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Tolerance of Tall Fescue (*Festuca arundinacea* Schreb.) Growing in Extensive Green Roof Systems to Saline Water Irrigation with Varying Leaching Fractions

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Abstract: As urbanization intensifies environmental challenges in contemporary cities, widespread green roof installations emerge as a potential solution. This study explores irrigating tall fescue (*Festuca arundinacea* Schreb.) turfgrass with saline water in extensive green roof systems, aiming to conserve freshwater resources. The objectives include determining the period of saline water tolerance and identifying the leachate electrical conductivity threshold affecting tall fescue's green coverage. This greenhouse study comprised 24 lysimeters equipped with extensive green roof layering. Treatments included three NaCl irrigation solutions with an electrical conductivity of 3 dS m^{-1}, 6 dS m^{-1}, and 9 dS m^{-1}, while tap water served as the control. Additionally, irrigation treatments were applied at two different regimes, resulting in an average leaching fraction of 0.3 for the low irrigation regime and 0.5 for the high irrigation regime. Tall fescue's tolerance to saline water was evaluated through the determination of green turf cover (GTC) as well as the clipping dry weight and the leachate electrical conductivity (EC_L) draining from the lysimeters. It was found that tall fescue turfgrass growing in extensive green roof systems can tolerate irrigation with water of electrical conductivity up to 9 dS m^{-1} for extended periods, approximating three months, without GTC declining below 90%, provided that a minimum leaching of 30% is maintained. Furthermore, irrigating with water at 9 dS m^{-1} resulted in a 24.5% reduction in cumulative clipping dry weight over the four-month study period. The regression analysis between GTC and EC_L highlighted a substantial decline in GTC when EC_L surpassed the critical threshold of 12.5 dS m^{-1}.

Keywords: clipping dry weight; green turf cover; lysimeter; salt tolerance; turfgrass management; urban horticulture

Citation: Ntoulas, N.; Papaioannou, G.; Bertsouklis, K.; Nektarios, P.A. Tolerance of Tall Fescue (*Festuca arundinacea* Schreb.) Growing in Extensive Green Roof Systems to Saline Water Irrigation with Varying Leaching Fractions. *Land* **2024**, *13*, 167. https://doi.org/10.3390/land13020167

Academic Editor: Amrakh I. Mamedov

Received: 18 December 2023
Revised: 27 January 2024
Accepted: 29 January 2024
Published: 31 January 2024

1. Introduction

The global trend toward urbanization has resulted in a dramatic increase in impervious surfaces, leading to a range of environmental issues [1]. The challenges faced by cities, such as the urban heat-island effect, stormwater runoff, and air pollution, have prompted the exploration of innovative solutions [2,3]. In response, green roof systems have emerged as a promising solution, offering numerous benefits. These vegetated roofs, composed of specialized substrates and a variety of plant species, serve as living ecosystems on top of man-made structures, functioning as natural insulators. They play a crucial role in reducing energy consumption for heating and cooling while also lowering ambient temperatures through plant evapotranspiration [4,5]. Furthermore, green roofs act as natural sponges, reducing both the volume and velocity of stormwater runoff, which is crucial for alleviating strain on urban drainage systems [6]. Additionally, they filter pollutants, enhancing urban aesthetics and providing habitats for diverse flora and fauna [7,8].

