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Article

Assessment of the Effects of Autonomous Mowers on Plant Biodiversity in Urban Lawns

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Abstract: Gaining information on the impact of lawn management with autonomous mowers on the floristic composition is crucial to improve their plant biodiversity. In this study, an autonomous mower with a reduced mowing frequency and a more sporadic mowing management system with a ride-on rotary mower were compared in terms of the effect on three dicotyledonous species (*Phyla nodiflora*, *Lotus corniculatus* and *Sulla coronaria*) transplanted onto stands of Bermuda and Manila grass. Regardless of the management system, *P. nodiflora* achieved the best results in terms of survival for both lawns (74.92 and 58.57% in Manila and Bermuda grass, respectively). In Bermuda grass, a higher percentage of surviving individuals was observed for the ordinary mower management system (42.59%), rather than with the autonomous mower (9.10%), while no differences emerged on Manila grass. On both Manila and Bermuda grass, a higher average percentage of coverage for single individual was observed for the ordinary mower management system (1.60 and 0.37%, respectively) compared to the autonomous mower system (0.55 and 0.08%, respectively). *P. nodiflora* had a higher percentage of individuals with flowers with the ordinary management system rather than with autonomous mower system both on Manila (60.73% and 33.90%, respectively) and Bermuda grass (48.66 and 3.32%, respectively). Despite a lower impact on the planted species being observed for the ordinary mower management system, encouraging results were obtained with the autonomous mower, for instance regarding the percentage of surviving individuals for *P. nodiflora* (33.95%) and *L. corniculatus* (22.08%) on Bermuda grass and the percentage of individuals with flowers for the same two species (33.90 and 13.59%, respectively) on Manila grass. Furthermore, the autonomous mower management system's primary energy consumption over the year was lower compared to that of the ordinary system both on Manila (200.4 and 614.97 kWh ha^{-1} year^{-1}, respectively) and Bermuda grass (177.82 and 510.99 kWh ha^{-1} year^{-1}, respectively).

Keywords: mowing frequency; robotics; residential gardens; turf management

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1. Introduction

The importance of residential yards is increasing in terms of their potential impact on ecosystem services and overall well-being. The extent of these benefits primarily relies on the diversity and composition of plant species [1]. In this context, residential gardens and parks are essential for bees and other pollinator populations which play a fundamental role in agriculture but face difficulties surviving in the conditions of modern intensive farming [2]. Pollinators in cities facilitate plant reproduction, boosting overall biodiversity. They also promote gardening and urban agriculture, aiding in local temperature regulation, water and carbon storage, human health, social benefits, and food sustainability [3,4]. Lawns are a common element in urban spaces, constituting approximately 70–75% of urban green spaces globally [5]. The 'ideal' lawn is a flat, uniformly mowed area covered exclusively in grass, mandated to showcase an even green color without any patches or imperfections, and it should possess a dense, soft texture [6,7]. Meeting these criteria is possible only for a select few grass species, resulting in the perfect lawn being inherently a monoculture with limited plant diversity [8,9]. As a result, these habitats serve as inadequate refuges for plant and animal communities because of the intensive management they undergo [10]. In the changing perspective of urban environments, there is a trend towards prioritizing eco-friendly characteristics, native flora and fauna, and sustainability in the decisions made by landscapers and gardeners. [11,12]. Enhancing biodiversity within turfgrass systems is pivotal for amplifying ecosystem services in urban landscapes and should be viewed as an essential component of sustainable management practices [13].

Among the lawn management practices that exert an environmental impact, in addition to irrigation and the application of harmful fertilizers and pesticides, mowing stands out as a notable contributor. Chollet et al. [10] found that the frequency of mowing plays a crucial role in determining plant species. Authors observed that a low mowing frequency favors greater plant diversity. Smith et al. [14] found that both the timing of mowing and the time interval between cuts can impact flower number. Mowing just before a species enters its flowering stage can have an adverse impact on the resulting floral outcomes. In contrast, providing extended periods of plant growth between mowing interventions has the potential to enhance floral development. Mowing lawns every three weeks resulted in up to 2.5 times more lawn flowers compared to the frequency of mowing every week or every two weeks [15]. Along with mowing frequency, height can also affect diversity. Regularly mowing at a low height diminishes the structure and composition of vegetation, promoting the dominance of low-growing annual or biennial plants species. This practice also diminishes floral resources available to pollinators by eliminating taller flowering structures [16]. Furthermore, this engenders a cascading impact within the ecological community, resulting in decreased ecosystem resilience and creating favorable conditions for the colonization of deleterious pest species [17].

Among the disadvantages related to frequent mowing, there is also noise pollution [18]. This form of pollution not only substantially impacts human health by causing diseases and other issues, but also affects biodiversity [19]. Furthermore, mowing also create growing environmental concerns for greenhouse gas emissions [18]. The level of carbon emissions resulting from mowing is contingent upon the size and type of mower utilized, as well as the frequency of mowing. The range for these emissions spans from 1.4 to 6.7 t C ha^{-1} over a period of two decades [20]. Integrating advanced mower technology to enhance fuel efficiency or employ alternative power sources, like electric or hybrid engines, offers an additional viable solution for reducing emissions from mowers [21].

