Cities 150 (2024) 105097

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Evaluating the impact of natural products to improve the sustainability or urban lawns

Lorena Parra [a], Jose F. Marin Peira [b], Angel T. Lloret [c], Jaime Lloret [a,*]

[a] Instituto de Investigación para la Gestión Integrada de Zonas Costeras Universitat Politècnica de València, Carretera Nazaret-Oliva, s/n, 46730 Gandia, Spain
[b] Area verde MG Projects SL, C/ Oña, 43, 28933 Madrid, Spain
[c] Universidad de Alicante, Carr. de San Vicente del Raspeig, s/n, 03690 San Vicente del Raspeig, Alicante, Spain

ARTICLE INFO

Keywords:
Biostimulant
Soil amendments
Sustainable development goals
Turfgrass
Green areas

ABSTRACT

It is known that natural products can be used to strengthen and minimise stress of the gardening and sportive lawns, thus reducing the required inputs. In this paper, a trial is designed that allows for the study of the effect of a combination of two biostimulants and water-retaining agent products on different types of lawns. During 6 months, including the summer, soil and plant parameters are evaluated to compare the effects of treatments on soil temperature, humidity, and electrical conductivity, along with the NDVI of the grasslands. Treatment with the water-retaining agent and the second tested biostimulants has increased soil moisture by 10 %, with a greater effect on ornamental grasslands with lower maintenance requirements than sports lawns. The treatments with the two biostimulants without the water retaining agent do not lead to a significant variation in the aspect of the lawn. Marginal increases in the NDVI have been observed in all the treatments, which include the biostimulants. According to these results, it is possible to achieve better water efficiency in managing urban lawns by using natural products, which leads to a more sustainable use of hydric resources.

1. Introduction

The green areas have multiple purposes in the urban environments, ranging from leisure spaces such as urban gardens to sports areas like golf courses or football fields. These spaces have considerable diversity among cultivated species, soil types, and grass requirements. The quality of the lawns can be assessed using various metrics, with NDVI being one of the most used (Marín et al., 2020; Zhang et al., 2019). Different species exhibit varying maximum NDVI values and trends throughout the year, with some species demonstrating greater resistance to heat and drought. Even though green areas are contributing to some of the Sustainable Development Goals (SDGs) (Schmidt-Traub et al., 2017), particularly to SDG11 (Sustainable cities and communities), SDG 13 (Climate Action), and SDG 15 Life on Land) (Lorenzo-Sáez et al., 2021). Their requirements pose a serious challenge for other SDGs, such as SDG 6, which are linked to water availability and sustainable production. The SDGs are defined as a series of targets and indicators commonly referred to by numerous publications (Trane et al., 2023). Despite numerous efforts to select the most suitable species to minimise water requirements and employ various irrigation techniques, the sustainability of urban lawns remains a challenge (Ignatieva et al., 2020), jeopardising the achievement of the Agenda 2030 objectives. The water footprint of urban green areas is particularly concerning in arid and semi-arid regions (Ruíz-Pérez et al., 2020), where water scarcity is already a reality. With increased awareness of water requirements and climate change's impact, combining different heat and drought-resistant species, such as C4 grasses, with C3 grasses has been advocated in recent years as a priority to ensure the sustainability of urban areas (Culpepper et al., 2019). The terms C3 and C4 are related to the metabolic pathways for carbon fixation. While C3 plants use only the Calvin cycle, C4 plants combine it with the C4 pathway, resulting in enhanced photosynthetic efficiency in hot and dry environments. The dynamic relationship between both grasses changes throughout the year in mixed lawns, which are recommended for gardening in areas with limited water availability.

The soil conditions in which lawns grow are arguably the most influential factor affecting turfgrass quality beyond grass species. While multiple biochemical parameters can be examined, physical parameters like soil moisture, soil electroconductivity (EC), and soil temperature offer reliable and low-cost insights into plant vigour (Marín et al., 2020). Of these, soil moisture, also referred to as volumetric water content, stands out as the most critical. The exploration of soil amendments to enhance soil moisture to establish high-quality green areas with reduced

* Corresponding author.
E-mail addresses: loparbo@doctor.upv.es (L. Parra), jmarin@areaverde.es (J.F. Marin Peira), jlloret@dcom.upv.es (J. Lloret).

https://doi.org/10.1016/j.cities.2024.105097
Received 16 March 2024; Received in revised form 30 April 2024; Accepted 1 May 2024
Available online 4 May 2024

water usage has been studied for decades (Hale et al., 2021) to improve the sustainability of urban lawns. Among these products, water-retaining agents or wetting agents have been employed in various types of lawns, yielding ambiguous results (Chang et al., 2020). Even though the findings are inconclusive, a recent report indicates that 80 % of golf courses across the United States integrate soil surfactants into their routine maintenance procedures (Fleetwood, 2021). Nevertheless, no information has been found on the use of these products in gardening areas, which constitute large surfaces of urban landscapes and might significantly impact water management in the future.

The use of biostimulants, generally with natural origins, such as humic acids, fulvic acids, protein hydrolysates, and seaweed extracts, have been applied in many agronomic fields, including green areas (Mackiewicz-Walec & Olszewska, 2023). Other biostimulants include chitosan, silicon, inorganic compounds, beneficial fungi, bacteria, and free amino acids. These products improve turfgrass's quality and enhance its tolerance to environmental stresses and diseases (Pennisi et al., 2022). In fact, 82 % of Georgia golf courses use biostimulants (Talar-Krasa et al., 2019). Consequently, their use to maintain lawn quality while reducing irrigation has become widespread. Nevertheless, due to the vast array of commercial products available, the lack of transparent and comprehensive information regarding their origins, and the varying lawn conditions, no definitive conclusions can be drawn yet, necessitating further research.

The primary issue with the current findings on the use of individual biostimulants and soil amendments is that many studies are conducted in pots rather than in real green areas. This restricts the generalisation of results to real gardens or sports lawns where the grasses have influenced the soil, and the dynamics are distinct. The water repellency in soils under turfgrass culture (Fidanza et al., 2020) is caused by the fungal hyphae and organic matter coating the soil particles. These soils exhibit a low water retention capacity and are prone to high leaching, resulting in reduced water efficiency. Consequently, dry spots often develop on the greens. Therefore, assessments of water-retaining agents in pots may yield results that are not applicable to real gardens or sports lawns. It is uncommon to find studies that combine biostimulants and soil amendments, yet their combined effects may produce interesting synergies. Soil amendments can increase the available water for plants, while biostimulants can improve plant efficiency in utilising this water. Therefore, research involving combined products is necessary to explore potential synergies between supplements.

In terms of irrigation requirements, while the mentioned products may have an impact, the grass species remains the determining factor. Therefore, it is essential to evaluate the effects of biostimulants and soil amendments not only in lawns consisting of a single species but also in mixed lawns, which are a promising approach to reaching sustainable lawns. Unfortunately, the application of these products in lawns with mixed grass species and varying irrigation levels is limited (Yousfi et al., 2021). The potential effects of biostimulants and soil amendments on growth and dynamics in mixed C3 and C4 lawns need to be considered. Hence, combining these specific lawns with products that enhance water efficiency could offer a sustainable solution for water management in the production and maintenance of urban green areas.

This study aims to assess the synergies between natural products, two biostimulants and a water-retaining agent in both gardening and sports lawns. Field trials will be conducted in established grasslands over three years. The sports lawns consist of a single species, while the gardening turfgrass comprises two mixed lawns with two different species each. The sports lawns receive regular irrigation, whereas the gardening lawns are subjected to both regular and reduced irrigation. This selection was made based on expected real-life scenarios that various species may encounter in the future. The performance of the lawns will be evaluated using NDVI measurements and soil characteristics such as moisture content, EC, and temperature. The study will span six months, from May to October, to encompass the critical summer period for these lawns.

2. Materials and methods

2.1. Studied turfgrasses

The products were tested across four types of turfgrasses, each with distinct environmental conditions, including variations in irrigation and soil characteristics. The tests were conducted in the city of Alcalá de Henares, Madrid (Spain). These turfgrasses can be categorised into two groups: sports lawns and gardening lawns, see Table 1.

In terms of the sports lawns, the products were applied to two areas within a golf course: the putting green and the chipping green. Both areas have soil with a sandy texture and are predominantly covered by *Agrostis stolonifera* Tee One grass, maintained at a cutting height of approximately 3 mm. Irrigation for both areas was determined based on Evapotranspiration (ETP) estimates according to the Toro system irrigation (Site pro-LTC Model, sprinkler 855S). The location of the golf course is 40°31′18.2″N 3°18′41.1″W.

As for the gardening lawns, there were two distinct areas: gardening area 1 and gardening area 2. Both areas have loamy topsoil. Gardening Area 1 comprised a blend of 50 % *Festuca arundinacea* and 50 % *Cynodon dactylon* grasses, while Gardening Area 2 comprised 50 % *Poa pratensis* and 50 % *Buchloe dactyloides*. This selection of mixed C3 and C4 grasses was based on prior research findings (Marín et al., 2020). Irrigation was applied to each mixture in two percentages, at 100 % of the estimated requirement according to ETP calculations and at 55 % of the required irrigation according to ETP estimates, therefore having 2 areas in gardening 1 and another two in gardening 2. A Rain Bird irrigation system (Model ESP-LXME, sprinkler 5004PCR) was used to manage the irrigation. These lawns were located at 40°31′33.8″N 3°17′37.2″W.

2.2. Tested products

This test evaluates two different mixtures of products, one consisting of a nutritional biostimulant mixed with a soil amendment (Treatment 2) and another mixed with a resistance-inducing agent (Treatment 1), compared with a control. The applied products in the different lawns are detailed in Table 2. All applied products, named Phytotrat, Nutran, and Viaqua+, are provided by BAIC company,

The biostimulant (I), a resistance-inducing agent (I) is designed by the company to control fungal and bacterial diseases. According to the company, this product improves disease control by adding bioflavonoids, amino acids and plant extracts and oils, which activate the crop's response to any type of stress. While bioflavonoids are powerful antioxidants that plants themselves produce as secondary metabolites, which regulate plant metabolic pathways directly related to defence and protection, the plant extracts and essential oils have a direct action against pathogens.

The biostimulant (II) is a fourth-generation nutritional product. It is composed of macro and micronutrients complexed with organic molecules, so the plant recognises them as its own and includes them in its metabolism. Among the nutrients, liquid organo-mineral fertiliser NPK 2–5-6.5 with B, Mn and Zn are included. It must be highlighted that nitrogen content comes from amino acids of plant origin obtained by

Table 1
Summary of characteristics of turfgrass in tested areas.

Area	Type of use	Type of Soil	Grass species	Irrigation
Sport Area 1	Putting green	Sandy	*Agrostis stolonifera* Tee One	100 % ETP
Sport Area 2	Chipping green	Sandy	*Agrostis stolonifera* Tee One	100 % ETP
Gardening Area 1	Garden	Loamy topsoil	50 % *F. arundinacea* and 50 % *C. dactylon*	100 % ETP
Gardening Area 2	Garden	Loamy topsoil	50 % *P. pratensis* and 50 % *B. dactyloides*	55 % ETP

Table 2
Summary of applied products in the different areas.

Area	Control	Treatment 1 (Phytotrat + Nutran)	Treatment 2 (Nutran + Viaqua+)
Sport Area 1	x	x	
Sport Area 2	x		x
Gardening Area 1 Test 1	x	x	
Gardening Area 1 Test 2	x		x
Gardening Area 2 Test 1	x	x	
Gardening Area 2 Test 2	x		x

acid. Meanwhile, micronutrients are complexed with organic molecules (amino acids, peptides, vitamins), facilitating their translocation throughout the plant. Additionally, indigestible Sugars serve as a direct carbon source for beneficial microbiota in root applications, greatly promoting soil health.

Soil amendment material (III) is a liquid amendment and a water-retaining agent that contains polymers and penetrating agents to maintain root moisture, obtained 100 % from plant-based raw materials (lignosulfonates). This product aims to reduce the surface tension of the grass, promoting water infiltration and penetration. It improves the effectiveness of irrigation water, solubilises nutrients in the substrate and reduces salinity and electrical conductivity, thanks to its behaviour as a clay floc, which increases the cation exchange capacity.

2.3. Applied dosage of tested products

The dosage of the products was administered according to the manufacturer's recommendations, which are included in its instructions. All products were applied diluted in water using a 200 L Hardy manual vat with the following dosages: Product I at 0.5 L/ha, Product II at an initial dose of 1 L/ha and subsequent application of 0.5 L/ha, and humectant product with an initial dose of 2 L/ha and subsequent application of 1.5 L/ha. Given that the products were mixed in the ways described and applied independently in each area, the two mixtures used on each grass surface will be studied; subsequent irrigation was carried out when applying the mixture with product III.