Extensive green roofs, characterized by a substrate depth of less than 15 cm, are typically planted with low-maintenance, shallow-rooting, and drought-resistant plants, such as succulents or other xerophytic species [9,10]. The use of turfgrasses, which fulfill aesthetic, functional, and recreational requirements in urban environments [11], has been rarely studied in shallow green roof systems, especially in arid and semi-arid climates where they demand more water compared to succulents and xerophytic plants. Studies on turfgrass performance and irrigation needs in extensive green roof systems have been limited primarily to the Mediterranean region. Nektarios et al. [12] investigated the drought tolerance of tall fescue (*Festuca arundinacea* Schreb. 'Plantation') on extensive green roofs and suggested that a substrate depth of 7.5 cm could be used without significantly stressing the turfgrass plants under 85% evapotranspiration-based irrigation. Ntoulas et al. [13] evaluated the response of three warm-season grasses (hybrid bermudagrass, *Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy 'MiniVerde'; seashore paspalum, *Paspalum vaginatum* Swartz 'Platinum TE'; and zoysiagrass, *Zoysia japonica* Steud. 'Zenith') at two substrate depths (7.5 cm and 15 cm) under 65% evapotranspiration-based irrigation. They reported that zoysiagrass appears to be one of the best options for creating an aesthetically pleasing and accessible surface on extensive green roofs, as it performed well even with a shallow substrate depth of 7.5 cm. In contrast, hybrid bermudagrass required a minimum of 15 cm of substrate to achieve acceptable green coverage, while seashore paspalum faced greater challenges even with a 15 cm substrate depth. Furthermore, Ntoulas et al. [14] found that for manilla grass (*Zoysia matrella* (L.) Merr. 'Zeon') to be established on extensive green roofs and maintain more than 50% green coverage, the substrate moisture content (SMC) should be kept higher than 13% (v/v). For seashore paspalum, when grown on extensive green roofs, the SMC should be retained from 23.7 to 28.5% (v/v) to ensure acceptable NDVI values [15].

In arid and semi-arid regions such as the Mediterranean, where rainfall is typically absent during the summer months, additional irrigation is necessary to sustain lush green turfgrasses growing on extensive green roofs [16]. However, the use of freshwater for irrigating greenery in these regions has raised environmental concerns. Consequently, alternative water sources, such as saline water, grey water, and recycled stormwater runoff, have been explored for green roof irrigation [17–19]. In rare cases, seawater has also been proposed as an alternative source of green roof irrigation [20,21]. Saline irrigation water sources include naturally saline groundwater as well as groundwater salinized due to salt leaching or seawater intrusion into the aquifer. Additionally, brackish surface water, grey water, saline sewage effluent, and reclaimed or recycled water are considered options [22].

The ability to utilize low-quality water for turfgrass irrigation has been evaluated by several researchers, particularly upon natural soil or sand-based artificial substrates [23–25]. However, it is worth considering that green roofs offer a more suitable environment for saline water irrigation. Green roof substrates are typically coarse-textured, mainly composed of inorganic material such as pumice, crushed bricks or tiles, sand, zeolite, heat-expanded shale, clay or slate, perlite, and lava, which enhances their infiltration rates [26], facilitating salt leaching [22]. Leaching is a crucial practice for alleviating or preventing the salinity stress of turfgrasses irrigated with saline water [27]. This involves applying irrigation water in quantities that surpass the actual irrigation demands, as determined by evapotranspiration replenishment, promoting a consistent downward movement of salts [28].

Proper selection of turfgrass species when using saline irrigation water is of utmost importance when considering maintenance costs and turf quality [29]. Warm-season grasses are generally more salt tolerant than cool-season grasses [30]. However, winter dormancy periods encourage the preference for cool-season over warm-season species, since they can sustain their green color throughout the year. In the Mediterranean region, tall fescue [*Festuca arundinacea* Schreb. syn., *Schedonorus arundinaceus* (Schreb.) Dumort.] emerges as the preferred choice among cool-season grasses due to its drought avoidance and its tolerance to several abiotic stressors such as increased summer temperatures, shade, salinity, and wear [31]. Several researchers have classified tall fescue as moderately salt-tolerant, capable of withstanding soil salinity levels of up to 10 dS m^{-1} [32–34].