Autonomous mowers are growingly ubiquitous in public and private green areas. These battery-powered machines that carry out lawn mowing without requiring an operator offer numerous benefits by saving time and energy. Pirchio et al. [22] observed a lower primary energy consumption for an autonomous mower (2.98 kWh per week) compared to a walk-behind gasoline rotary mower (4.64 kWh per week). Grossi et al. [23] also observed a markedly lower primary energy consumption for an autonomous mower (4.80 kWh per week) relative to a traditional gasoline rotary mower (12.60 kWh per week). Additionally, these machines eliminate the risk for operators encountering allergens, potential injuries, and noise emissions. Furthermore, autonomous mowers do not emit polluting gases in the areas where they operate, offering a more environmentally sustainable management [24–26]. The prevailing navigation system for these mowers still involves random trajectories in a working area delimited by a buried electric boundary wire. Regarding the effect of these machines commonly employed to work every day on plant biodiversity, Pirchio et al. [22] observed a greater development in the width of creeping species transplanted onto turf (*Trifolium repens* L., *Trifolium. subterraneum* L., *Lotus. corniculatus* L.) when managed with an autonomous mower rather than with a rotary mower. In agreement with the authors of [27,28], this might be attributed to the lower average height of the turf in comparison to the turf mown with the rotary mower. These creeping species succeeded by spreading horizontally beneath mowing height without competing for light with tall fescue turf as the autonomous mower maintained a constant turf height. Pirchio et al. [22] observed an adaptation of the growth of these transplanted plants at a low height, thereby avoiding being cut by the autonomous mower. Instead, when the turf was mowed by the rotary mower once a week, the transplanted species needed to grow taller to compete for light with the tall fescue turf. Hence, those species that exceeded the mowing height were susceptible to being cut by the rotary mower. Gaining information on the impact of lawn management with autonomous mowers in terms of cutting frequency and height on the floristic composition of lawns, has the potential to substantially improve the biodiversity of this common type of green space. In this study, in a context of residential gardens, the use of an autonomous mower with reduced mowing frequency and a more sporadic management system with a ride-on rotary mower were compared in terms of effect on three herbaceous dicotyledonous species manually transplanted on stands of Bermuda and Manila grass.

2. Materials and Methods

2.1. Site Characteristics

The experimental trial was carried out at Podere Rottaia, S. Piero a Grado, Pisa (43°40′33″ N 10°18′41″ E, 2 m a.s.l.) from April 2022 to September 2023 on two mature stands: one comprising Bermuda grass *Cynodon dactylon* × *transvaalensis* "*Patriot*" *(Cd* × *t)*, and the other comprising Manila grass *Zoysia matrella* (L.) *Merr. (Zm)* cv "*Diamond*". The soil texture was silty loam (28% sand, 55% silt, and 17% clay). Soil comprised 18 g kg^{-1} of organic matter and had a pH of 7.8. The weather exhibited a Mediterranean pattern, characterized by seasonal peaks of rainfall during spring and fall. Figure 1 shows the monthly total rainfall (mm) and mean maximum and minimum air temperatures at the experimental site for both years in which the trial was performed (2022 and 2023), together with the 10-year mean values.

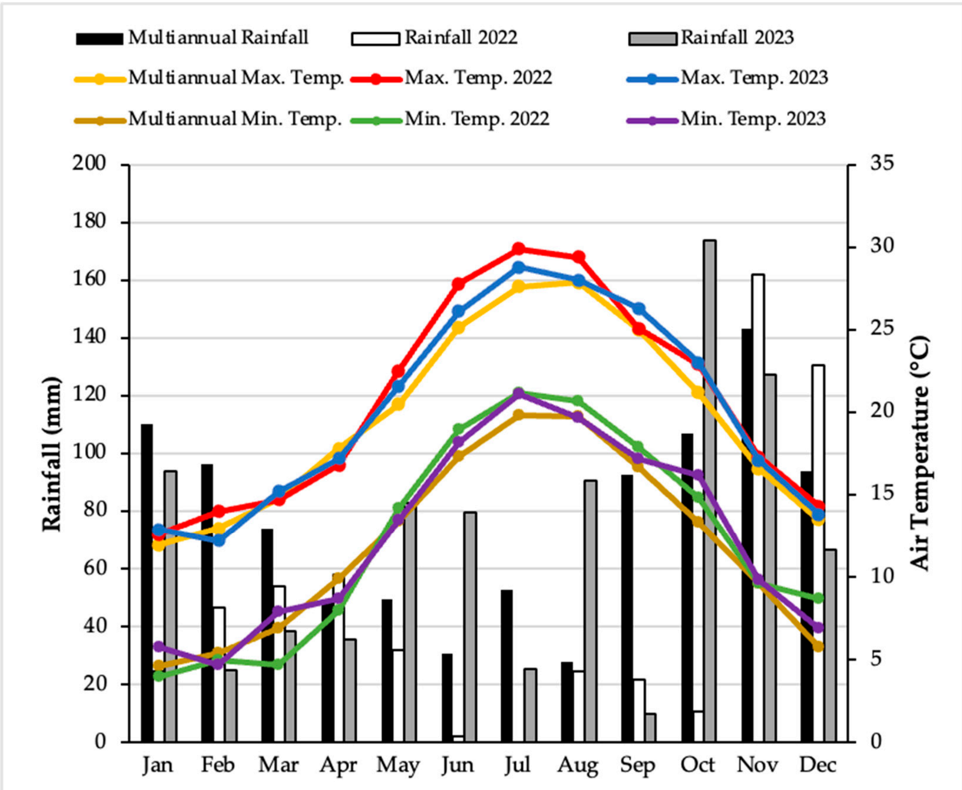

Figure 1. Monthly total rainfall (mm) and mean minimum and maximum air temperatures (°C) at the experimental site in 2022 and 2023 together with the 10-year mean values.

