agronomy

Communication

Continuous Mowing for *Erigeron canadensis* L. Control in Vineyards

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Abstract: *Erigeron canadensis* L. directly competes with vines for nutrients, light, and water, and its management represents a challenge, especially under a vineyard trellis. Conventional weed control in the under-trellis area is achieved by cultivation or multiple herbicides applications, thus leading to relevant environmental issues. For this reason, several eco-friendly or nature-based weed control strategies such as the use of cover crops (CC) that become more relevant in last years. A two-year trial was conducted on a vineyard aimed at evaluating the effect of CC (sown both inter-rows and under-trellis) managed with an autonomous mower (AM) on *E. canadensis* under trellis control. The combination of CC and AM provided an *E. canadensis* reduction between 61 and 84% compared to conventional management. The AM work when managing a spontaneous cover provided a density reduction of 26%. Moreover, an analysis of the trampling effect of the AM on the vineyard floor and *E. canadensis* density was conducted.

Keywords: living mulch; mechanical weed control; autonomous machines; trampling analysis

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Citation: Peruzzi, A.; Gagliardi, L.; Fontanelli, M.; Frasconi, C.; Raffaelli, M.; Sportelli, M. Continuous Mowing for *Erigeron canadensis* L. Control in Vineyards. *Agronomy* **2023**, *13*, 409. https://doi.org/10.3390/agronomy13020409

Academic Editor: Anestis Karkanis

Received: 12 December 2022
Revised: 23 January 2023
Accepted: 29 January 2023
Published: 30 January 2023

1. Introduction

Erigeron canadensis L. is a winter or summer annual weed belonging to the Asteraceae family [1]. It is native to North America and is widespread in several countries in Africa, Asia-Pacific, and Europe [2]. In some cases, *E. canadensis* may develop resistance to herbicides such as glyphosate [3], paraquat [4], and triazines [5]; however, it does not represent a troublesome weed in agricultural systems where tillage is provided [6]. *E. canadensis* seeds germinability significantly decreases as burial depth increases [7], thus is considered a major weed in contexts such as roadsides, berms, fallow fields, no-till and perennial cropping systems (i.e., vineyards) [8,9]. In vineyards *E. canadensis* directly compete with vines for nutrients, light, and water, causing a reduction in vines' vigor [10]. Holm et al. [11] reported a yield reduction of 28% due to *E. canadensis* infestation. In the Mediterranean basin, vineyard weed control is conventionally fulfilled by soil tillage in the inter-rows and under vines trellis [12], while herbicides applications are usually provided under vines-trellis [13]. However, environmental issues derived from soil tillage and herbicide application serve as a driving force to find more sustainable practices. A permanent soil cover by means of cover crops (CC) has shown potential as a sustainable weed control strategy that also brings a series of ecosystem services (i.e., soil and water quality improvement and biodiversity enhancement) [14]. Usually, permanent CCs are sown in vineyards inter-rows while no vegetal cover under vines-trellis is preferred to avoid competition When selecting CC species for a complete floor cover competition level, height and their management should be considered [15]. A planned under-trellis CC management has been shown to significantly improve weed control efficacy [16]. In addition, operations efficiency can be improved if small autonomous machines are employed [17]. Magni et al. [18] tested an autonomous mower (AM) for grass CC complete cover in a vineyard funding this solution advantageous in terms of power consumption and CO_2 emissions. AM's small size and intense mowing perfectly match weeds and CC management in vineyards. The aim of this trial was to evaluate how the combination between CC species and continuous mowing management could improve vineyard sustainability in terms of noxious weed control. The present study provides additional evidence to that presented by Sportelli et al. [19]. This study was based on preliminary observations of intensive mowing effects on *E. canadensis* in vineyards inter-rows and under-trellis.