Based on the above, it would be interesting to investigate the possibility of using saline water to irrigate tall fescue when grown on extensive green roofs, aiming to conserve freshwater reserves. The objective of this study is two-fold: (i) to determine the period during which tall fescue grown on extensive green roofs can tolerate irrigation with saline water of various levels without compromising its growth and green coverage and (ii) to identify a threshold value of leachate electrical conductivity beyond which the green coverage of tall fescue begins to decline.

2. Materials and Methods

2.1. Experimental Setup

This research was conducted in the experimental greenhouse of the Laboratory of Floriculture and Landscape Architecture, Agricultural University of Athens, Athens, Greece (37°59′ N and 23°42′ E, 30 m a.s.l.) from 5 December 2019 to 30 May 2020. The experimental setup was similar to that of a previous study by the authors [20]. It involved 24 polyvinyl chloride (PVC) lysimeters with an inner diameter of 300 mm and a surface area of 0.07 m^2 (Figure 1), arranged on levelled benches. Each lysimeter had a central outflow opening with a diameter of 10 mm at the bottom. A flexible hose was attached to the outlet, directing the leachate into a 2 L tank positioned beneath each lysimeter. A complete layered simulation of an extensive green roof system was established within the lysimeters (Figure 1). Specifically, a protection mat (VLS-500, DIADEM, Landco Ltd., Athens, Greece) capable of retaining 3.6 L m^{-2} of water was placed at the bottom of the lysimeters. This mat, made of non-rotting synthetic fibers, had a 4 mm thickness, a dry weight of 0.5 kg m^{-2}, and a water permeability of 50 mm s^{-1}. A drainage board layer with a height of 25 mm and a weight of 1.35 kg m^{-2} (DiaDrain-25H, DIADEM, Landco Ltd.) was placed on top of the protective mat. The drainage layer, constructed from recycled high-impact polystyrene, featured water-retentive troughs with an 11.8 L m^{-2} water-holding capacity and openings to enhance subsurface aeration. A non-woven geotextile (VLF-150, DIADEM, Landco Ltd.) with a thickness of 1.2 mm, a weight of 150 g m^{-2}, and a water permeability of 105 mm s^{-1} covered the drainage layer. The geotextile prevented fine particle migration from the substrate towards the drainage layer, ensuring its proper function.

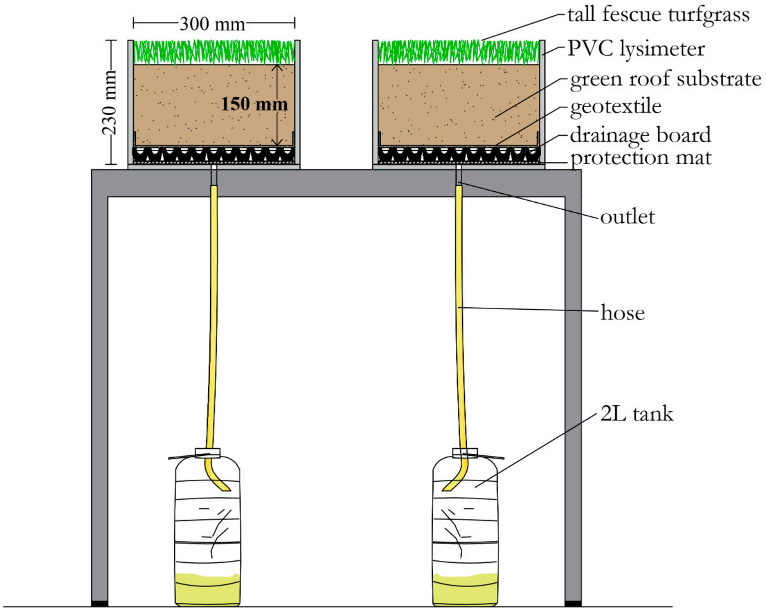

Figure 1. Construction detail of the experimental lysimeters illustrating the various layers of the extensive green roof system.