2.2. Experimental Design

Three herbaceous dicotyledonous species, naturally occurring in Italy, were selected for the current experiment (Table 1). All chosen species demonstrated the potential to produce visibly distinct and colorful flowers. Among the three species, *Lotus corniculatus* L. and *Sulla coronaria* (L.) B.H.Choi & H.Ohashi were propagated from seeds. The seeds were initially sown in containers with 2.5 cm peat cells, then placed in germination cells at 20 °C and an 80% relative humidity for a duration of 10 days. Plants remained in the alveolate container until sufficient vigor for transplantation was achieved. *Phyla nodiflora* (L.) Greene was acquired in 8 cm pots and was prepped for transplantation. The actual transplantation occurred on 29 March 2022 on both turf types.

Table 1. Transplanted species characteristics [29].

Species	Family	Life Form	Biological Form	Growth Tendency	Height (cm)	Observed Flowering Period
Lotus corniculatus L.	*Fabaceae*	Perennial	Hemicryptophytes	Prostrate/erect	10–40	May–September
Sulla coronaria (L.) B.H.Choi & H.Ohashi	*Fabaceae*	Perennial	Hemicryptophytes	Prostrate/erect	30–100	May–September
Phyla nodiflora (L.) Greene	*Verbenaceae*	Perennial	Hemicryptophytes	Prostrate	10–30	June–September

Transplanting occurred in plots measuring 2.5 m^2 (1 × 2.5 m). Nine plants of each species were transplanted per plot, except for *P. nodiflora*, of which five plants were transplanted. A quincunx planting layout was adopted, with a distance of 50 cm between plants in the row and 10 cm between the rows.

In 2022, prior to the transplantation of the species, a scalping intervention was performed at a height of 3.5 cm on 22 February with a flail mower. On 22 March, fertilization was carried out with 100 kg ha^{-1} of N, 11.4 kg ha^{-1} of P, and 41.5 kg ha^{-1} of K. On 17 May, a subsequent fertilization was applied with 27 kg ha^{-1} of N. In 2023, the turf underwent scalping at a height of 3.5 cm on 5 April, and fertilization was carried out on 10 May with 27 kg ha^{-1} of N. During both 2022 and 2023, irrigation was managed to stimulate the establishment of the three species and to prevent water stress. The above-mentioned operations were performed on both turf types.

Two mowing management systems were applied on both turf types: (i) mowing performed by an autonomous mower with a cutting height of 9 cm and at frequency of 3 days a week, 24 h per day (charging time included); (ii) mowing carried out with a ride-on rotary mower with a cutting height of 11 cm and at frequency once every 2 weeks (ordinary mower management system) (Figure 2).

Autonomous mowers are usually employed for the daily management of the turf, they are in fact equipped with blades suitable for cutting small amounts of plant material which allows for reduced energy consumption and at the same time results in the best physiological conditions for the turf. In the trial, we decided to reduce the mowing frequency of the autonomous mower, which was suitable for its correct functioning and for a residential garden, in order to evaluate any positive effects on the transplanted species. Regarding ride-on rotary mowers, mowing once every two weeks is part of the ordinary management practice of residential gardens. The autonomous mower employed was a Husqvarna Automower® 450XH (Husqvarna, Stockholm, Sweden) (Figure 3a). This machine operates by following random trajectories within areas defined by a shallow-buried boundary wire that generates an electromagnetic field. Once the autonomous mower perceives the electromagnetic field, it stops and changes direction. It has two pivoting front wheels and two course-treaded rear driving wheels. The mower cutting tool consists of three small pivoting blades mounted on a disc with a cutting width of 24 cm. During the trial, the autonomous mower was set to work with a cutting height of 9 cm. A brushless electric motor propels each of the rear wheels, while a third brushless electric motor is responsible for operating the cutting disc. The machine has a maximum working capacity of 5000 m^2 for a 24 h d^{-1} working time. Mean energy consumption at maximum use was 23 kWh $month^{-1}$. The ordinary management system was undertaken with a ride-on rotary mower GR2120 (Kubota, Osaka, Japan) powered with a 15.5 kW diesel engine (Figure 3b). The cutting unit was equipped with three blades with a total cutting width of 1.22 m. During the experimental trial, the cutting height was set to 11 cm and the cut grass was conveyed into a rear integrated collection chamber.

(a) (b)

Figure 2. View of the two mowing management systems on both Manila and Bermuda grass stands: (**a**) Manila grass, with the autonomous mower management system shown on the left and ordinary management system on the right; (**b**) Bermuda grass, with the ordinary management system shown on the left and the autonomous mower management system on the right.

(a) (b)

Figure 3. Mowers employed in the trial: (**a**) autonomous mower; (**b**) ride-on rotary mower.

The lawn mowing period began following full green-up and extended until the onset of dormancy, spanning from June to September in 2022 and 2023. Regarding the presence of weeds, during the trial, on both Manila and Bermuda grass, infestation levels were low and spontaneously occurring species were removed manually. The adopted experimental layout consisted of a randomized complete block design with a split plot arrangement, placing the mowing management system in main plot and the three herbaceous species in the subplots with three replications.