2. Materials and Methods

2.1. Experimental Design

A two years trial was conducted at the Tuscany Association of Viticulture Producers (Tos.Sco.Vit) in S. Piero a Grado, Pisa, Italy (43°39′ N, 10°20′ E). The investigation was carried out on a *Vitis vinifera* L. cv. Sangiovese N. vineyard, was established in 2004 and arranged in a 0.9 × 2.5 m planting layout with rows of 40 vine plants. Vineyard floor conventional management provided multiple inter-row flail mowing of spontaneous species and post-emergence non-selective herbicide under-trellis applications. In this study, four vineyard floor management systems were compared for their capacity of *E. canadensis* control. All the management systems provided CC or resident species managed with repeated mowing treatments so as to obtain a living mulch (LM). Thus, the four-floor management systems were: living mulch 1 managed with an AM (LM1-AM), living mulch 2 managed with an AM (LM2-AM), living mulch 3 managed with an AM (LM3-AM), and living mulch 3 conventionally managed (LM3-CM). Each management system was replicated four times (16 plots in total) and each plot measured 30 m^2 (12 × 2.5 m). Experimental plots managed by AM have been settled in a 740 m^2 area of the vineyard, including the AM plots and a cushion area, to ease AM base station and boundary wire installation. The cushion area consisted of a buffer area covered by resident species and the first vines row. In the next four rows, three plots per row were defined by maintaining the vine row in the middle and measuring 1.25 m on both sides. Neighboring plots shared their edges between treatments and the three AM different treatments were randomly placed within the row. A Husqvarna AM 535 AWD (Husqvarna, Stockholm, Sweden) was used to fulfill autonomous mowing in AM plots. AM was set to work at a mowing height of 5 cm, 5 days per week and 5 h per day (charging time included). For both years AM was employed as a management strategy form May to November. The four replicates of CM experimental plots were defined in four different rows of the vineyard, one per each row (so as to obtain the four replication). Additional details on CM and AM plots operations are reported in Table 1, figures of the experimental design can be found in Sportelli et al. [19]. LM1 and LM2 sowing was carried out in November 2018 and November 2019 (Table 1). In LM3 plots, floor cover consisted of growing resident species. A total of 35 different resident species were found and major species were *Erodium cicutarium* (L.) L'Hér., *Malva sylvestris* L., *Matricaria chamomilla* L., *Schedonorus arundinaceus* (Schreb.) Dumort, *Veronica persica* Poir, *Bellis perennis* L., *Capsella bursa-pastoris* (L.) Medik., *Poa annua* L., *Stellaria media* (L.) Vill., *Geranium molle* L., *Erigeron canadensis* L., *Symphyotrichum squamatum* (Spreng.) G.L. Nesom, *Taraxacum officinale* Weber, *Euphorbia prostrata* Aiton, *Digitaria sanguinalis* (L.) Scop., *Cynodon dactylon* (L.) Pers, *Portulaca oleracea* L. and *Paspalum dilatatum* Poir. According to [20,21], only *V. persica*, *E. canadensis*, *S. squamatum* and *P. dilatatum* were considered invasive and aggressive species. However, this study focuses only on *E. canadensis* since it was considered the major threat from vineyard managers and it showed promising results from preliminary tests.

Table 1. Trial operations program for 2019 and 2020.

Operation	Number of Operations	Product/Equipment	Rate	Plots			
				LM1–AM	LM2–AM	LM3–AM	LM3–CM
			2019				
Herbicide application	2	Glyphos Dakar	1.8 kg ha^{-1}	-	-	-	✓
Conventional mowing	3	Celli TCB/S Mulcher	n.a.	-	-	-	✓
Autonomous mowing	132	Husqvarna automower 535 AWD	5 h d^{-1}	✓	✓	✓	-
Living mulch hand sowing *	1	-Living mulch 1 (LM1) blend: *Lolium perenne* L. cv Tetragreen (50%) *L. perenne* L. cv Dasher 3 (50%). -Living mulch 2 (LM2) blend: *Trifolium repens* L. cv Huia (95%) *T. repens* L. cv Pertina (5%).	LM1: 50·g·m^{-2} LM2: 20 g m^{-2}	✓	✓	-	-
			2020				
Herbicide application	2	Glyphos Ultra	7 kg ha^{-1}	-	-	-	✓
Conventional mowing	4	Celli TCB/S Mulcher	n.a.	-	-	-	✓
Autonomous mowing	131	Husqvarna automower 535 AWD	5 h d^{-1}	✓	✓	✓	-

* Living mulch hand sowing operations were analogus for year 2018.

2.2. Assessments

During both 2019 and 2020, from May to October, *E. canadensis* plant density was established in the inter-row (IR) and under-trellis (UT). Plants were manually counted from the four fixed quadrats of 0.25 m^2 (50 × 50 cm) positioned in the IR and four UT. Plant numbers from the four quadrants in the same position were summed to obtain the plant density values in one m^2. Two Emlid Reach RTK (Emlid Ltd., Hong Kong) devices [22] were used to record AM operative performances. Subsequently, recorded data were processed with a custom-built software "Robot mower tracking data calculator" (Qprel srl, Pistoia, Italy) version 1.8.0.0 [23] to compute the number of times the AM passed on the same position. This last parameter was used to assess the AM trampling effect on the inter-rows and under the vineyard trellis. A total of 50 measurements for each position were carried out in every repetition. At the end of the trial, 400 measurements for each position were used to estimate the autonomous mower trampling action in the studied vineyard.