A green roof substrate (Patent No. 1008610) was added into the lysimeters to a depth of 15 cm, comprising 65% pumice, 15% thermally treated attapulgite clay, 15% composted grape marc, and 5% clinoptilolite zeolite. Table 1 lists the chemical and physical characteristics of the substrate. After placement in the lysimeters, the substrates were subjected to light compression and levelling.

Table 1. Physical and chemical properties of the substrate, which comprised 65% pumice, 15% thermally treated attapulgite clay, 15% grape marc compost, and 5% clinoptilolite zeolite by volume.

Parameter	Units Measured	Value
pH ($CaCl_2$)		7.2
Electrical conductivity (water, 1:10, m:v),	dS m^{-1}	0.60
Dry bulk density	kg L^{-1}	0.80
Bulk density at maximum water-holding capacity	kg L^{-1}	1.20
Total pore volume	%	63.8
Maximum water-holding capacity	% (*v*/*v*)	54.2
Hydraulic conductivity	mm min^{-1}	7.62
Organic matter content	% (*w*/*w*)	10.5
Phosphorus, P_2O_5 (CAL)	mg L^{-1}	112.6
Potassium, K_2O (CAL)	mg L^{-1}	578.6
Magnesium, Mg ($CaCl_2$)	mg L^{-1}	289.3
Nitrate + ammonium ($CaCl_2$)	mg L^{-1}	10.4
Particle size analysis:		
9.5–6.3 mm	% (*w*/*w*)	1.9
6.3–3.2 mm	% (*w*/*w*)	23.6
3.2–2.0 mm	% (*w*/*w*)	17.3
2.0–1.0 mm	% (*w*/*w*)	25.9
1.0–0.25 mm	% (*w*/*w*)	20.4
0.25–0.05 mm	% (*w*/*w*)	4.4
0.05–0.002 mm	% (*w*/*w*)	5.4
<0.002 mm	% (*w*/*w*)	1.1

2.2. Turfgrass Establishment

Tall fescue was established in the lysimeters on 5 December 2019 using washed sod sourced from a local sod farm. The sod consisted of a seed blend that included various tall fescue varieties. Tall fescue is a cool-season turfgrass species that is classified as an excellent choice for transitional climatic zones. For 57 days, until the initiation of saline water treatments (31 January 2020), lysimeters were irrigated daily with tap water (EC of 0.3 dS m^{-1}) to promote the adequate establishment of the turfgrass. During the establishment period, the turfgrass sward was mowed at a height of 50 mm at weekly intervals with a handheld electric shear mower (Bosch ISIO3; Robert Bosch GmbH, Gerlingen, Germany), and clippings were removed. Fertilization was applied as foliar applications of a water-soluble fertilizer (Nutrileaf, 20-20-20; Miller Chemical & Fertilizer Corp., Hanover, PA, USA) at a rate of 5 g L^{-1} m^{-2} every two weeks.

2.3. Greenhouse Climate Conditions

Air temperature and relative humidity inside the greenhouse were measured using a HOBO U23 Pro v2 data logger (Onset Computer Corporation, Bourne, MA, USA), placed at a height of 1.8 m near the lysimeters. Figure 2 presents the maximum, average, and minimum air temperature (°C) and the relative humidity (%) during the study period. The average temperature and relative humidity were 20.4 °C (±2.9 °C) and 57.3% (±7.7%), respectively.