2.3. Data Collection

During the trial, for each species, the percentage of surviving individuals, the average percentage of coverage for a single individual, and the percentage of individuals with flowers were assessed on both turf types in the two different management systems [22,30]. For the percentage of surviving individuals per plot, the plants present within the plot were counted. The value was then converted into the percentage of individuals present compared to individuals planted initially. The ground cover of each individual present inside plots was visually estimated and averaged to obtain the average percentage of coverage for a single individual. The percentage of individuals with flowers was measured by counting the plants that had at least one flower within the plots. Even in this case, the value was reported as the percentage of individuals with flowers, referring to the number of plants planted per plot initially. The measurements of the percentage of individuals with flowers were carried out monthly, in June, July, August, and September in 2022 and 2023 on both turf types. For both the percentage of surviving individuals and the average percentage of coverage for a single individual, the surveys were carried out in June and September in 2022 and 2023 on both turf types. In 2022 and 2023, the heights of both turf types were measured monthly from June to September in the two different management systems. The measurements were carried out using a herbometer.

The primary energy consumption of the autonomous mower management system and the ordinary management system with a ride-on rotary mower was estimated. The hourly fuel consumption of the ride-on rotary mower was calculated using Equation (1) [31] as follows:

$$Ch = W \times d \times Cs \tag{1}$$

where Ch is the hourly consumption of the ride-on rotary mower (kg of fuel·h^{-1}), W is the engine power (kW), d is the effort percentage of the ride-on rotary mower engine, and Cs is the energetic efficiency of the ride-on rotary mower engine, which is considered equal to 0.25 kg fuel kWh^{-1}. The measurement of the primary energy consumption of the ride-on rotary mower was carried out considering the diesel heating value, which is 11.8 kWh·kg^{-1}. The tested autonomous mower operated in ECO mode, meaning that the boundary wire consumed energy solely during mowing. For the estimation of the primary energy consumption of the autonomous mower required to manage one hectare and the respective charging bases of the boundary wire, the efficiency of the Italian National Electric System, which is equal to 0.566, and the charging efficiency of the Li-ion batteries, which is 91%, were considered [32].

2.4. Statistical Analysis

The Shapiro–Wilk test was used to assess data normality and the Bartlett test was used for homoscedasticity. To evaluate changes in the percentage of surviving individuals; the average percentage of coverage for a single individual; and the percentage of individuals with flowers over time, management, species and the interaction among factors, repeated-measures analysis was performed using a generalized linear model (GENLIN) with a binomial distribution and a logit link function [33]. Time (years and months) was included as a repeated factor in the model. To evaluate the effect of the management system on turf height, a one-way ANOVA was performed [34]. Pairwise comparisons were performed with an LSD post hoc test at the 0.05 probability level. Statistical software SPSS version 27

(IBM Corp, Armonk, NY, USA) was used for the above-mentioned analysis. The analyses were conducted separately for the two turf types.

3. Results

3.1. Effect of the Two Management Systems on the Planted Species

3.1.1. Manila Grass

Repeated-measures analysis revealed that the percentage of surviving individuals was affected by species ($p < 0.001$), while the management and the interaction among factors had no significant effect on the parameters. The average percentage of coverage for a single individual was affected by both management system and species ($p < 0.001$ for both the factors), while the interaction among factors had no significant effects on the parameter. Species and the interaction among management systems and species affected the percentage of individuals with flowers ($p < 0.001$ and $p < 0.01$, respectively), while management system did not affect the parameters. Table 2 shows the results of the repeated-measure analysis.

Table 2. Results of the generalized linear model with repeated-measure analysis evaluating the effect of time, management system, species, and their interaction on percentage of surviving individuals, the average percentage of coverage for a single individual, and the percentage of individuals with flowers.

Factors	Percentage of Surviving Individuals	Average Percentage of Coverage for a Single Individual	Percentage of Individuals with Flowers
	***p*-Value**	***p*-Value**	***p*-Value**
Management System	0.533	***	0.419
Species	***	***	***
Management system × Species	0.269	0.076	**

*** $p < 0.001$; ** $p < 0.01$.

Overall, *P. nodiflora* obtained higher values for the percentages of surviving individuals compared to both *L. corniculatus* and *S. coronaria* (with values of 74.92, 49.26, and 26.21%, respectively) ($p < 0.05$). *S. coronaria* achieved lower parameter values compared to the other two species ($p < 0.05$).

Regarding the average percentage of coverage for a single individual, a lower value was recorded in the management system with the autonomous mower compared to the ordinary system, with values equal to 0.55% and 1.60%, respectively ($p < 0.05$). Overall, *L. corniculatus* achieved a greater average percentage of coverage for a single individual than *P. nodiflora* (with values of 1.59 and 0.41%, respectively) ($p < 0.05$) and a percentage similar to *S. coronaria* (1.25%).

In terms of percentage of individuals with flowers, a higher value was observed in the ordinary mower-managed plots for *P. nodiflora* rather than plots mown with the autonomous mower (60.73% and 33.90%, respectively) ($p < 0.05$) (Figure 4). No significant differences emerged in the comparison of the two management types for *L. corniculatus* (13.59% and 9.54%, respectively, for management with autonomous mower and the ordinary one) and *S. coronaria* (1.83% and 3.29%, respectively, for management with autonomous mower and the ordinary one). In general, it was found that there was a higher percentage of individuals with flowers for *P. nodiflora* (47.11%) than for *L. corniculatus* (11.41%) and *S. coronaria* (2.46%) ($p < 0.05$).