2.3. Statistical Analysis

Data were analyzed using the statistical software SPSS (IBM Corp, Armonk, NY, USA). Repeated-measures analysis was performed to evaluate how treatments and positions affected *E. canadensis* plant density. Data were fitted into a generalized linear mixed model (GENLINMIXED) with a Poisson distribution and a log link function. Months and years were considered as repeated factors. Treatments, position, and the interaction between treatments and positions were considered fixed effects, while the experimental plot repetition was included as a random effect. The comparisons between pairs of estimated values were computed by estimating the 95% confidence interval of the difference between the values based on Bonferroni's test (Equation (1)):

$$CI\ (difference) = (x_1 - x_2) \pm 1.96\sqrt{(SE_{x1})^2 + (SE_{x2})^2} \quad (1)$$

where (x_1) is the mean of the first value, (x_2) is the mean of the second value, (SEx_1) is the standard error of (x_1), and (SEx_2) is the standard error of (x_2). If the resulting 95% confidence interval (*CI*) of the difference between values did not cross the value 0, the null hypothesis that the compared values were not different was rejected.

3. Results

Repeated-measures analysis revealed treatment ($p < 0.001$), position ($p < 0.001$), and their interaction ($p < 0.01$) significantly affected *E. canadensis* plant density. Pairwise comparisons and mean separation results have been reported in Table 2.

Over the two years, the highest *E. canadensis* plant density was recorded under a vineyard trellis of the LM3-CM plots with an average of 7.14 (±0.37) plants m^{-2}. The lowest plant density, instead, was obtained on the inter-row of the LM2-AM plots with an average of 0.1 (±0.04) plants m^{-2} (Figure 1). In general, *E. canadensis* plant density was higher under a vineyard trellis with 4.2 (±0.15) plants m^{-2} compared to the inter-rows 0.5 (±0.07) plants m^{-2}.

Within inter-rows areas, no differences emerged between conventional management and AM areas provided with a spontaneous cover. In contrast, the presence of LM significantly reduced *E. canadensis* plant density in the inter-rows. Among the two LM adopted in this trial, *T. repens* resulted in a lower plant density compared to *L. perenne* ($p < 0.001$). Indeed, *E. canadensis* density reduction resulted in approximately 61% for *L. perenne* LM and 84% for *T. repens*. LM significantly boosted the weed control effect also under vineyard trellis compared to spontaneous cover plots ($p < 0.001$), while no differences were detected between the two LM typologies.

The trampling effect in terms of the number of times the AM passed in the same position was analyzed both in the inter-rows and under the vineyard trellis (Figure 2).

Table 2. Results of pairwise comparisons for *Erigeron canadensis* plant density in function of treatments (LM1–AM, LM2–AM, LM3–AM, LM3–CM) and positions (IR and UT). LM1–AM: living mulch 1 autonomously mowed; LM2–AM: living mulch 2 autonomously mowed; LM3–AM: living mulch 3 autonomously mowed; LM3–CM: living mulch 3 conventionally managed. IR: inter-rows, UT: Under vineyards trellis. Mean separations have been carried out separately for positions.

Position	Treatment	Plant Density Mean Values (Plant m^{-2})	Standard Error	95% CI	
				Lower Bond	Upper Bond
IR	LM1–AM	0.48 b [1]	0.09	0.32	0.70
	LM2–AM	0.09 c	0.04	0.03	0.22
	LM3–AM	1.02 a	0.14	0.78	1.33
	LM3–CM	1.38 a	0.16	1.09	1.74
UT	LM1–AM	3.07 c	0.24	2.63	3.58
	LM2–AM	2.70 c	0.23	2.29	3.18
	LM3–AM	5.29 b	0.32	4.70	5.95
	LM3–CM	7.14 a	0.37	6.45	7.90

[1] Different letters within the same position group (IR or UT) represent mean values significantly different based con 95% Confidence Interval (CI).

