	0.639	0.341

Table 4. One-Way Anova test of the NDVI values between the two sides of the orchard inter rows

Test Condition	F Value	p value
Before the treatment (27th September 2018)	0.02	0.9037
After the treatment (10th October 2018)	24.44	0.0011

One can note that that the Grass Killer side of the orchard appear significantly darker in the 10th October 2018 image. This is due to the fact that the implement removed the majority of the weeds roots, so the regrowth is slower (Figure 5).

Figure 5. Picture of an inter row after the treatment performed with the Grass Killer taken the 27th September 2018.

The results of the One-Way Anova test reported in Table 4 show that there were not significant differences between the two side of the inter rows before the treatments. The mean value of the inter row NDVI indices mean values were 0.347 and 0.376 for the grass mulcher and for the Grass Killer respectively.
On the other hand, after the two treatments the One-Way Anova test show that there are significant differences between the two side of the inter rows. The NDVI values obtained after the treatment shows that the Grass Killer performed better than the grass mulcher since the mean value of the inter row NDVI indices mean values were 0.244 and 0.313 for the two implements respectively.
Regarding the maximum NDVI indices measured after the treatment there aren't meaningful differences, in fact the difference of the values between the two side of the inter rows is always less then 5.5 %. This is due to the fact that both implements could not eliminate completely the weeds, so the peaks of the NDVI indices are almost the same.

CONCLUSIONS

The following conclusions can be drawn from the study:

- The Grass Killer is perfectly suited for organic farming since it works without chemical herbicides;
- The average operation speed is around 1.72 km/h with a mean fuel consumption of 9.16 l/h. The average speed of other mechanical implement for weed control is higher since is around 3 km/h (Merfield et al., 2017), but the speed of the Grass Killer could increase in case of a lower density of weeds;
- The Grass Killer absorbs the 65.63% of the total power used for the operation;
- The NDVI values shows that the Grass Killer performed better than the grass mulcher in terms of weed control efficiency. Consequently, this permits to reduce the number of treatments per year.
- A future development of this study could be the adoption of this test methodology to compare the Grass Killer to other mechanical weed control implements such as flame, steam or foam weeders.

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