Fig. 1 shows the application procedure in a) putting green, b) chipping green, c) mixed grass with regular irrigation, and d) mixed grass with reduced irrigation. Work was done in each area, and 3 repetitions were carried out when sampling all the parameters studied. Application of the products was scheduled monthly from May to October 2023. The products were applied to the turf on the following dates: May 12, 2023; June 5, 2023; July 31, 2023; August 23, 2023; September 26, 2023; and October 11, 2023.

2.4. Evaluated parameters

Four different parameters were evaluated in the studied lawns to evaluate the effectiveness of these products. The selected parameters included information from the soil and the grass. The parameters were the following ones: soil temperature, soil EC, soil moisture, and Normalised Difference Vegetation Index (NDVI). The soil parameters were recorded using a Spectrum FieldScout TDR 350, and the NDVI was measured with the GreenSeeker® Handheld Crop Sensor. These parameters were selected to include information from the soil and objective data on turfgrass quality.

In order to evaluate not only the effect of the products but also the required time to see the benefits, these parameters were analysed a few days after applying the products to all the lawns. We will refer to the mixture of Product II and III as Treatment 1 application and the mixture of Product I and II as Treatment 2. Generally, data were gathered 2 to 4 days after the application of products. Nevertheless, the data gathering was delayed in June due to scheduling reasons. The date ID used in the results section, dates of application of products, and data collection can be seen in Table 3.

2.5. Other applied treatments

The grass meadows in both test areas, sports lawns and garden lawns, recorded conventional maintenance to keep their surfaces in good condition, both in the treated areas and in the control areas. The same tasks of mowing, fertilising, and irrigation were conducted, with greater intensity in cutting and work than in sports grass areas in gardening grass. No additional treatments were conducted in the treatment area other than the control areas.

2.6. Statistical analyses

In order to evaluate the effects of the tested products, collected data were statistically analysed using a two-way Analysis Of Variance (ANOVA). Two-way ANOVAs were calculated for each of the studied parameters and for each of the areas. The reason for generating different ANOVAs for the different areas was due to the variations between areas and the applied treatments. The factors included in the analysis were the treatment and the date. In the event of significant *p*-values in the two-way ANOVA, post hoc multiple comparison tests were conducted. For this purpose, we choose the Duncan method to differentiate between the groups. When no differences were observed due to the treatment, individualised data for each date were analysed with a single-factor ANOVA:

Table 3
Dates of treatment and data collection.

Date ID (num)	Months after the first treatment (months)	Treatment date (DD/MM/YYYY)	Data collection date (DD/MM/YYYY)
1	0	12/05/2023	16/05/2023
2	1	05/06/2023	15/06/2023
3	2	31/07/2023	02/08/2023
4	3	23/08/2023	25/08/2023
5	4	26/09/2023	28/09/2023
6	5	11/10/2023	13/10/2023


a) b) c) d)

Fig. 1. Treatment in different studied areas a) putting green, b) chipping green, c) gardening lawns with regular irrigation, and d) gardening lawns with restricted irrigation.

The statistical analyses were conducted using Statgraphics Centurion XVIII (STATGRAPHICS Centurion XVIII Software, n.d.).

3. Results

In this section, we detail the obtained results for the different types of grasses. First of all, we analyse the improvement in the quality of the lawns in sports turfgrass. Then, we evaluate the results of the gardening turfgrass.

3.1. Sport turfgrass

3.1.1. Effects on soil characteristics in putting green and chipping green

First of all, we are going to detail the effect of treatment 2 on soil characteristics, as summarised in the two-way ANOVAs shown in Tables 4, 5, and 6. In these tables, we have summarised the ANOVA, including the degrees of freedom (df), the F-value (F), and the significance of p-vañue (Sig.). Among the three soil characterisation parameters analysed, the two-way ANOVA indicates that the treatment has no significant impact on soil moisture (*p*-value of 0.8501), EC (p-value of 0.8814), or soil temperature (p-value of 0.3479). Moreover, the date emerges as a significant factor across all parameters studied, with a minimum p-value of 0.0104.

Since no significant effect for any of the evaluated parameters is indicated by the two-way ANOVA, results for individual dates are analysed using single-factor ANOVA. The individual single-factor ANOVAs indicated no statistically significant differences for treatment 2 in soil moisture and EC. Nevertheless, punctual effects of treatment 2 are identified in soil temperature. In months 2 to 4 (June to August), the soil temperature was higher in the treated soil than in the control. The observed differences range between 0.5 °C and 1.7 °C, representing variations from 2.5 to 7.3 % compared to the control. However, in month 5 (September), this trend is altered, with the soil temperature in the control higher (22.3 °C) than in the treated soil (21.0 °C), which represents a decrease of more than 5 % compared to the control.

Following, the effect of Treatment 1 on soil characteristics, which are summarised in the two-way ANOVAs shown in Tables 7, 8, and 9, is analysed. Among the studied soil parameters, the two-way ANOVAs indicate that the first treatment significantly impacts soil moisture (*p*-value of 0.0108) and temperature (p-value of 0.0012). No effect on soil EC has been found (p-value of 0.1132). Moreover, the date emerges as a significant factor across all parameters studied, with *p*-values of 0.0000 for both soil EC and temperature and a p-value of 0.0458 for soil moisture.

Below, we present an analysis of the soil parameters influenced by the treatment. Regarding soil moisture, refer to Fig. 2 for an overview. Treatment 1 increases the soil moisture compared to the control. The soil moisture in the control is 43.91 %, while in treatment 1, it reaches 48.29 %, representing an increment of 9.97 %.

Fig. 3 illustrates the varying soil moisture levels across different data combinations for treatment 1. It is noticeable that the treatment exhibits a more pronounced effect during month 4 (August), with minimal impact in months 3 and 6 (July and October) and moderate impact in months 1, 2, and 5 (May, June and September). Analysing the average soil moisture values for each period and treatment, it's clear that throughout the study period, the soil treated with treatment 1 exhibits the lowest average standard deviation among the replicates. This finding suggests that treatment 1 reduces the spatial variability of soil moisture for chipping greens, thus improving the lawn's uniformity.

Based on the data obtained, it can be concluded that the product tested in treatment 1 increases moisture and homogenises soil moisture,

Table 4
Two-way ANOVA for EC in putting green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.443956	5	0.0887911	3.69	0.0104
Treatment	0.000544444	1	0.000544444	0.02	0.8814
Error	0.697189	29	0.024041		
Total (Corrected)	1.14169	35			

Table 5
Two-way ANOVA for moisture in putting green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	678.232	5	135.646	4.62	0.0032
Treatment	1.06778	1	1.06778	0.04	0.8501
Error	852.052	29	29.3811		
Total (Corrected)	1531.35	35			

Table 6
Two-way ANOVA for temperature in putting green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	135.028	5	27.0056	68.99	0.0000
Treatment	1.1025	1	1.1025	2.82	0.1041
Error	11.3525	29	0.391466		
Total (Corrected)	147.483	35			

Table 7
Two-way ANOVA for EC in chipping green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	1.12745	5	0.225489	16.97	0.0000
Treatment	0.0354694	1	0.0354694	2.67	0.1132
Error	0.385447	29	0.0132913		
Total (Corrected)	1.54836	35			

Table 8
Two-way ANOVA for moisture in chipping green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	303.173	5	60.6347	2.61	0.0458
Treatment	172.484	1	172.484	7.42	0.0108
Error	674.302	29	23.2518		
Total (Corrected)	1149.96	35			

Table 9
Two-way ANOVA for temperature in chipping green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	200.383	5	40.0767	148.58	0.0000
Treatment	3.48444	1	3.48444	12.92	0.0012
Error	7.82222	29	0.269732		
Total (Corrected)	211.69	35			

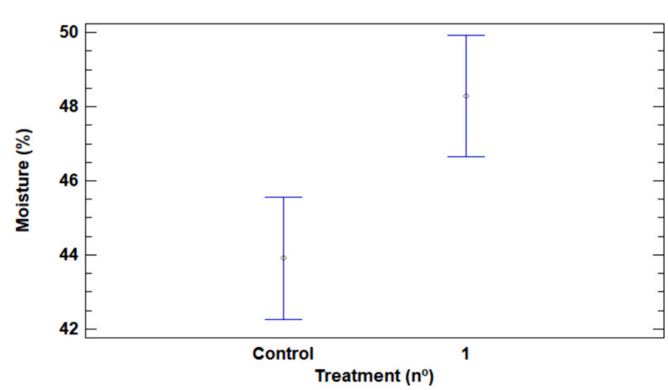

Fig. 2. Soil moisture in chipping green under control and treatment 1.

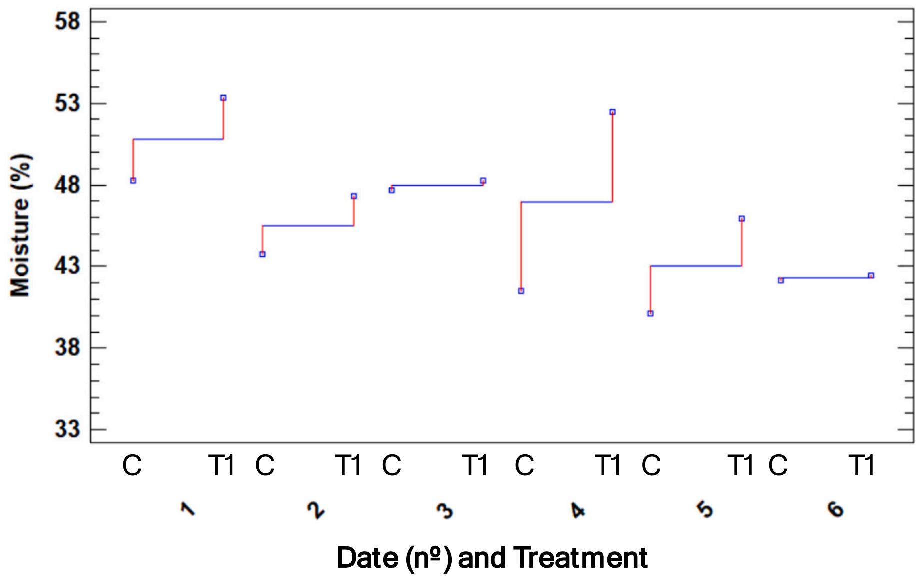

Fig. 3. Soil Moisture in chipping green under control and treatment 1 along the studied period. On each date, we can see the values of the control on the left and the values of the treated area on the right.

reducing hydric stress and improving the lawn's appearance. Although the achieved temporal stability, indicated by the lower standard deviation of soil moisture over the different dates, is greater in control, the highest moisture values of the chilling green ensure no absence of water, especially in August and September. Water disposal is essential at this moment, as the grasses are recovering from the stress experienced during the summer, and average growth at optimal temperatures is resuming. Therefore, to ensure the quickest possible recovery of the green, water and nutrient availability for *A. stolonifera* is essential.

Even though soil temperature was identified as an affected parameter by the first treatment in the two-way ANOVA, the results of the single-factor ANOVA indicated no effect. This discrepancy might be due to the significant influence of the date. Therefore, individual single-factor ANOVAs were calculated for different dates. For all dates, the ANOVA results show statistically significant differences with *p*-values of 0.0065, 0.0148, 0.0204, 0.0158, 0.0026, and 0.0004 for months 1 to 6, respectively. The effect of the treatment varies across months, with an increase in temperature compared to the control in months 2, 3, 4, and 6 (June, July, August, and October) and a decrease in temperature compared to the control in months 1 and 5 (May and September). This erratic trend appears to be unrelated to soil temperature or other factors such as EC or soil moisture. Typically, higher soil moisture results in lower soil temperatures in summer. However, in regions where night-time temperatures are low, moisture may have the opposite effect if data is collected early in the morning before the soil is heated by the sun.

3.1.2. *Effects on grass vigour in putting green and chipping green*

On the one hand, the ANOVA results for the putting green and NDVI factor for the second treatment are presented in Table 10. The findings suggest no significant treatment effect on NDVI, with a *p*-value of 0.7835. On the other hand, the results of the ANOVA for the NDVI values of the chipping green and treatment 1 can be seen in Table 11. According to the ANOVA results, similar to treatment 2, treatment 1 does not significantly affect the NDVI values (p-value equal to 0.7985). Date proves to be a significant factor, with *p*-values of 0.0000 according to data obtained from Statgraphics. Although differences are not statistically significant, the average NDVI values for the control group are slightly lower than those for treatment 1 and treatment 2, with treatment 1 exhibiting the highest average NDVI value. Nevertheless, these differences are marginal. Considering the expected increase in NDVI due to the application of these products and the considerable variability of NDVI across different dates, single-factor ANOVAs are conducted for each date. These analyses with individual single-factor ANOVAs showed no significant differences along the studied period in sportive lawns.