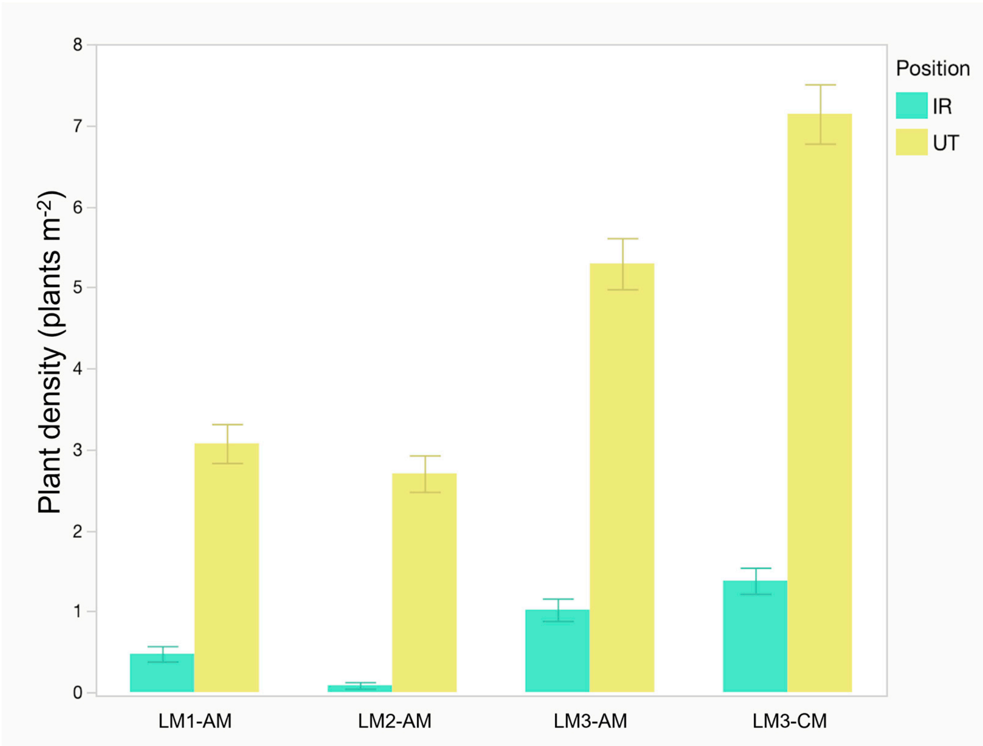

Figure 1. *Erigeron canadensis* plant density mean values during the two years trial in function of treatments (LM1–AM, LM2–AM, LM3–AM, LM3–CM) and positions (IR and UT). LM1–AM: living mulch 1 autonomously mowed; LM2–AM: living mulch 2 autonomously mowed; LM3–AM: living mulch 3 autonomously mowed; LM3–CM: living mulch 3 conventionally managed. IR: inter-rows, UT: Under vineyards trellis. Error bar represents the upper and lower limits of the Standard error.

Trampling effect of the AM managed plot resulted higher under vineyards trellis with an average of 24 passages (ranging from 7 to 53) compared to the inter-row area with an average of 4 passages (ranging from 0 to 14). The number of passages were counted after 5 h of work.