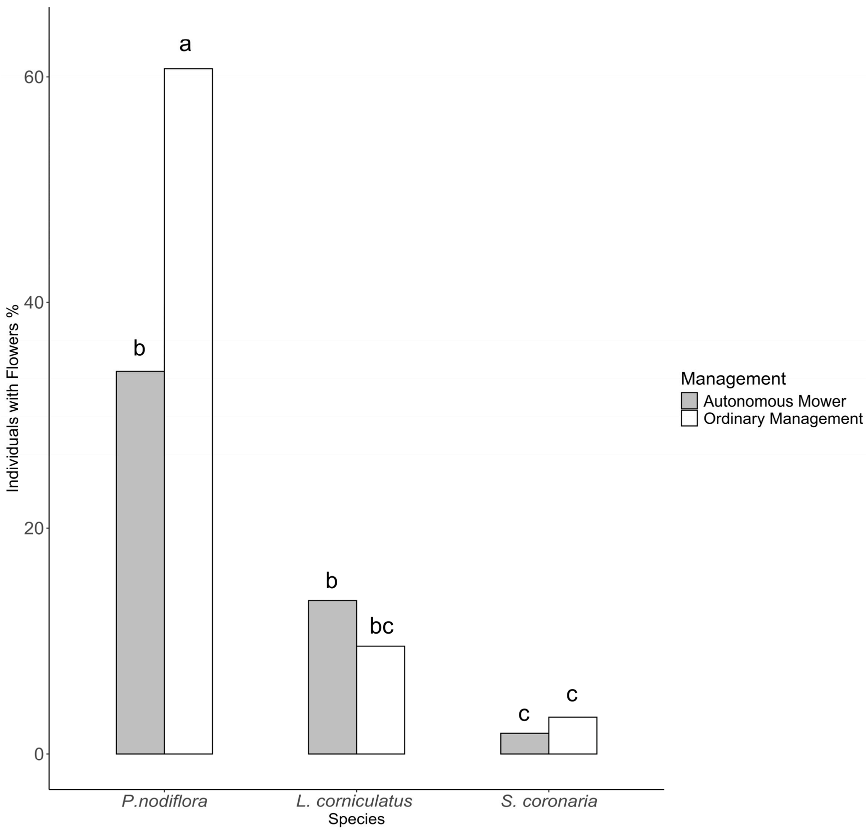

Figure 4. Effect of the interaction among species and management on the percentage of individuals with flowers. Means denoted by different letters indicate statistically significant differences at $p < 0.05$ (LSD test).

3.1.2. Bermuda Grass

The analysis revealed that the percentage of surviving individuals was affected by management ($p < 0.001$), species ($p < 0.001$), and interactions among factors ($p < 0.01$). Management system and species affected the average percentage of coverage of a single individual ($p < 0.05$, and $p < 0.01$, respectively), while the interaction had no significant effect on the parameter. The percentage of individuals with flowers was affected by all factors and interactions ($p < 0.001$). Table 3 shows the results of the analysis.

Table 3. Results of the generalized linear model with repeated-measure analysis, evaluating the effect of time, management, species, and their interactions on the percentage of surviving individuals, the average percentage of coverage for a single individual, and the percentage of individuals with flowers.

Factors	Percentage of Surviving Individuals	Average Percentage of Coverage for a Single Individual	Percentage of Individuals with Flowers
	***p*-Value**	***p*-Value**	***p*-Value**
Management System	***	*	***
Species	***	**	***
Management System × Species	**	0.684	***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Higher percentages of surviving individuals were recorded in ordinary mower-managed plots (42.59%) rather than in plots managed with the autonomous mower (9.10%) ($p < 0.05$). Overall, a higher percentage of surviving individuals was achieved by *P. nodiflora* (58.57%) compared to *L. corniculatus* (25.29%) and *S. coronaria* (4.05%) ($p < 0.05$). *S. coronaria* achieved lower values of the parameters compared to both *P. nodiflora* and *L. corniculatus* ($p < 0.05$). A higher percentage of surviving individuals was recorded in ordinary mower-managed plots compared to plots managed with an autonomous mower for both *P. nodiflora* (79.55 and 33.95%, respectively) and *S. coronaria* (20.60 and 0.68%, respectively) ($p < 0.05$), while no significant differences among the two types of management emerged for *L. corniculatus* (28.80 and 22.08%, respectively) (Figure 5).

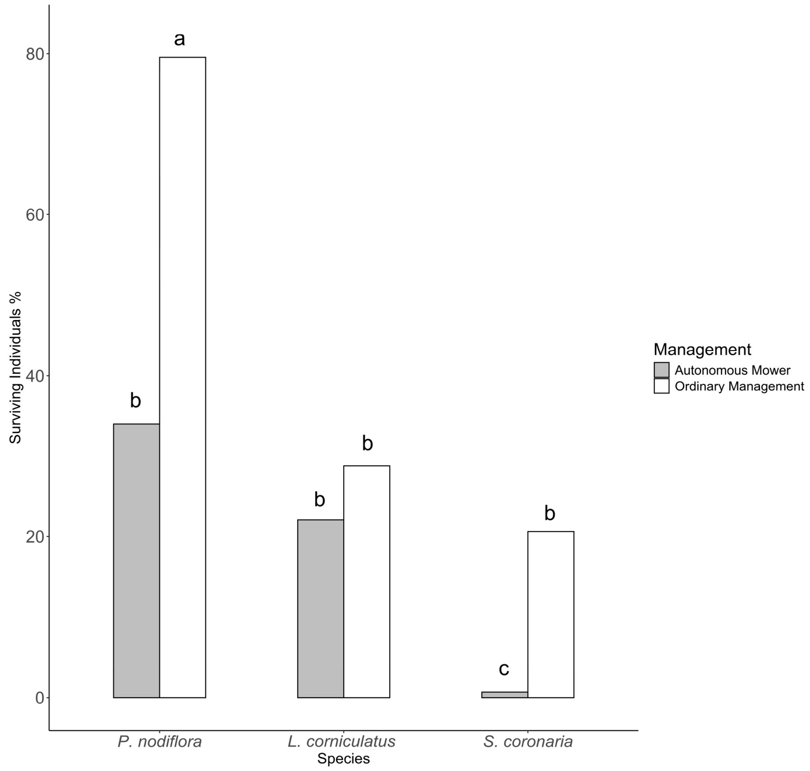

Figure 5. Effect of the interaction among species and management on the percentage of surviving individuals. Means denoted by different letters indicate statistically significant differences at $p < 0.05$ (LSD test).