Table 10
Two-way ANOVA for NDVI in putting green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.0723556	5	0.0144711	100.18	0.0000
Treatment	0.0000111111	1	0.0000111111	0.08	0.7835
Error	0.00418889	29	0.000144444		
Total (Corrected)	0.0765556	35			

Table 11
Two-way ANOVA for NDVI in chipping green.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.0665472	5	0.0133094	35.33	0.0000
Treatment	0.000025	1	0.000025	0.07	0.7985
Error	0.010925	29	0.000376724		
Total (Corrected)	0.0774972	35			

3.2. *Gardening turfgrass*

3.2.1. *Effects on soil characteristics with regular irrigation*

The outcomes of the ANOVAs conducted for the three factors are displayed in Table 12, Table 13, and Table 14. The two-way ANOVA reveals that the treatment significantly influences moisture (*p*-value of 0.0188) and EC (p-value of 0.0426) among the three soil characterisation parameters examined. Nonetheless, treatment has no discernible effect on soil temperature (p-value of 0.3479). Additionally, the date emerges as a significant factor across all the parameters studied, with *p*-values recorded as 0.0000 according to the data obtained through Statgraphics.

Table 12
Two-way ANOVA for EC in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	2.74971	5	0.549941	49.16	0.0000
Treatment	0.0742347	2	0.0371174	3.32	0.0426
Error	0.716024	64	0.0111879		
Total (Corrected)	3.53997	71			

Table 13
Two-way ANOVA for moisture in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	1967.92	5	393.583	23.65	0.0000
Treatment	140.824	2	70.4119	4.23	0.0188
Error	1064.97	64	16.6401		
Total (Corrected)	3173.71	71			

Table 14
Two-way ANOVA for temperature in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	532.166	5	106.433	1076.08	0.0000
Treatment	0.212361	2	0.106181	1.07	0.3479
Error	6.33014	64	0.0989084		
Total (Corrected)	538.709	71			

Below, we present the analysis of soil parameters influenced by the treatment. Concerning EC, as depicted in Fig. 4 and the results obtained from the post hoc multiple comparison tests, we confirm that the first treatment, consisting of moisturising and nutritional compounds, significantly increases soil EC. The EC increment resulting from the first treatment represents an increase of 23.3 % compared to the control. Conversely, despite showing increased EC values, the second treatment does not exhibit significant differences from the control. Although the application of the second treatment does not yield significant differences compared to the control, it increases the average EC level by less than 8.5 %.

The variation in EC levels across different combinations of date and treatment is summarised in Fig. 5. It is evident that the second treatment exerted a more significant influence during months 2 to 4 (June to August). The impact was minimal in month 4 (September) and moderate in months 1 and 6 (May and October). Moreover, we observe an increase in EC due to treatment 1 compared to the control in months 1, 4, and 6 (May, August, and October). This increase in months 1 and 6 surpasses that observed for the second treatment. Upon examining individual EC values for each treatment, it becomes apparent that there is a consistent rise in EC values in the soil from May to August, followed by a reduction in September and a subsequent increase in October. However, the increase is slightly less pronounced in the soil treated with the second treatment. Although the total increase from the beginning to the end of the study is equal for treatment 1 and the control, the occasional higher EC values in the soil resulting from treatment 1 should be taken into consideration. Based on the gathered data, it can be inferred that the products used in treatment I elevate soil EC levels with an accumulative effect. Therefore, this aspect must be considered in soils with high EC values, which may escalate post-treatment and potentially pose problems for grasses.

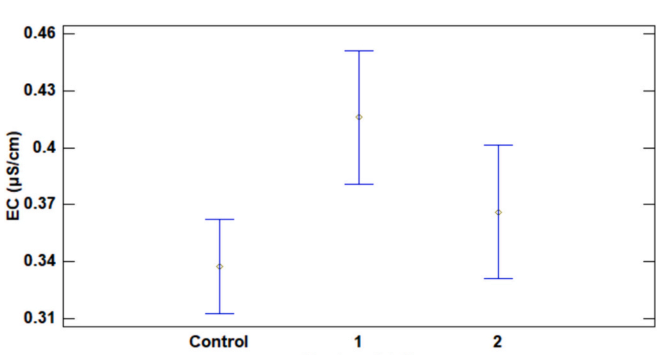

Fig. 4. Soil EC in gardening lawn with regular irrigation under control, treatment 1, and treatment 2.

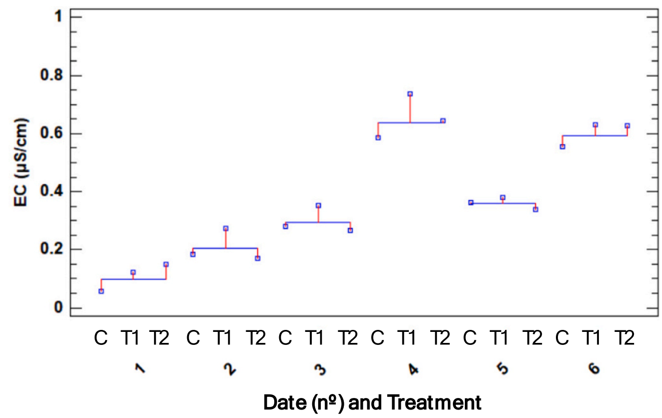

Fig. 5. Soil EC in gardening lawn with regular irrigation under control and treatment 1 along the studied period. On each date, we can see the values of the control on the left, central value treatment 1, and in the right treatment 2.

Regarding soil moisture, as presented in Fig. 6, the post hoc multiple comparison test indicates differences between treatment 1 and the control, as well as between treatment 2 and treatment 1. Treatment 1 has increased the average soil moisture by 3.13 % compared to the control, representing an increase of 11.2 % compared to the control. Meanwhile, treatment 2, although its effect was not significant, reduced the soil moisture by 0.3 %, which is less than 1 % of the soil moisture in control (28 %).

Fig. 7 illustrates the soil moisture values across different combinations of date and treatment. It is evident that the second treatment provokes a more pronounced effect during months 2 to 4 (June to August). The impact is minimal in month 5 (September) and moderate in months 1 and 6 (May and October). The soil moisture values of soils treated with the control and the second treatment exhibit different trends throughout the study period. Considering the averaged soil moisture values for each period and treatment, we can affirm that along the studied period, the soil with treatment 1 is the one with the lower average standard deviation. Meanwhile, soil with treatment 2 has the lowest standard deviation of the mean soil moisture values. This indicated that, for gardening lawns with regular irrigation, treatment 1 reduces the spatial variability of soil moisture, which will impact the uniformity of the lawn. Nevertheless, in this type of scenario, the capacity to stabilise the moisture values over time has not been proved.

Considering the parameter unaffected by the various treatments, soil temperature (refer to Fig. 8), we observed a slight increase in temperature in treatments 1 and 2. This minor rise is less than 0.5 % compared to the control, resulting in an average increase of 0.1 °C.

3.2.2. Effects on grass vigour with regular irrigation

The ANOVA results for the NDVI factor are displayed in Table 15. These findings indicate no significant impact of treatment on NDVI, with a *p*-value of 0.3161. However, the date emerges as a significant factor, with *p*-values recorded as 0.0000 based on the data obtained from Statgraphics. Despite the absence of statistically significant differences, the average NDVI values for the control group (0.63) are lower than those for treatment 1 (0.66) and treatment 2 (0.65). Considering the anticipated increase in NDVI due to the application of these products and the considerable variability of NDVI across different dates, single-factor ANOVAs are conducted for each date.

Based on data from the fourth month, see Table 16, and the post hoc multiple comparison test indicated significant differences between treatment 1 and control. Treatment 1 has resulted in an increase of the NDVI values for the gardening turfgrass with regular irrigation, with an average value of 0.69 compared to the control (0.60), accounting for a 15 % increase compared to the control. This trend, with higher values in treatment 1 compared to the control, is also evident in month 3, the

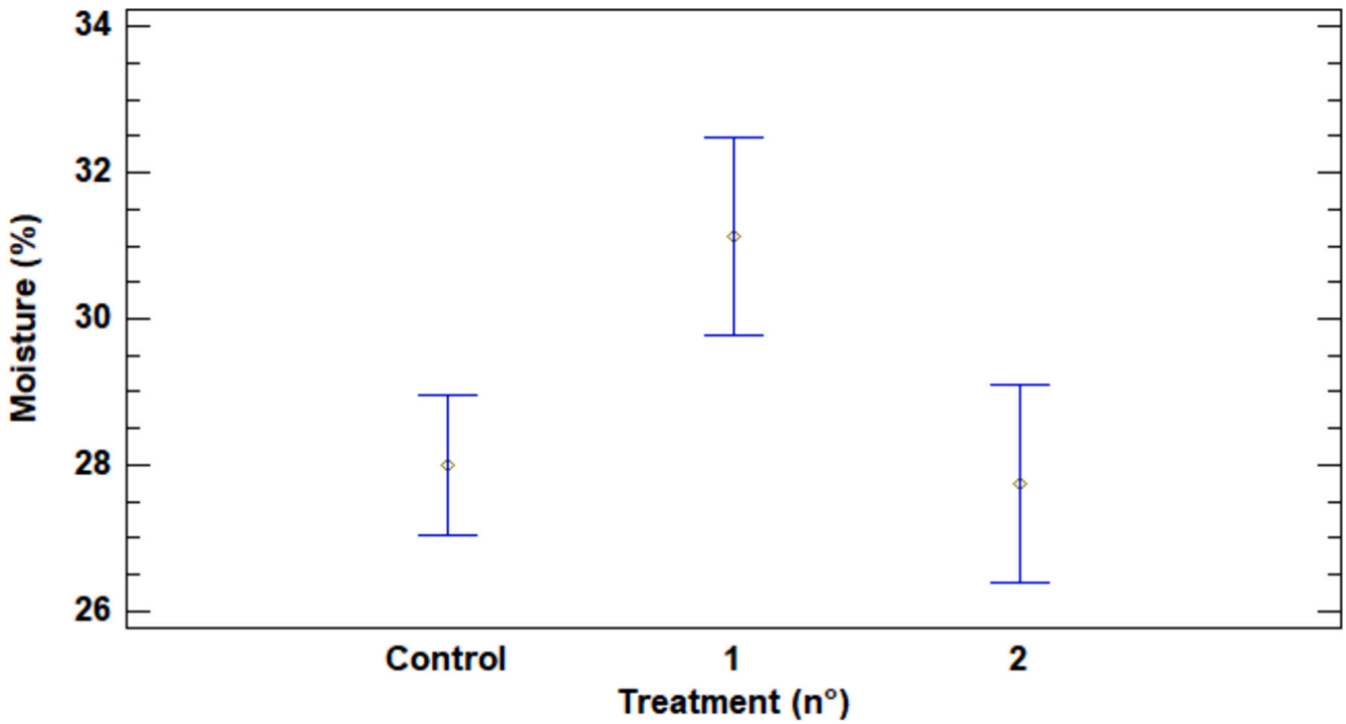

Fig. 6. Soil moisture in gardening lawn with regular irrigation under control, treatment 1, and treatment 2.

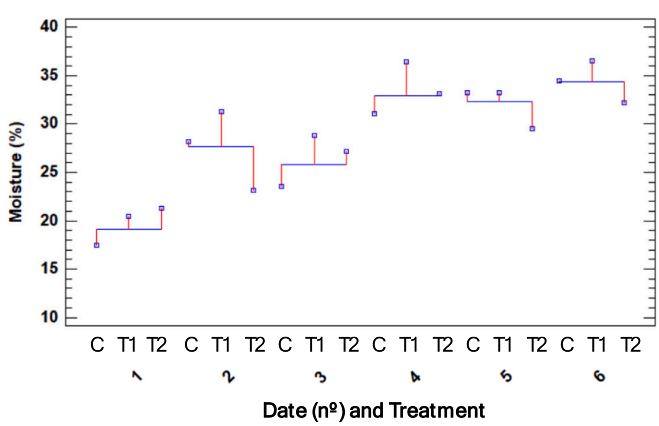

Fig. 7. Soil moisture in gardening lawn with regular irrigation under control and treatment 1 along studied period. On each date, we can see the values of the control on the left, central value treatment 1, and in the right treatment 2.