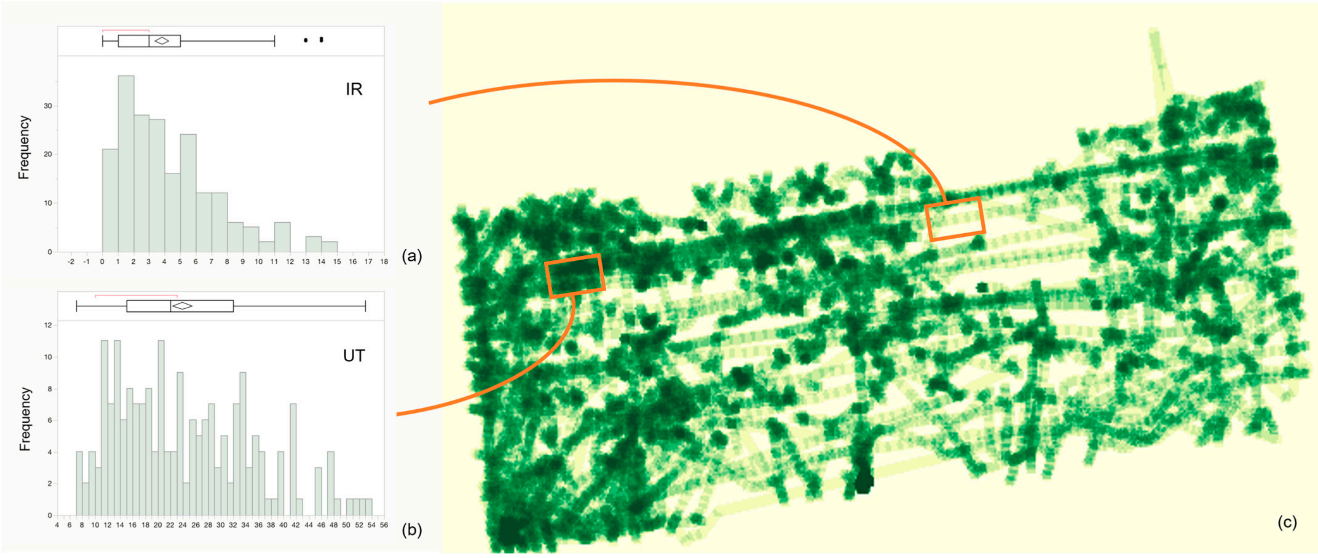

Figure 2. Number of passages distributions on vineyards positions. (**a**) Number of passages distribution on the inter-rows area. (**b**) Number of passages distribution under vineyard trellis. (**c**) An example of trampling distribution on the whole experimental area managed by autonomous mowers.

4. Discussion

The aim of this trial was to evaluate the effect of different LM managed by an autonomous mower on *E. canadensis*. Plant density was recorded over the 2 years trial and in general, a higher *E. canadensis* plant density was detected in plots conventionally managed compared to the AM-managed plots and under vineyards trellis (4.2 plants m^{-2}) compared to the inter-rows (0.5 plants m^{-2}). Moreover, *E. canadensis* can grow inside the vine canopy and up to two meters high [17], thus causing operations and product quality issues. According to these findings, the presence of an LM showed to be particularly effective for *E. canadensis* suppression. Sanguankeo et al. [24] found that CC can suppress several major weeds in vineyards, including *E. canadensis*, by up to 48% compared with herbicides application and cultivation weed control methods. Wallace et al. [25] also studied the effect of different CC on *E. canadensis* density and obtained a reduction due to CC ranging from 52% to 86%. A reduction of 26% was obtained in plots with spontaneous cover and managed with AM, thus resulting in a significantly lower number of plants growing in LM3-CM plots ($p < 0.001$). When compared to LM3-CM plots, AM-managed plots maintained a 5 cm high floor canopy and a lower plant dry biomass (results from Sportelli et al. [19]). Providing this CC or LM management may be beneficial in maintaining an optimal balance between vines, weeds, and CC [26] with low energy requirements [27,28]. AM management was characterized by a high overlapping; however, differences were detected between positions (Figure 2). Indeed, the AM achieved an average of 24 passages under a vineyard trellis and compared to the inter-row area with an average of 4 passages. The higher trampling under the vineyard trellis occurred because the AM became stuck in this area and because of its random working pattern, multiple maneuvers were required to reach inter-rows. Despite AM trampling resulting in up to six times higher under vineyards trellis compared to inter-rows, this did not affect *E. canadensis* plant density. However, a few things need to be considered: (i) AM moved following random trajectories, thus reducing its working efficiency when employed in contexts with a large number of obstacles [29]. (ii) Due to safety regulations, AM working width (24 cm) is significantly smaller than its cowling width (55 cm) and weeds can develop close to the trunks of the vines because of the blades and cowling distance gap. (iii) AM hit the vines' trunks several times before exiting the under-trellis area. Whenever the AM hit an obstacle, it stops moving, and it stops the cutting disk as well; thus, the majority of weed control under the trellis was exploited by AM trampling. (iv) In general, plants that can stand trampling cope with this stress with radial growth. Dumitraşcu et al. [30] studied the effect of different levels of trampling in various herbaceous species and found an increase in the number of lateral branches and the number of shoots that reached fruition in *E. canadensis.* The combination of continuous mowing and intense trampling obtained in AM plots together with the effect of LM provided a satisfactory *E. canadensis* control. These findings confirm that small and light autonomous machines have the potential to enhance weed control and overall sustainability [31]. Eventually, a good balance between tractor-implements combination [32] together with small and light autonomous machines will improve the top-soil compaction distribution and the overall vineyard sustainability.

Author Contributions: Conceptualization, M.S. and A.P.; methodology, M.S.; software, M.S.; validation, C.F., M.R. and L.G.; formal analysis, M.S.; investigation, M.S.; resources, M.F.; data curation, M.S.; writing—original draft preparation, L.G.; writing—review and editing, M.S.; visualization, M.S.; supervision, M.R.; project administration, M.F.; funding acquisition, A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the Husqvarna group for providing the autonomous mower and technical support; the Tuscany Association of Viticulture Producers (Tos.Sco.Vit) for their technical support.

Conflicts of Interest: The authors declare no conflict of interest.

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