Overall, higher average percentage of coverage for a single individual was obtained in ordinary mower-managed plots compared to plots managed with an autonomous mower (0.37 and 0.08%, respectively). *L. corniculatus* achieved a higher value of this parameter compared to *P. nodiflora* and *S. coronaria* (0.46, 0.14 and 0.07%, respectively) ($p < 0.05$). *S. coronaria* obtained a lower value of this parameter compared to the other two species ($p < 0.05$). In ordinary mower-managed plots, a higher percentage of individuals with flowers was recorded compared to plots managed with the autonomous mower (4.33 and 2.42×10^{-4}, respectively) ($p < 0.05$). Overall, *P. nodiflora* recorded a higher percentage of individuals with flowers compared to both *L. corniculatus* and *S. coronaria* (15.28, 2.58, and 7.61×10^{-7}%, respectively) ($p < 0.05$). For *P. nodiflora*, in plots managed with the autonomous mower, a lower value of this parameter was achieved compared to ordinary mower-managed plots (3.32 and 48.66%, respectively) ($p < 0.05$) (Figure 6). No differences emerged for *L. corniculatus* and *S. coronaria* in the comparison of the management system with autonomous mower and the system with ordinary mower (with values of 2.58 and 2.59% for *L. corniculatus*, and 1.57×10^{-7} and 0.37% for *S. coronaria*).

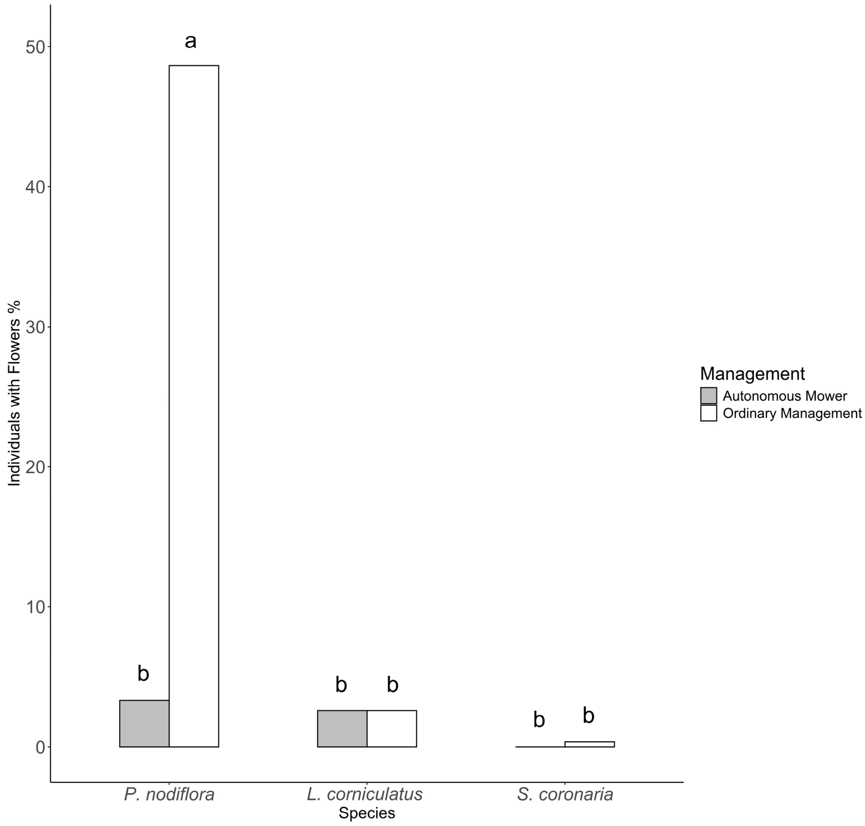

Figure 6. Effect of the interactions among species and management system on the percentage of individuals with flowers. Means denoted by different letters indicate statistically significant differences at $p < 0.05$ (LSD test).

3.2. Effect of the Two Management Systems on the Turf Height

Management affected the turf height both on Manila grass ($p < 0.05$) and Bermuda grass ($p < 0.001$). On both turf types, the ordinary mower-managed turf yielded a higher turf height compared to autonomous mower management. On Manila grass, a height of 9.91 cm was obtained for ordinary mower management, while with the autonomous mower a height of 6.40 cm was recorded. As regards Bermuda grass, a height of 10.72 cm was recorded for ordinary mower management and 5.86 cm for the autonomous mower.

3.3. Operative Performance of the Two Management Systems

The operative parameters relating to the management systems with autonomous mower and ride-on rotary mower on Manila grass are shown in Table 4.