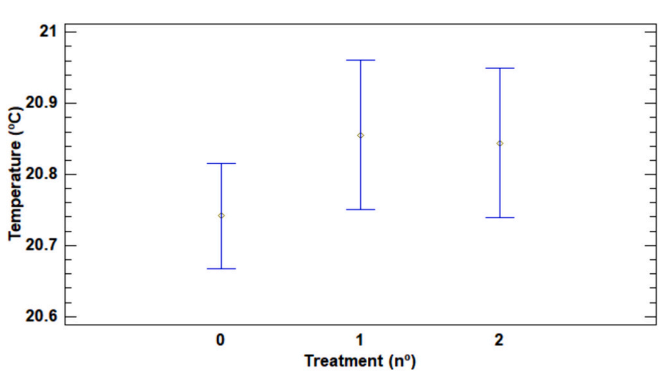

Fig. 8. Soil temperature in gardening lawn with regular irrigation under control, treatment 1, and treatment 2.

Table 15
Two-way ANOVA for NDVI in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.449211	5	0.0898422	34.43	0.0000
Treatment	0.0107417	2	0.00537083	2.06	0.1361
Error	0.167025	64	0.00260977		
Total (Corrected)	0.626978	71			

Table 16
Single ANOVA for NDVI in gardening turfgrass with reduced irrigation for date 2.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Inter group	0.0179417	2	0.00897083	4.84	0.0374
Intra group	0.0166833	9	0.0018537		
Total (Corrected)	0.034625	11			

previous month. However, in this case, the differences between treatment and control were not statistically significant. Specifically, NDVI for treatment 1 was 0.65, while for treatment 2 and the control, they were 0.63 and 0.58, respectively. It must be noted that in the second month, the NDVI value for lawns with treatment 1 was lower than for control and treatment 2.

3.2.3. Effects on soil characteristics with reduced irrigation

The results of the ANOVAs for the three factors are presented in Tables 17, 18, and 19. Among the three parameters studied to

Table 17
Two-way ANOVA for EC in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	819.995	5	163.999	14.98	0.0000
Treatment	190.367	2	95.1835	8.69	0.0005
Error	700.687	64	10.9482		
Total (Corrected)	1711.05	71			

Table 18
Two-way ANOVA for moisture in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.472024	5	0.0944047	9.05	0.0000
Treatment	0.167904	2	0.0839521	8.05	0.0008
Error	0.667804	64	0.0104344		
Total (Corrected)	1.30773	71			

Table 19
Two-way ANOVA for Temperature in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	507.271	5	101.454	473.67	0.0000
Treatment	0.71125	2	0.355625	1.66	0.1982
Error	13.7079	64	0.214186		
Total (Corrected)	521.69	71			

characterise the soil, the two-way ANOVA indicates that treatment is a significant factor for moisture with a *p*-value of 0.0008 and EC with a p-value of 0.0005. However, treatment does not significantly affect soil temperature (p-value equal to 0.1982). The date proves to be a significant factor for all the studied parameters, with *p*-values equal to 0.0000 according to the data obtained from Statgraphics.

Following, we present the analysis of soil parameters affected by the treatment. Regarding EC, as shown in Fig. 9, the post hoc multiple comparison tests indicated differences between treatment 1 and the control. However, no effect of treatment 2 has been identified on EC. Treatment 2 has increased on average by 0.115 μS/cm compared to the control, representing an increment of 46.52 %. Meanwhile, treatment 1, although its effect was not significant, increased EC by 0.012 μS/cm, which is less than 5 %.

Fig. 10 depicts the varying EC levels corresponding to different combinations of date and treatment. It is evident that the treatment had a more pronounced effect during months 3 to 6 (July to October). The impact was minimal in month 2 (June) and moderate in month 1 (May). Upon examining individual EC values for each treatment, it is apparent that there is an increment in EC values in the soil in all cases. However, the increment is lower in the soil where the first treatment has been applied. Although the total increment from the beginning to the end of the study is equal for treatment 1 and the control, the occasional higher EC values in soil caused by treatment 1 must be considered. Based on the collected data, it can be concluded that the products applied in treatment 1 increase soil EC, and there is an accumulative effect. Thus, this must be considered in soils with high EC values, which can increase after treatment, causing potential problems for the grasses.

Regarding soil moisture, as depicted in Fig. 11, and based on the results obtained from the post hoc multiple comparison test, we can confirm that the first treatment, composed of moisturising and

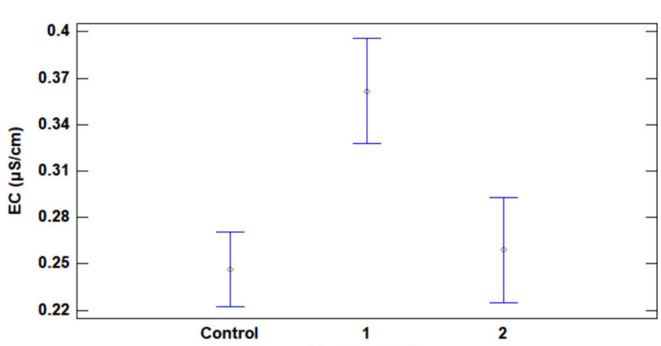

Fig. 9. Soil EC in gardening lawn with reduced irrigation under control, treatment 1, and treatment 2.

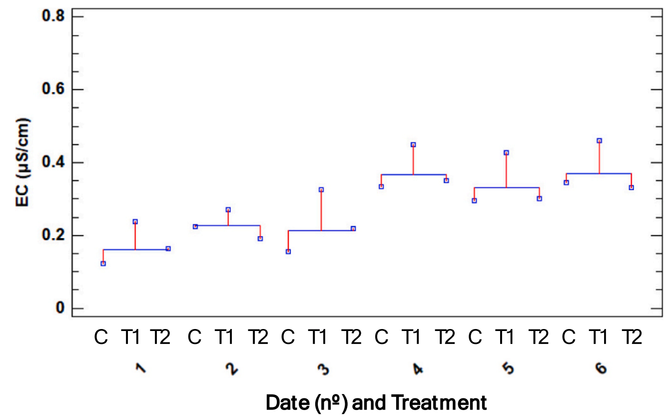

Fig. 10. Soil EC in gardening lawn with reduced irrigation under control and treatment 1 along the studied period. On each date, we can see the values of the control on the left, central value treatment 1, and in the right treatment 2.

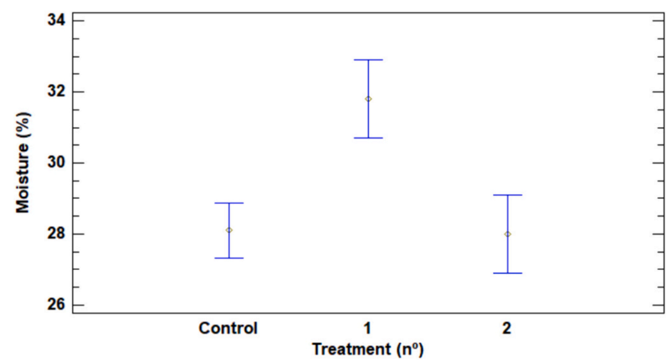

Fig. 11. Soil moisture in gardening lawn with reduced irrigation under control, treatment 1, and treatment 2.

nutritional compounds, significantly increases soil moisture. The second treatment did not affect soil moisture, showing values similar to the control's. The increase in moisture due to the first treatment is more than 3 % compared to the soil moisture in the control, representing up to a 10 % increase in moisture levels. Conversely, the application of the second treatment, although not significantly different from the control, resulted in a minimal reduction in the average moisture value, less than 0.1 %.

In Fig. 12, the different moisture values for the combination of date and treatment are represented. It is evident that the effect of the

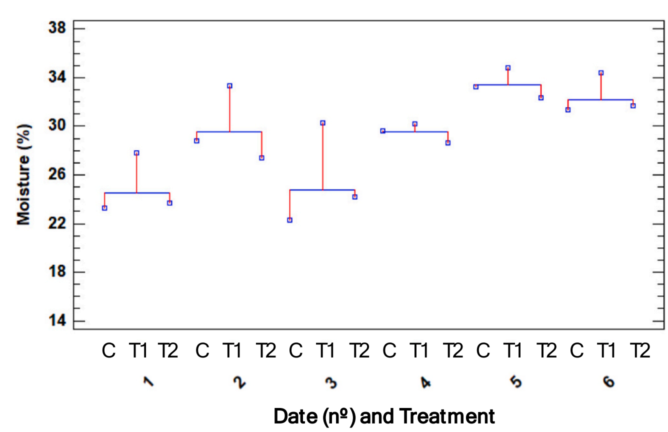

Fig. 12. Soil moisture in gardening lawn with reduced irrigation under control and treatment 1 along studied period. In each date, we can see on the left the values of the control, central value treatment 1, and on the right treatment 2.

treatment was more pronounced in months 1 to 3 (mid-May to early August). The effect was almost negligible in month 4 (August) and moderate in months 5 and 6 (September and October). Generally, the soil moisture values of the control and treatment 2 are similar. Considering the averaged soil moisture values for each period and treatment, we can assert that throughout the studied period, the soil treated with treatment 1 has the lowest average standard deviation from the replicas. This data suggests that, for gardening lawns with reduced irrigation, treatment 1 reduces the spatial variability of soil moisture, thereby affecting the uniformity of the lawn. Additionally, soil treated with treatment 1 has a lower standard deviation of the mean soil moisture values than the control, indicating greater temporal uniformity of soil moisture. Based on the obtained data, we can conclude that the tested product present only in treatment 1, the soil amendment, increases moisture content and provides more stable moisture values in the lawns, reducing water stress in gardening lawns with reduced irrigation.

Considering the parameter which has not been significantly affected by the different treatments, the soil temperature (see Fig. 13), we observed a small increment of temperature in treatment 1. This small increment is less than 2 % compared with the control. It proposes an average increment of 0.2 °C.

3.2.4. *Effects on grass vigour with reduced irrigation*

The results of the ANOVAs for the NDVI factor are presented in Table 20. The analysis indicates that treatment has no significant effect on NDVI, with a *p*-value of 0.2506. However, the date is found to be a significant factor, with *p*-values of 0.0000 based on the data obtained from Statgraphics. Despite the lack of statistically significant differences, it is noteworthy that the average NDVI values for the control group are lower than those for treatment 1 and treatment 2, with treatment 2 exhibiting the highest average NDVI value. Considering the anticipated increase in NDVI due to the application of these products and the considerable variability of NDVI across different dates, single-factor ANOVAs are conducted for each date.

According to the data from the second month and the post hoc multiple comparison test analyses, statistically significant differences are observed between treatment 1 and treatment 2, as shown in Table 21. Nevertheless, no significant differences exist between the treatments and the control group. The first treatment resulted in a reduction in the NDVI values of the gardening turfgrass, with an average value of 0.7 compared to the control group's average value of 0.76, representing a reduction of 7.6 %. On the other hand, the second treatment, although not showing significant changes, led to an increase in the NDVI to an average value of 0.79, which is 4.22 % higher than the NDVI value in the control group. This trend of lower values in treatment 1 compared to the control is also observed in month 5; however, in this case, the differences between treatment and control were not statistically significant. Specifically, the NDVI for treatment 1 was 0.71, while for treatment 2 and the control, they were 0.75 and 0.74, respectively.

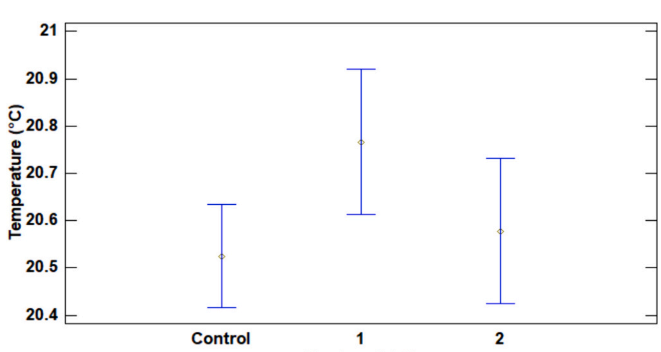

Fig. 13. Soil moisture in gardening lawn with reduced irrigation under control, treatment 1, and treatment 2.

Table 20
Two-way ANOVA for NDVI in gardening turfgrass with reduced irrigation.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Date	0.732057	5	0.146411	29.58	0.0000
Treatment	0.0140014	2	0.00700069	1.41	0.2506
Error	0.316807	64	0.00495011		
Total (Corrected)	1.06287	71			

Table 21
Single ANOVA for NDVI in gardening turfgrass with reduced irrigation for date 2.

Source	Sum of Squares	df	Mean Squares	F	Sig.
Inter group	0.0126833	2	0.00634167	4.89	0.0366
Intra group	0.0116833	9	0.00129815		
Total (Corrected)	0.0243667	11			

4. Discussion

In this section, the obtained results are discussed. Firstly, a detailed analysis of the observed effects in the different types of lawns is conducted. Subsequently, a comparison with existing literature is presented to highlight the contribution of this paper. Then, the main limitations of this study are identified and justified. Finally, the potential benefits of the tested products in the sustainability of grasses are summarised.

4.1. *General findings*

In Table 22, we summarise the observed trends throughout this study. It is evident that the treatment without the superabsorbent polymer has decreased the water content of the soil, while the treatment with the polymer increases soil moisture. In almost all treated soils, there has been an increase in EC. Conversely, marginal increases are

Table 22
Summary of observed effects.

Studied area and treatment	Soil moisture (%)	EC (μS/cm)	Temperature (°C)	NDVI
Sportive Grass – T1	General increase of ≈ 10 %[a]	Moderate increase of ≈ 12 %	Marginal increase 0.6 % -	n.e.
Sportive Grass – T2	n.e.	n.e.	Marginal increase of ≈ 0.2 %	n.e.
Gardening Grass Regular Irrigation – T1	General increase of ≈ 10 %[a]	General increase of ≈ 23.3 %[a]	Marginal increase of ≈ 0.5 %	Marginal increase of ≈ 3 %
Gardening Grass Regular Irrigation – T2	Marginal reduction of ≈ 0.3 %	Moderate increase of ≈ 8.5 %	Marginal increase of ≈ 0.5 %	Marginal increase of ≈ 4 %
Gardening Grass Reduced Irrigation – T1	General increase of ≈ 10 %[a]	General increase of ≈ 46.6 %[a]	Marginal increase of ≈ 1 %	Marginal increase of ≈ 2.5 %[a]
Gardening Grass Reduced Irrigation – T2	Marginal reduction of ≈ 0.1 %	Moderate increase of ≈ 5 %	n.e.	Marginal increase of ≈ 5 %

[a] Indicates that effect was significant, n.e. indicate no effect. Different patterns (solid or dotted) indicate the positive or negative effect, and the colour intensity reflects the effect's intensity.

found for both soil temperature and grass NDVI. In the following subsections, we detail the effects of each individual parameter and present our possible explanations for the trends observed.

4.1.1. Effect of treatments on soil moisture

A summary of soil moisture values for all areas and treatments is presented in Fig. 14. According to the obtained results, treatment 1 has a significant and similar effect on soil moisture in all the tested lawns: the chipping green and in the gardening lawns with regular or reduced irrigation, with an average moisture increase of 10 %. The greatest effect of this treatment was observed in the chipping green in the month of August, with an increase in soil moisture of 26.4 % over the control. This treatment, composed of the moisturiser and the nutritional complement, has a positive effect in increasing soil moisture.

As expected, treatment 2, which does not include the moisturiser, has no significant effect on soil moisture across the tested areas. Although sporadically, this treatment has increased soil moisture in May and September in sportive lawns and in July in gardening lawns. In some specific cases, however, this treatment has led to a decrease in soil moisture compared to the control. This decrease is particularly noticeable in gardening lawns with both regular and reduced irrigation in June and September. The same effect is observed in sports lawns in August. It appears to not correlate with baseline values of moisture or with changes in soil temperature, EC, or NDVI. This effect should be investigated in more detail in the future to explore other possible explanations for this irregular effect.

A possible explanation is the potential increase in the biological activity of the grasses due to the nutrients from the biostimulant, which may result in greater water consumption by the plant. The effect of biostimulants on increased plant activity might not be evident in treatment 1 due to the moisturising effect of superabsorbent polymers. Therefore, it is conceivable that higher moisture values may be observed when using the moisturiser without a biostimulant. Consequently, the fact that treatment 1 leads to a direct increase in soil moisture, which is not observed in treatment 2, clearly indicates the potential of moisturisers for enhancing soil moisture.

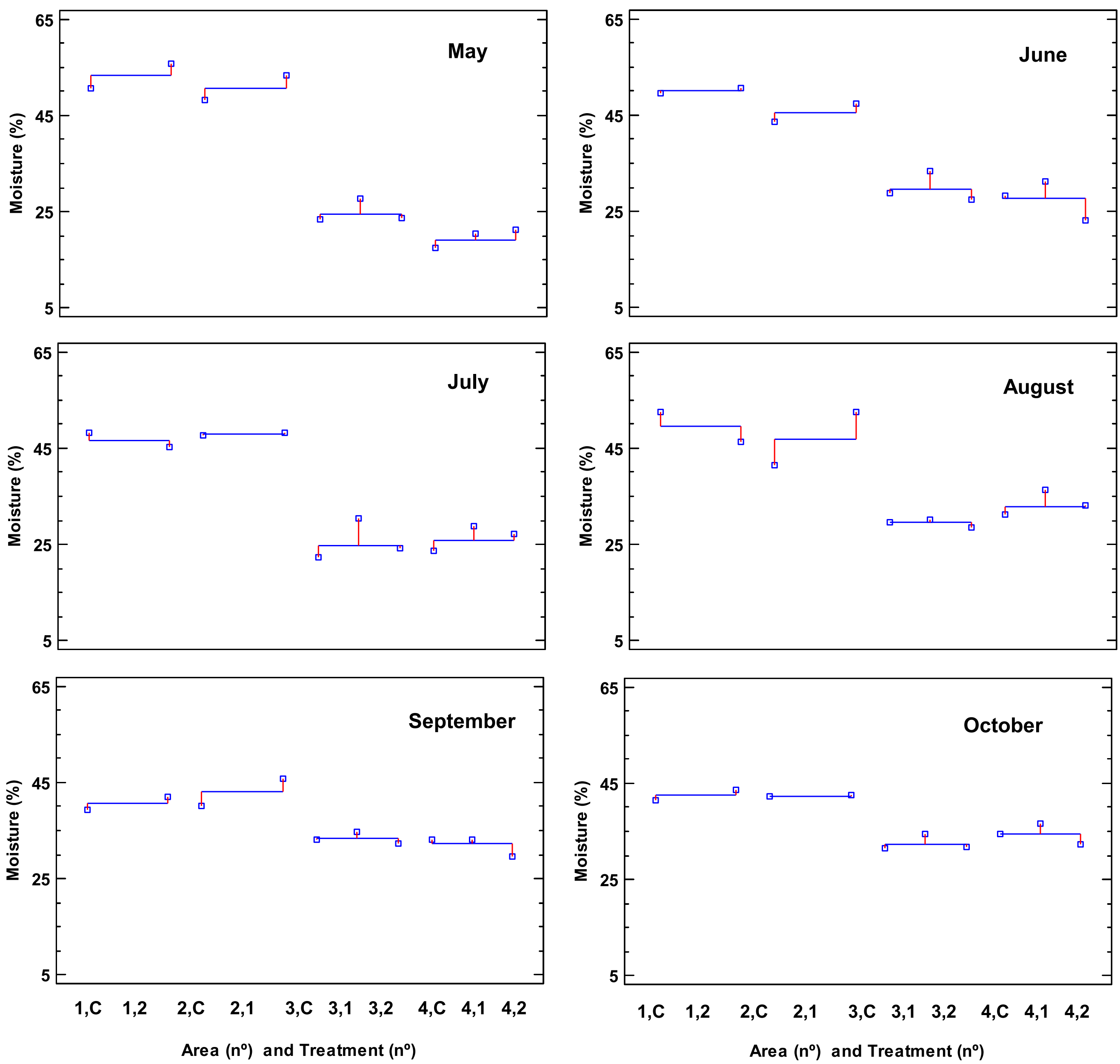

Fig. 14. Soil moisture in all tested lawns under control, treatment 1, and treatment 2 along studied period.

4.1.2. Effect of treatments on soil EC

A summary of EC values across all areas and treatments is presented in Fig. 15. According to the findings, treatment 1 has a significant impact on soil moisture levels in gardening lawns, although the same positive effect is also observed for sportive turfgrass, although it is not significant. Among the gardening lawns, the increase in soil EC is higher in turfgrass with reduced irrigation (an increase of 46.6 % compared to the control) than in regular irrigation (an increase of 23.3 % compared to the control). This increase in soil EC, which is double in lawns with irrigation restrictions, might be strongly related to the provided water in irrigation. This is confirmed by the data from sportive lawns, where the increment of EC is 12 %. In sportive lawns, the irrigation provided is higher than for gardening lawns. The most significant effect of this treatment was observed in the chipping green area during August, with a remarkable 98.9 % rise in EC moisture compared to the control group. Thus, we can confirm that treatment 1 implies an increment of soil EC, which seems to be inversely proportional to the amount of provided irrigation.

On the other hand, treatment 2, lacking the moisturiser component, does not exhibit a significant effect on soil moisture levels across the tested areas. Even though the averaged values indicate increments of EC in gardening soils (from 8.5 to 5 % in regular and reduced irrigation), analysing data individually shows no general trend. Conversely, in some cases, treatment 2 has led to a reduction in EC moisture compared to the control in sport lawns in August, with a reduction of more than 27.5 % compared to the control. Even with this strong reduction, the effect was not significant. This irregular trend seems unrelated to changes in soil moisture, as the irregular change in EC values of soil with treatment 2 was caused by the decrease in soil moisture for the same date. Further investigation is necessary to explore alternative explanations for this irregular effect.

4.1.3. Effect of treatments on soil temperature

According to the obtained values and their analyses, it is possible to

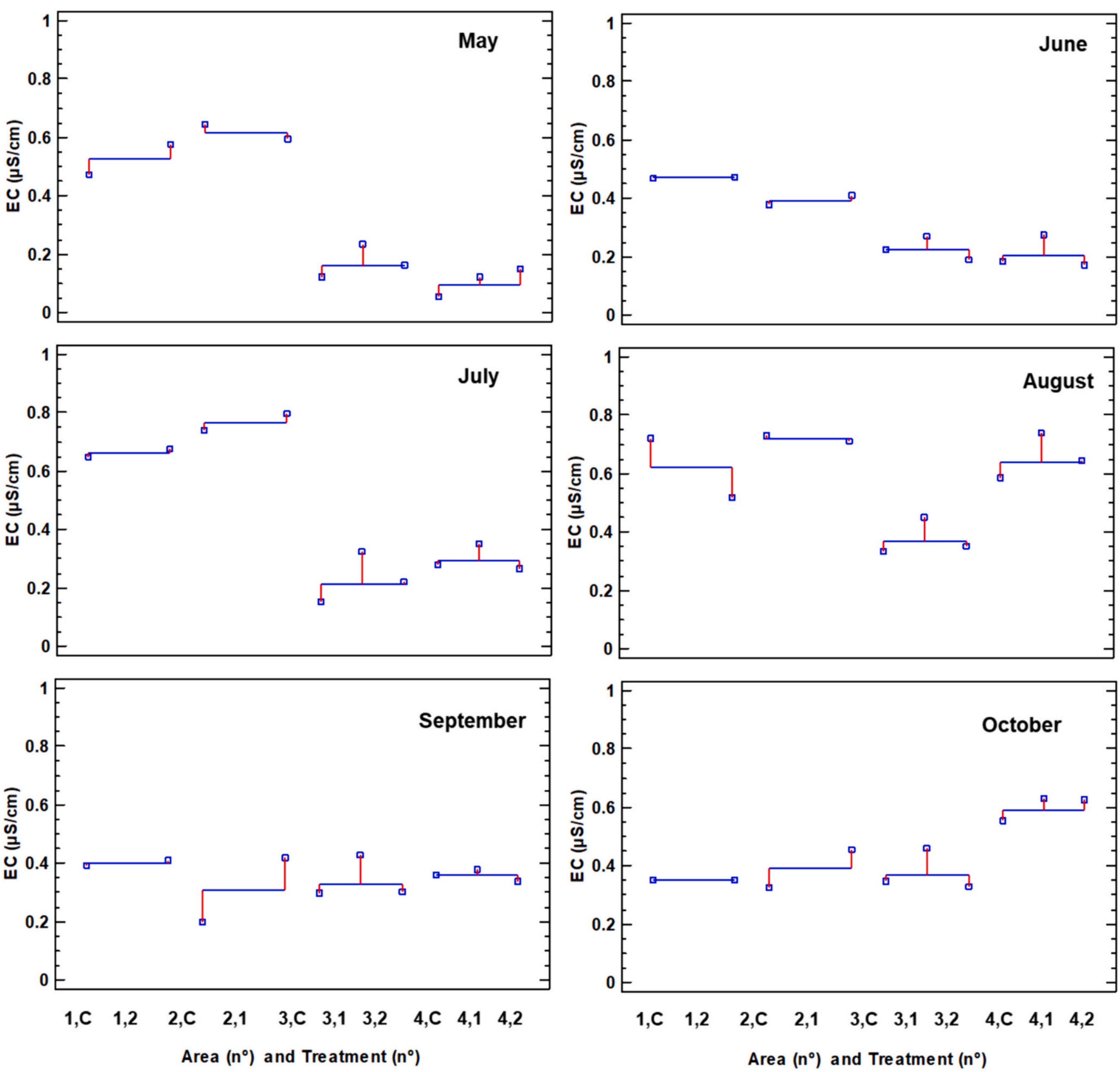

Fig. 15. Soil EC in all tested lawns under control, treatment 1, and treatment 2 along studied period.

confirm that the increment of soil EC is mainly caused by treatment 1; see Fig. 16. The presence of polymers in the moisturiser, which can be polar macromolecules, can directly impact the conductivity of the water if they are water-soluble polymers. Moreover, the moisturiser increases the water content of the soil, which directly affects the soil EC. As mentioned above, it must be noted that the use of treatment with the moisturiser should be evaluated properly in order to avoid excessive EC, which can be harmful to the turfgrass.