It can be observed that in the case of the autonomous mower management system, 2.50 mowers operating 19.64 h a day are needed to manage 1 ha, while in the case of ride-on rotary mowers, a single vehicle manages to complete the operation in 4.71 h. However, the primary energy consumption over the year of the autonomous mower management is lower than that of ride-on rotary mower, with a percentage reduction equal to 67.47%. Table 5 shows the operative parameters relating to the management systems with autonomous mower and ride-on rotary mower on Bermuda grass.

It is possible to observe the same trend for Manila grass. In this case, the primary energy consumption of the autonomous mower management system is lower than that of the ride-on rotary mower system with a percentage reduction equal to 65.21%.

Table 4. Operative parameters relating to the two management systems of Manila grass, i.e., the ride-on rotary mower system and the autonomous mower system.

	Ride-on Rotary Mower			Autonomous Mower	
	Unit	Values		Unit	Values
Working Speed	km h^{-1}	3.70	Mowing Time	h day^{-1}	19.64
Total Mowing Time	h ha^{-1}	2.22	Charging Time	h day^{-1}	4.36
Total Turning Time	h ha^{-1}	0.20	Number of Mowers to Mow 1 ha		2.50
Total Time to Unload the Collection Chamber	h ha^{-1}	2.30	Mowers Energy Consumption	kWh ha^{-1} $year^{-1}$	89.03
Total Field Time	h ha^{-1}	4.71	Charging Bases Energy Consumption	kWh ha^{-1} $year^{-1}$	13.90
Fuel Consumption	kg ha^{-1}	6.50			
Primary Energy Consumption	kWh ha^{-1} $year^{-1}$	614.97	Primary Energy Consumption	kWh ha^{-1} $year^{-1}$	200.04

Table 5. Operative parameters relating to the two management systems of Bermuda grass, i.e., of the ride-on rotary mower system and the autonomous mower system.

	Ride-on Rotary Mower			Autonomous Mower	
	Unit	Values		Unit	Values
Working Speed	km h^{-1}	3.70	Mowing Time	h day^{-1}	19.64
Total Mowing Time	h ha^{-1}	2.22	Charging Time	h day^{-1}	4.36
Total Turning Time	h ha^{-1}	0.20	Number of Mowers to Mow 1 ha		2.22
Total Time to Unload the Collection Chamber	h ha^{-1}	2.00	Mowers Energy Consumption	kWh ha^{-1} $year^{-1}$	79.14
Total Field Time	h ha^{-1}	4.41	Charging Bases Energy consumption	kWh ha^{-1} $year^{-1}$	12.36
Fuel Consumption	kg ha^{-1}	5.41			
Primary Energy Consumption	kWh ha^{-1} $year^{-1}$	510.99	Primary Energy Consumption	kWh ha^{-1} $year^{-1}$	177.82

4. Discussion

Overall, regardless of the type of management system adopted, *P. nodiflora*, a creeping perennial plant, achieved the best results in terms of survival on both turf types (74.92 and 58.57% in Manila and Bermuda grass, respectively). This is in agreement with what was observed by other authors, according to whom, mowing promotes the development of shorter plants [35,36]. *L. corniculatus* recorded a greater survival rate (49.26 and 25.29%, in Manila and Bermuda grass, respectively) than *S. coronaria* (26.21 and 4.05%, in Manila and Bermuda grass, respectively). This is probably attributable to the fact that the first species is a creeping type and therefore adapts better to mowing than *S. coronaria*, which has varying growing habits, e.g., prostrate or erect, and the latter was favored during the trial. In Bermuda grass, a higher percentage of surviving individuals was observed for ordinary mower management system (42.59%), rather than with the autonomous mower system (9.10%). In this regard, Chollet et al. [10] found that mowing frequency is a key determinant of plant species. The authors observed that a low mowing frequency results in greater plant diversity. In the present study, ordinary mowing was performed twice a month, while for the autonomous mower, a higher mowing frequency was implemented, consisting of 12 interventions per month. Frequent mowing restricts the survival of plant species to only those species that are able to tolerate repeated defoliation [37,38]. These results are in line with those of Sehrt et al. [38], who observed a 30% increase in the species richness of urban lawns by reducing mowing frequency. Similarly, other authors found that less intensively managed urban lawns harbor greater plant species diversity [39,40].

In Bermuda grass, both for *P. nodiflora* and *S. coronaria*, higher percentages of surviving individuals were observed in the case of an ordinary mower management system (79.55 and 20.60% for *P. nodiflora* and *S. coronaria*, respectively) rather than using the autonomous mower (33.95 and 0.68% for *P. nodiflora* and *S. coronaria*, respectively). However, although the high mowing frequency can negatively influence the survival of the plant species, according to Mirabile et al. [30], the absence of mowing can also have a negative effect in terms of survival due to the competition exerted by the turf.

In terms of the average percentage of coverage for a single individual on both turf types, a higher value was observed for the ordinary management system (1.60 and 0.37% on Manila and Bermuda grass, respectively) compared to the management system with autonomous mower (0.55 and 0.08% on Manila and Bermuda grass, respectively). This is in contrast to Pirchio et al. [22], who observed greater development in the width of creeping-type species planted in turf when this environment was managed with an autonomous mower (used 8 h a day, every day of the week), rather than with a walk-behind rotary mower (used once per week). However, this may be due to the lower cutting frequency with which the rotary mower was used in this study (twice a month) compared to the authors' study, which may have allowed the species to develop and subsequently cover more surface area. Furthermore, regarding management with an autonomous mower, in the present study, the higher height of the turf compared to the case of Pirchio et al. may have resulted in the vertical rather than horizontal development of the transplanted plants [17,41] due to the competition for light with the turf. Regardless of the type of management system, *L. corniculatus* obtained a higher average percentage of coverage for a single individual compared to *P. nodiflora* on both Manila grass (with values of 1.59 and 0.41%, respectively) and Bermuda grass (with values of 0.46, and 0.14%, respectively).