In general terms, the averaged data indicates that both treatments marginally increased the soil temperature, even though this effect is not significant in most cases; the increase is only significant in the sportive grass with treatment 1. The increment in soil temperature never surpasses 1 %. Nevertheless, when individual data is checked, the results indicate that the effect on temperature is exceptionally irregular, as can be seen in Fig. 16. According to the literature, the measurement moment and the environmental variables strongly affect soil temperature. Thus, the different environmental conditions on different days might explain part of the observed variability.

4.1.4. *Effect of treatments on NDVI*

A summary of the NDVI values across the entire study is illustrated in Fig. 17. The results suggest that neither of the treatments had any effects on sportive lawns. Meanwhile, both treatments marginally increased the NDVI values for gardening grasses compared to the control.

This effect is particularly notable in July and August, the months in which the grass is exposed to higher temperatures and higher evapotranspiration, leading to stress. During this period, treatment 1 raised the NDVI by 12.5 % and 16.0 % compared to the control, and treatment 2 increased the NDVI by 9.0 % and 11.4 % in July and August.

Moreover, this effect has not been found in treatment 2 for these dates. In fact, treatment 2 in June increased the NDVI by 7.2 % compared with the control. Thus, we can suggest that treatment 2, which does not affect soil moisture, can potentially benefit the initial development of C4 growth in the heat- and drought-tolerant species.

4.2. *Comparison with literature*

The effect of biostimulants and water-retaining agents has been widely studied with variable results. Nonetheless, in this subsection, we are going to compare our main results with existing literature on biostimulants and water-retaining agent agents, mainly in lawns.

Multiple authors have studied the positive effect of water-retaining agents on soil moisture. Our results suggest that the increment of soil moisture is about 10 % with the given dose compared to the control and

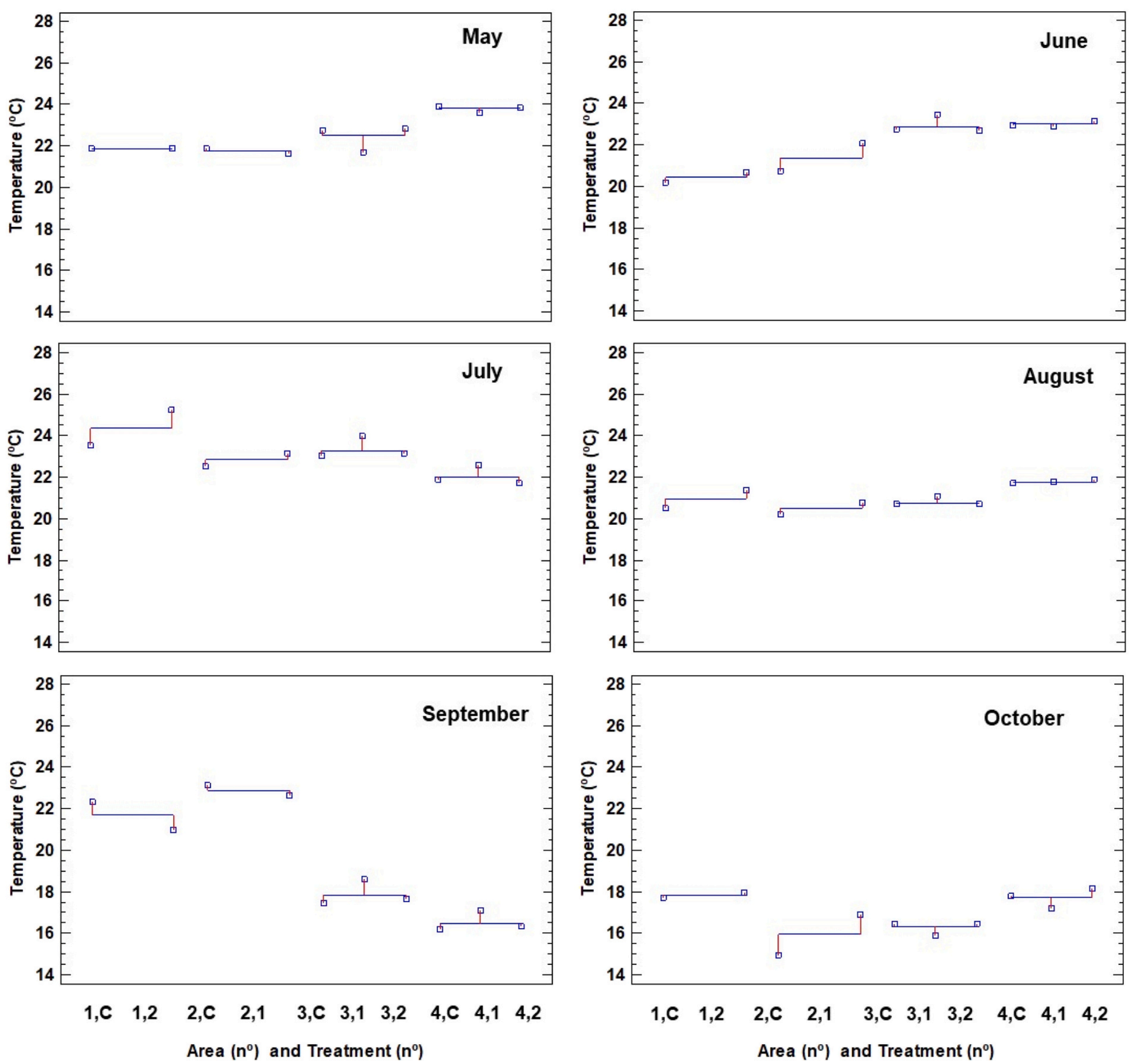

Fig. 16. Soil temperature in all tested lawns under control, treatment 1, and treatment 2 during the studied period.

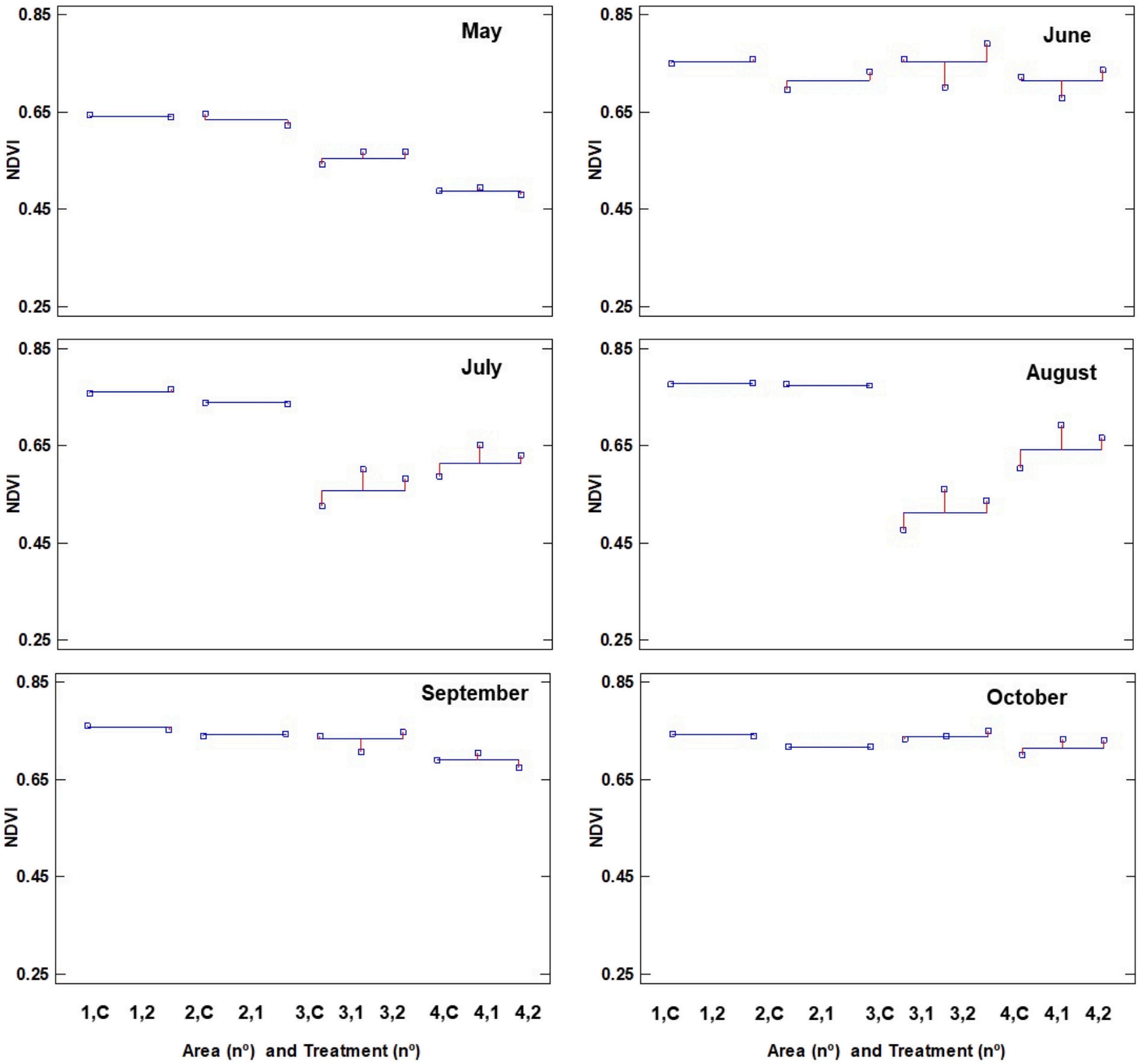

Fig. 17. Grass NDVI was in all tested lawns under control, treatment 1, and treatment 2 during the studied period.

improves the temporal and spatial uniformity of soil moisture. Several authors have pointed out the benefits of using polymer-coated, hydrophilic sand for topdressing in sandy soil and *D. dactylon*, demonstrating the increase in soil moisture uniformity (Alvarez et al., 2016).

Nevertheless, the application of the proposed product in this paper is easier and less time-consuming. Some studies demonstrate the significant benefits of treatments applied in liquid form, such as modified methyl-capped block copolymer and alkyl polyglucoside blended with a straight block copolymer (Schiavon et al., 2014) on soil moisture levels. Multiple wetting agents were evaluated with *C. dactylon* under hydric stress, and these products increased the volumetric water content of soil and soil moisture uniformity (Xiang et al., 2021), while similar studies indicated an irregular soil moisture increase (Serena et al., 2018). Nevertheless, there is huge variability in the response of soil moisture for the different tested products, with a maximum soil moisture increment of 15 % (Xiang et al., 2021) and 32 % (Serena et al., 2018) when surfactants are combined with Trinexapac-Ethyl. Other authors (Shaddox & Unruh, 2020) indicate that the effect of wetting treatments on *C. dactylon* putting greens reduced the soil moisture, this effect being maximum in February and not significant in March to June, August, and October. Meanwhile, other studies indicated no effect of wetting agents on green soil moisture (DeBoer et al., 2020) or irregular effects with increases and decreases in soil moisture (Schiavon et al., 2019). Finally, some studies indicate an irregular effect according to the irrigation conditions, with soil moisture increasing only in reduced irrigation but with no effects on regular irrigation (Liu & Chan, 2015). Another study compared the use of Hydrophilic sands with surfactant liquid products to retain water moisture, with no significative effect on soil water content or its uniformity (Baliga et al., 2019). The authors of (Baliga et al., 2019) suggested that the type of soils used might have limited hydrophobicity, which minimises the effect of treatment.

Concerning *F. arundinacea*, the effects of diversity in the effects of superabsorbents (Rabbani Kheir Khah et al., 2019) on soil moisture. This diversity in the wetting agents' treatments was also observed in *A. stolonifera* (Song et al., 2019); in the first years of treatment, there were no differences, and in the second year, there were differences in some treatments. This irregular effect of wetting agent in *A. stolonifera* was also reported in greens using multiple products, and results indicate no effect on soil moisture (Bauer et al., 2017). The authors suggested the lack of water repellency in the trial area. In other studies, the effect of the wetting agent on greens of *A. stolonifera* was null (Thoms et al., 2021), even under reduced irrigation conditions (Golden et al., 2017). The reduction of soil moisture due to wetting agents is also reported in *A. stolonifera* (Aamlid & Pettersen, 2022; Laskowski et al., 2018).

Nonetheless, new research has proved that surfactants increased the soil moisture in *A. stolonifera* greens (Bigelow et al., 2024). Concerning soil moisture uniformity, surfactants indeed have a positive effect on *A.stolonifera* greens with sand soil, according to (Soldat et al., 2010).

Moreover, the data obtained pointed out an increment in the soil EC, which is related to the scheduled irrigation. Nevertheless, no references to this effect have been found in the literature, and it might be linked to the quality of irrigation water combined with the water-retaining agent.

Finally, we focus on the plan vigour. In this study, we found that both biostimulants increased the NDVI even though the effects were minimal and insignificant in the whole study period. Nevertheless, for summer, both biostimulants increased the NDVI, while in June and September, the treatment which increased the soil moisture decreased the NDVI and set the hypothesis that the delay in the decay of the C3 species might cause it. The study of biostimulants on mixed turfgrasses has not been well studied, and it is not possible to find a similar test to confirm our hypothesis. Biostimulant application in mixed grasses is mainly for forage application (Zielewicz et al., 2021), and the mixed species are not comparable with the tested ones. Additional studies of biostimulants were found in mixed lawns, but none of the species was C4 (Yousfi et al., 2021).

The application of biostimulants on individual turfgrass species has been widely studied. Different authors found that the quality of *C. dactilon* in different periods has increased with the addition of the effect of natural plant extracts (Bashir, 2015), amino acid-based biostimulants (De Luca & Gómez de Barreda, 2021), and seaweed extract (Zhang et al., 2022a). The parameters used to evaluate the turf quality were the colour, density, and uniformity (Bashir, 2015; De Luca & Gómez de Barreda, 2021) or chlorophyll (Zhang et al., 2022a). The NDVI, which represents an objective measure of grass quality and vigour, has been selected in our study. The effect of biostimulants was evaluated in the quality of *F. arundinacea* under drought stress with a positive effect of *Pseudomonas fluorescens* (Mahdavi et al., 2020) and humic substances (Zhang et al., 2003a; Zhang & Schmidt, 2000). Other authors (Guillard & Inguagiato, 2017) did not find any effect on the NDVI values of *F. arundinacea* and *P. pratensis* using different seaweed extracts and suggested that the effect might not be seen since severe stress did not affect the turf. This might explain the fact that our results only indicate differences in the NDVI in the summer period, where the hydric stress was greater. Regarding *P. arundinacea*, humic acid has proved to be an improvement in this aspect (Talar-Krasa & Świerszcz, 2015). As far as we are concerned, no biostimulant experiments were conducted on *B. dactyloides*. Concerning *A. stolonifera*, more studies are being conducted due to their interest in sportive green areas. The quality and chlorophyll content of the Creeping bentgrass has been improved by numerous biostimulants (Bosi et al., 2023), *Ascophyllum nodosum* extract (Zhang et al., 2023), humic acids (Zhang et al., 2003b; Zhang et al., 2022b), plant growth regulators and osmoregulants (Burgess & Huang, 2014). In general terms, the effects of biostimulants are more significant in pastures prone to stress. Since the sportive grasses were not under specific stress, no benefits of biostimulants have been detected in this study.

Nevertheless, the monthly evaluation of parameters, which leads to the hypothesis about the effects in mixed lawns, is not typical, and no data has been found which can confirm our explanation of the trends in the NDVI in June and September in gardening lawns. Thus, we suggest studying in detail this effect in future research with a particular focus on the decay of C3 and the emergence of C4 species in early summer in control and treated areas by checking the number of leaves from each species in a given portion of the lawn.

4.3. Limitation of conducted study

The primary limitation of our study is the absence of testing treatment 1 and treatment 2 in the same areas of the sports lawns. We initially selected the putting green and chipping green, anticipating similar responses due to the same grass species and soil composition. Nevertheless, the usage of these areas differs, influencing the controls' response in each location. Consequently, we categorised the greens into distinct areas, resulting in a lack of data on treatment 2 in the chipping green and treatment 1 in the putting green. Additionally, we acknowledge the limitation of not individually testing the soil amendments. Nonetheless, the limited testing area, particularly in the gardening lawns, prevented the addition of a third treatment.

Furthermore, while NDVI offers some insights into treatment effects on grasses, significant impacts were only observed with treatment 2 in gardening lawns with reduced irrigation. Therefore, it is imperative to incorporate additional metrics to comprehensively evaluate treatment effects. This may include assessing parameters that could indicate disturbances in C3 and C4 equilibrium, such as growth and density, especially in mixed lawns. Moreover, biochemical analyses like chlorophyll content or micro and macronutrient levels can provide valuable insights into plant dynamics. In mixed lawns, conducting these analyses while distinguishing between individuals of each species to discern their respective impacts is essential. Finally, having data with greater temporal resolution might offer valuable information on the plants and soil dynamics and the effect of treatments. Thus, in the future, the possibility of using monitoring technologies for the lawn (García et al., 2020; Marín et al., 2018) and soil (Diaz et al., 2024) will be assessed.

4.4. Potential benefits for sustainability of urban green areas and the Agenda 2030

The results of this study offer promising outcomes in the journey toward sustainable urban green areas. Enhancing soil moisture by 10 % through the use of tested soil amendments will lead to water savings in irrigation practices. Applying these soil liquid amendments to gardens and sports lawns can increase the volumetric water content, thereby reducing direct water usage. It is imperative to study the effect of adding these products on the water footprint of lawns. Considering that soil moisture has increased by 10 % when these products have been applied, it is feasible to consider the possibility of reducing irrigation requirements of the urban green areas with no direct impact on the quality of the green area. Thus, their application will contribute to the achievement of SDG 6. More specifically, it can contribute to Target 6.4. Increase water-use efficiency and ensure freshwater supplies and to indicator 6.4.1 Change in water-use efficiency over time, by reducing the required water for irrigation. These are some of the indicators and targets included in the description of the original SDGs. Other authors have adapted and proposed additional indicators for SDG 6, which exploits the potential synergies with other SDGs (Benson et al., 2020; Essex et al., 2020). Nevertheless, existing indicators are very generic and economic-based, ignoring water's social and environmental value and must be improved (Hellegers & van Halsema, 2021). Thus, indicators specific to agriculture are proposed (Heiba et al., 2023). The main problem when applying those indicators for the green areas is that these particular products do not provide economic profits or quantifiable products as a harvest. Therefore, specific indicators that consider lawn quality as a function of water and other inputs are necessary. Currently, the water footprint is the main tool used to evaluate the sustainability of green areas, but its application requires a high degree of expertise. The necessary tools for a correct and easy evaluation of green area sustainability the synergies and trade-offs of SDGs must be adequately explored. It must be noted that SDG 6 is the one with the highest number of interlinkages (Fronza et al., 2023), and these need to be assessed case by case, given local context specificities. Therefore, the potential relationship between irrigation management in green areas and the SDGs must be studied in more detail, and studies must be adapted to different locations and future scenarios.

Moreover, the increase in NDVI observed in gardening grasses with limited irrigation suggests that these products can potentially improve water efficiency in grasses. The combination of the biostimulant with the water retaining agent enhances the quality of turfgrass under water-stress conditions, while the effect of the biostimulant alone is minimised without a wetting agent. Again, this data indicates that reducing the water provided to urban lawns is possible. Water reduction is particularly important given the future water scarcity scenarios driven by climate change. Thus, these products might be a promising option as a measure to mitigate the effect of climate change in urban areas.

Considering that both products can be diluted with water, they offer an easy application method that can be integrated into maintenance tasks in urban gardens. Considering these products might be applied manually, their application will not directly impact the carbon footprint. Moreover, considering that these products come from raw materials of vegetal production, their use contributes to a more sustainable production linked to SDG 12. Additionally, since neither supplement is regulated as a phytosanitary product, the limitations in terms of use and required certification for their application are less compared to other products.

If the requirements of urban green areas are reduced, it will be feasible to increase the surface for new areas, and the quality of existing ones will be improved. According to (Lorenzo-Sáez et al., 2021), the benefits of the green areas over SDG 11, SDG 13, and SDG 15 will be greater fi the surface of green areas and their aspect will increase. Therefore, the application of these products might indirectly contribute to the achievement of other SDGs.

It must be noted that the results of these tests should be contextualised in the meteorologic conditions of the studied area (Upper Mesomediterranean) and the particular conditions of the summer of 2023. Nevertheless, these results can be easily extrapolated to other regions with dry and hot summers, where water availability is limited and reduced irrigation is applied. The fact that the increment of soil moisture of 10 % when treatment 1 is applied is almost a constant among the studied plots (with diverse plants, soils, and irrigation regimes) is a clear indicator that the tested product might have a similar impact in other areas. Meanwhile, the varied increased conductivity indicates a clear dependence on external factors, and it must be considered in small pilot studies before recommending its general use in other regions or with other irrigation regimes.

To summarise the benefits of this research for the sustainability of green areas, the following recommendations:

(i) Using biostimulants and soil amendments in dry areas can help increase soil moisture by 10 % regardless of the reduced irrigation, facilitating a reduction of the water supply allocated for irrigation.
(ii) Soil amendments must be used carefully in soils with high conductivity or with reclaimed water irrigation, which generally has higher conductivity to avoid the need for flushing, which will reduce water efficiency.
(iii) High soil moisture at the beginning of the summer must be avoided if mixed lawns are grown to facilitate the C4 growth.
(iv) With tested doses, the NDVI has only increased in the month with the most extreme conditions (July and August) and only in gardening lawns; thus, their use might be suppressed in golf courses.
(v) Soil temperature might not be a useful variable for assessing the grass status or water efficiency due to its fast temporal variability and the problems of collecting data from different locations at the same time.

5. Conclusions

This paper aims to continue the numerous projects and studies related to the use of biostimulant products on different types of soil and grass meadows by monitoring data under different scenarios, thereby providing real information on the efficiency of their use. Two combinations of biostimulants have been tested, and data have been collected on their effects on two areas of grassland that are very different in terms of soil, type of grass, and maintenance carried out on them.

The most relevant data is the effect of the water-retaining product, which has caused an increase in soil moisture content of 10 % compared to the control in both types of meadows. The electrical conductivity value of the soil has also increased. The test data show that the value varies depending on the type of soil and irrigation provision it receives, increasing in greater amounts, in the order of double (23.3 %) in soils with heavy textures compared to sandy soils and also doubling its value (46.6 %) in grasslands with restricted water supplies (55 % of the required ETP). The efficiency is understood and corroborated since the water retaining agent contains polymers and penetrating agents to maintain the humidity of the roots, and the product II used aims to reduce the surface tension of the grass, favouring the infiltration and penetration of water, being more effective in gardening meadows than in sports. Temperature does not show significant differential behaviour in any of the cases studied.

The effects of the combined biostimulation on the plant, especially with the use of product III, should have reflected higher values in NVDI measurements, but these have not been demonstrated in any of the treatments carried out. The NDVI register differential values in meadows C3-C4 in transition dates, June, which could well mean greater resistance to the dominance of C4, not observing that behaviour in sports grass, C3 grasslands. This must be contextualised in the used grasslands with a correct phytosanitary state, without deficiencies or damages, which may encourage us not to differentiate ourselves too much.

All of this encourages us to continue working with the management of these products, both in doses and in active materials involved, in order to improve the physical environment and the physiology of the plant itself as an advance in the management of sports and ornamental green areas of our cities. Moreover, combining these products with less aggressive water irrigation regimes in gardening and sports lawns, with special attention to C3 and C4 interaction, must be studied. Finally, more information is needed in order to evaluate the real impact of these treatments on EC levels in the medium and long term, particularly in lawns with restricted irrigation; thus, the use of monitoring systems is foreseen.

CRediT authorship contribution statement

Lorena Parra: Writing – original draft, Methodology, Investigation, Conceptualization. **Jose F. Marin Peira:** Visualization, Validation, Investigation, Data curation. **Angel T. Lloret:** Visualization, Investigation. **Jaime Lloret:** Writing – review & editing, Visualization, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Aamlid, T. S., & Pettersen, T. (2022). Benefits of a soil surfactant on putting greens under dry and wet conditions. *International Turfgrass Society Research Journal, 14*(1), 157–168.

Alvarez, G., Sevostianova, E., Serena, M., Sallenave, R., & Leinauer, B. (2016). Surfactant and polymer-coated sand effects on deficit irrigated bermudagrass turf. *Agronomy Journal, 108*(6), 2245–2255.