However, *P. nodiflora* had a higher percentage of individuals with flowers compared to both *L. corniculatus* and *S. coronaria*, both on Manila grass (47.11, 11.41, and 2.46%, respectively) and on Bermuda grass (15.28, 2.58, and 7.61×10^{-7}%, respectively). This could be attributable to the particularly low height at which *P. nodiflora* flowers (around 7 cm) [42]. In Bermuda grass, a higher percentage of individuals with flowers was recorded for the ordinary mower management system rather than for the autonomous mower (4.33 and 2.42×10^{-4}, respectively). Moreover, *P. nodiflora* achieved a higher percentage of individuals with flowers with the ordinary management system rather than with the autonomous mower both on Manila grass (60.73% and 33.90%, respectively) and on Bermuda grass (48.66 and 3.32%, respectively). These results are probably attributable to mowing frequency. Smith et al. [14] found that the timing of mowing and the length of the time period between cuts, i.e., mowing frequency, can influence flowers number. Mowing just before a species enters its flowering stage can have an adverse impact on the resulting floral outcomes. Conversely, allowing extended periods of plant growth between mowing sessions has the potential to enhance floral development. Frequent lawn mowing, such as once a week, generally prevents plants from flowering [43]. Halbritter et al. [44], who evaluated the effect of three mowing regimes (no mowing, mowing every 6 weeks, and mowing every 3 weeks) on floral resources, observed that the highest mowing frequency resulted in the lowest floral densities. This is in agreement with what has been suggested by several other authors [4,15,45], according to whom the increase in floral resources in green public spaces can be achieved through a reduction in mowing frequency. In terms of operative performance, the primary energy consumption over the year using a management system with an autonomous mower was lower compared to the system with a ride-on rotary mower both on Manila grass (with values of 200.4 and 614.97 kWh ha^{-1} year^{-1}, respectively) and Bermuda grass (with values of 177.82 and 510.99 kWh ha^{-1} year^{-1}, respectively), with reductions of 67.47% and 65.21%, respectively. This is in agreement with what was observed by other authors who identified a lower primary energy consumption for these small autonomous mowers compared to mowers with endothermic engines [22,23,31]. However, to manage one hectare with an autonomous mower, 2.5 mowers are necessary for Manila grass and 2.22 mowers for Bermuda grass, while for the ordinary mower management system, a single machine is sufficient. This could be solved by using autonomous machines that are more efficient in terms of working capacity. The most recent models of autonomous mowers move with systematic trajectories. Sportelli et al. [46] observed that an autonomous mower with random trajectories required a longer time and traveled a greater distance to cover the working area compared to an autonomous mower with systematic navigation system, with working efficiencies of 35% versus 80%, respectively. However, regardless of the navigation system, the use of these machines is advantageous. Indeed, these machines eliminate the risk for operators encountering allergens, potential injuries, and noise emissions. Furthermore, autonomous mowers do not emit polluting gases in the areas where they operate, offering a more environmentally sustainable management [26].

Although a lower impact on the planted species was observed with the ordinary mower management system, encouraging results were still obtained with the autonomous mower system. For this reason, we refer to the results achieved on Bermuda grass with the autonomous mower in terms of the percentage of surviving individuals for *P. nodiflora* and *L. corniculatus*. Furthermore, encouraging results were observed on both turf types, but in particular on Manila grass, in terms of percentages of individuals with flowers for *P. nodiflora* and *L. corniculatus*. The presence of floral resources available for pollinators is necessary for their conservation, and residential gardens and parks are essential for pollinator populations that are facing difficulties surviving under the conditions created by modern intensive agriculture [2].

5. Conclusions

This study has contributed to broadening knowledge on the impact of lawn management utilizing autonomous mowers on lawn's floral composition. According to the mowing systems chosen, despite the lower impact on transplanted species by the ordinary mowing management system with a ride-on rotary mower, the management of the lawn with the autonomous mower achieved encouraging results. This can be seen from the positive results obtained with the autonomous mower in terms of the survival of individuals for *P. nodiflora* (33.95%) and *L. corniculatus* (22.8%) on Bermuda grass. Encouraging results were also observed in terms of the percentages of individuals with flowers, in particular on Manila grass, for the same species (33.90% and 13.59, respectively) with the autonomous mower. In terms of operative performance, to manage one hectare with the autonomous mower, 2.5 and 2.22 mowers are necessary for Manila and Bermuda grass, respectively, while with ordinary mowing management system, a single ride-on rotary mower is sufficient. This could be solved by using more efficient autonomous mowers in terms of working capacity, such as models with a systematic navigation system. Nonetheless, management system with autonomous mower recorded lower primary energy consumption on both Manila and Bermuda grass (200.4 and 177.82 kWh ha^{-1} $year^{-1}$, respectively) compared to the ordinary mower management system. In order to encourage greater biodiversity on turf for the greater sustainability of these green areas, it is possible to consider further reviewing the systems of these small autonomous mowers in terms of mowing frequencies and height, as well as selecting suitable species. Furthermore, it would be useful to conduct further studies on the impact of small autonomous mowers with systematic navigation systems on lawns' floral compositions to evaluate whether their greater efficiency, which is achieved even with less overlap, could further benefit the plant biodiversity of lawns.

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