Baliga, V. B., Young, J. R., & Carrillo, M. A. (2019). Evaluation of water retention products to conserve urban water resources in home lawns. *Crop, Forage & Turfgrass Management, 5*(1), 1–9.

Bashir, M. (2015). Natural plant extracts induced-alterations in growth, physiology and quality of turf grass (Cynodon dactylon) under summer stress. *Pakistan Journal of Science, 67*(3).
Bauer, S. J., Cavanaugh, M. J., & Horgan, B. P. (2017). Wetting agent influence on putting green surface firmness. *International Turfgrass Society Research Journal, 13*(1), 624–628.
Benson, D., Gain, A. K., & Giupponi, C. (2020). Moving beyond water centricity? Conceptualising integrated water resources management for implementing sustainable development goals. *Sustainability Science, 15*(2), 671–681.
Bigelow, C. A., Powlen, J. S., & Kostka, S. J. (2024). Localised dry spot recovery and water repellency in a sand golf green. In *Sandy soils* (pp. 245–253). Springer Nature Switzerland: Cham.
Bosi, S., Negri, L., Accorsi, M., Baffoni, L., Gaggia, F., Gioia, D. D., & Marotti, I. (2023). Biostimulants for sustainable management of sport turfgrass. *Plants, 12*(3), 539.
Burgess, P., & Huang, B. (2014). Effects of sequential application of plant growth regulators and osmoregulants on drought tolerance of creeping bentgrass (Agrostis stolonifera). *Crop Science, 54*(2), 837–844.
Chang, B., Wherley, B., Aitkenhead-Peterson, J., Ojeda, N., Fontanier, C., & Dwyer, P. (2020). Effect of wetting agent on nutrient and water retention and runoff from simulated urban lawns. *HortScience, 55*(7), 1005–1013.
Culpepper, T., Young, J., Montague, D. T., Sullivan, D., & Wherley, B. (2019). Physiological responses in C3 and C4 turfgrasses under soil water deficit. *HortScience, 54*(12), 2249–2256.
De Luca, V., & Gómez de Barreda, D. (2021). Effect of a biostimulant on bermudagrass fall color retention and spring green-up. *Agronomy, 11*(3), 608.
DeBoer, E. J., Karcher, D. E., McCalla, J. H., & Richardson, M. D. (2020). Effect of late-fall wetting agent application on winter survival of ultradwarf bermudagrass putting greens. *Crop, Forage & Turfgrass Management, 6*(1), Article e20035.
Diaz, F. J., Ahmad, A., Parra, L., Sendra, S., & Lloret, J. (2024). Low-cost optical sensors for soil composition monitoring. *Sensors, 24*(4), 1140.
Essex, B., Koop, S. H. A., & Van Leeuwen, C. J. (2020). Proposal for a national blueprint framework to monitor progress on water-related sustainable development goals in Europe. *Environmental Management, 65*, 1–18.
Fidanza, M., Kostka, S., & Bigelow, C. (2020). Communication of soil water repellency causes, problems, and solutions of intensively managed amenity turf from 2000 to 2020. *Journal Of Hydrology And Hydromechanics, 68*(4), 306–312.
Fleetwood, M. C. (2021). *Influence of various wetting agents on water status in USGA greens as determined by their physical properties* (Doctoral dissertation, University of Missouri—Columbia).
Fronza, V., Barbero Vignola, G., Borchardt, S., Valentini, S., Buscaglia, D., Maroni, M., & Marelli, L. (2023). *Uncovering SDG interlinkages: Interconnection at the core of the 2030 agenda*.
García, L., Parra, L., Jimenez, J. M., Lloret, J., Mauri, P. V., & Lorenz, P. (2020). DronAway: A proposal on the use of remote sensing drones as mobile gateway for WSN in precision agriculture. *Applied Sciences, 10*(19), 6668.
Golden, L. C., DaCosta, M., & Ebdon, J. S. (2017). Evaluation of Agrostis species and cultivars and a wetting agent for use on golf course fairways under reduced irrigation. *International Turfgrass Society Research Journal, 13*(1), 58–64.
Guillard, K., & Inguagiato, J. C. (2017). Normalised difference vegetative index response of nonirrigated Kentucky bluegrass and tall fescue lawn turf receiving seaweed extracts. *HortScience, 52*(11), 1615–1620.
Hale, L., Curtis, D., Azeem, M., Montgomery, J., Crowley, D. E., & McGiffen, M. E., Jr. (2021). Influence of compost and biochar on soil biological properties under turfgrass supplied deficit irrigation. *Applied Soil Ecology, 168*, Article 104134.
Heiba, Y., Nasr, M., Fujii, M., Mohamed, A. E., & Ibrahim, M. G. (2023). Improving irrigation schemes using sustainable development goals (SDGs)-related indicators: A case study of tomato production in pot-scale experimentation. *Environment, Development and Sustainability*, 1–27.
Hellegers, P., & van Halsema, G. (2021). SDG indicator 6.4. 1 "change in water use efficiency over time": Methodological flaws and suggestions for improvement. *Science of the Total Environment, 801*, Article 149431.
Ignatieva, M., Haase, D., Dushkova, D., & Haase, A. (2020). Lawns in cities: From a globalised urban green space phenomenon to sustainable nature-based solutions. *Land, 9*(3), 73.
Laskowski, K., Frank, K., & Merewitz, E. (2018). Surfactant effects on creeping bentgrass and annual bluegrass exposed to different irrigation and traffic stress treatments. *Agronomy Journal, 110*(1), 193–199.
Liu, X., & Chan, Z. (2015). Application of potassium polyacrylate increases soil water status and improves growth of bermudagrass (Cynodon dactylon) under drought stress condition. *Scientia Horticulturae, 197*, 705–711.
Lorenzo-Sáez, E., Lerma-Arce, V., Coll-Aliaga, E., & Oliver-Villanueva, J. V. (2021). Contribution of green urban areas to the achievement of SDGs. Case study in Valencia (Spain). *Ecological Indicators, 131*, Article 108246.
Mackiewicz-Walec, E., & Olszewska, M. (2023). Biostimulants in the production of forage grasses and turfgrasses. *Agriculture, 13*(9), 1796.
Mahdavi, S. M. E., Salehi, H., & Zarei, M. (2020). Morpho-physiological and biochemical attributes of tall fescue (Festuca arundinacea Schreb.) inoculated with Pseudomonas fluorescens under deficit irrigation. *Journal of Soil Science and Plant Nutrition, 20*, 1457–1471.
Marín, J., Parra, L., Rocher, J., Sendra, S., Lloret, J., Mauri, P. V., & Masaguer, A. (2018). Urban lawn monitoring in smart city environments. *Journal of Sensors, 2018*.
Marín, J., Yousfi, S., Mauri, P. V., Parra, L., Lloret, J., & Masaguer, A. (2020). RGB vegetation indices, NDVI, and biomass as indicators to evaluate C3 and C4 turfgrass under different water conditions. *Sustainability, 12*(6), 2160.
Pennisi, S. V., Habteselassie, M., Kostandini, G., & Waltz, F. C. (2022). Familiarity and use of biostimulants by the Georgia golf industry: Information from a survey of golf course superintendents. *HortTechnology, 32*(4), 382–387.
Rabbani Kheir Khah, S. M., Kazemi, F., & Shoor, M. (2019). Evaluating the effect of superabsorbents on soil moisture and physiological characteristics of *Lolium perenne* L. 'Chadegan' and *Festuca arundinacea*. *Desert, 24*(2), 229–240.
Ruíz-Pérez, M. R., Alba-Rodríguez, M. D., & Marrero, M. (2020). The water footprint of city naturalisation. Evaluation of the water balance of city gardens. *Ecological Modelling, 424*, Article 109031.
Schiavon, M., Leinauer, B., Serena, M., Maier, B., & Sallenave, R. (2014). Plant growth regulator and soil surfactants' effects on saline and deficit irrigated warm-season grasses: I. Turf quality and soil moisture. *Crop Science, 54*(6), 2815–2826.
Schiavon, M., Orlinski, P., Petelewicz, P., Pudzianowska, M., & Baird, J. H. (2019). Effects of trinexapac-ethyl, surfactant, and nitrogen fertilisation on bermudagrass water use. *Agronomy Journal, 111*(6), 3057–3066.
Schmidt-Traub, G., Kroll, C., Teksoz, K., Durand-Delacre, D., & Sachs, J. D. (2017). National baselines for the sustainable development goals assessed in the SDG index and dashboards. *Nature Geoscience, 10*(8), 547–555.
Serena, M., Sportelli, M., Sevostianova, E., Sallenave, R., & Leinauer, B. (2018). Combining trinexapac-ethyl with a soil surfactant reduces bermudagrass irrigation requirements. *Agronomy Journal, 110*(6), 2180–2188.
Shaddox, T. W., & Unruh, J. B. (2020). Do wetting agents influence golf ball roll distance? *HortTechnology, 30*(3), 404–410.
Soldat, D. J., Lowery, B., & Kussow, W. R. (2010). Surfactants increase uniformity of soil water content and reduce water repellency on sand-based golf putting greens. *Soil Science, 175*(3), 111–117.
Song, E., Pan, X., Kremer, R. J., Goyne, K. W., Anderson, S. H., & Xiong, X. (2019). Influence of repeated application of wetting agents on soil water repellency and microbial community. *Sustainability, 11*(16), 4505.
STATGRAPHICS Centurion XVIII Software. Available at: https://statgraphics.net/descar-gas/. Last access on 25/02/2021.
Talar-Krasa, M., & Świerszcz, S. (2015). The influence of using biostimulant on the visual quality of turf. *Episteme, 26*, 365–373.
Talar-Krasa, M., Wolski, K., & Biernacik, M. (2019). Biostimulants and possibilities of their usage in grassland. *Grassland Science, 65*(4), 205–209.
Thoms, A., Pease, B., & Lindsey, A. J. (2021). Wetting agents on golf course surfaces. *Iowa State University Research and Demonstration Farms Progress Reports, 4*.
Trane, M., Marelli, L., Siragusa, A., Pollo, R., & Lombardi, P. (2023). Progress by research to achieve the sustainable development goals in the EU: A systematic literature review. *Sustainability, 15*(9), 7055.
Xiang, M., Schiavon, M., Orlinski, P., Forconi, A., & Baird, J. H. (2021). Identification of wetting agents for water conservation on deficit-irrigated hybrid bermudagrass fairways. *Agronomy Journal, 113*(5), 3846–3856.
Yousfi, S., Marín, J., Parra, L., Lloret, J., & Mauri, P. V. (2021). A rhizogenic biostimulant effect on soil fertility and roots growth of turfgrass. *Agronomy, 11*(3), 573.
Zhang, J., Virk, S., Porter, W., Kenworthy, K., Sullivan, D., & Schwartz, B. (2019). Applications of unmanned aerial vehicle based imagery in turfgrass field trials. *Frontiers in Plant Science, 10*, 279.
Zhang, X., & Schmidt, R. E. (2000). Hormone-containing products' impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. *Crop Science, 40*(5), 1344–1349.
Zhang, X., Ervin, E. H., & Schmidt, R. E. (2003a). Seaweed extract, humic acid, and propiconazole improve tall fescue sod heat tolerance and posttransplant quality. *HortScience, 38*(3), 440–443.
Zhang, X., Ervin, E. H., & Schmidt, R. E. (2003b). Physiological effects of liquid applications of a seaweed extract and a humic acid on creeping bentgrass. *Journal of the American Society for Horticultural Science, 128*(4), 492–496.
Zhang, X., Taylor, Z., Goatley, M., Booth, J., Brown, I., & Kosiarski, K. (2022a). Seaweed extract-based biostimulant impacts on nitrate reductase activity and root viability of ultradwarf bermudagrass subjected to heat and drought stress. *HortScience, 57*(10), 1328–1333.
Zhang, X., Goatley, M., McCall, D., Kosiarski, K., & Reith, F. (2022b). Humic acids-based biostimulants impact on root viability and hormone metabolism in creeping bentgrass putting greens. *International Turfgrass Society Research Journal, 14*(1), 288–294.
Zhang, X., Taylor, Z., Goatley, M., Wang, K., Brown, I., & Kosiarski, K. (2023). Photosynthetic rate and root growth responses to Ascophyllum nodosum extract–based biostimulant in creeping bentgrass under heat and drought stress. *HortScience, 58*(8), 917–921.
Zielewicz, W., Swędrzyński, A., Dobrzyński, J., Swędrzyńska, D., Kulkova, I., Wierzchowski, P. S., & Wróbel, B. (2021). Effect of forage plant mixture and biostimulants application on the yield, changes of botanical composition, and microbiological soil activity. *Agronomy, 11*(9), 1786.