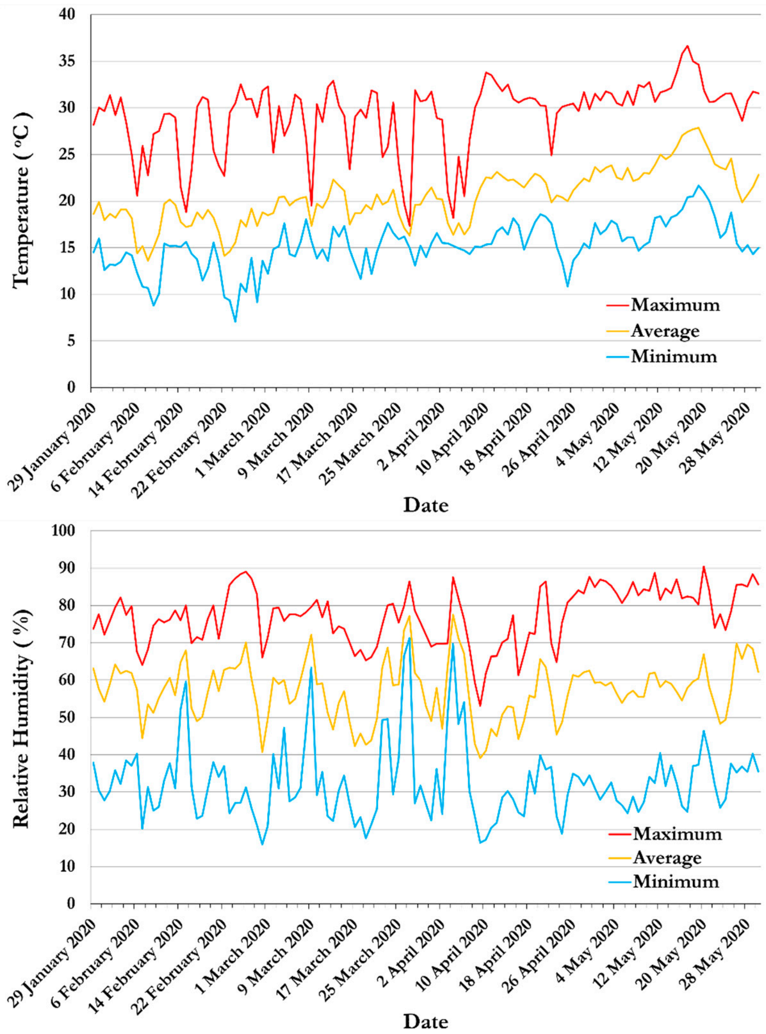

Figure 2. Greenhouse maximum, average, and minimum air temperature (°C) and relative humidity (%) during the study period (29 January–30 May 2020).

2.4. Turfgrass Maintenance and Irrigation Regimes

Saline water irrigation treatments commenced on 31 January 2020 and concluded on 30 May 2020, totalling 120 d of salinity stress. Two days before the initiation of the saline water irrigation period (29 January 2020), all lysimeters received thorough irrigation with abundant tap water (EC of 0.3 dS m^{-1}) to establish uniform substrate moisture conditions. Then, the turfgrass was irrigated every other day at two different depths, resulting in an average leaching fraction (LF) of 0.3 for the low irrigation regime and 0.5 for the high irrigation regime. Specifically, from 31 January 2020 to 17 March 2020, irrigation was applied at depths of 8 mm for high irrigation and 6 mm for low irrigation. From 19 March 2020 to 22 April 2020, irrigation was applied at depths of 10 mm for high irrigation and 8 mm for low irrigation, while from 24 April 2020 to the end of this study (30 May 2020), irrigation was applied at depths of 12 mm for high irrigation and 10 mm for low irrigation. The gradual increase in irrigation depth aimed to maintain a constant LF for both irrigation regimes as the greenhouse temperature increased (Figure 2). Specifically, from 29 January 2020 to 18 March 2020, the average air temperature inside the greenhouse was 18.3 °C. From 19 March 2020 to 23 April 2020, it increased to 20.3 °C, and from 24 April 2020 to 30 May 2020, it further increased to 23.5 °C.

To assess the impact of saline water irrigation on tall fescue growing on extensive green roofs, three irrigation solutions with an EC of 3, 6, and 9 dS m^{-1} were used, while tap water (EC of 0.3 dS m^{-1}) served as the control. To prepare the irrigation solutions, NaCl

(MW = 58.44, Scharlau Chemie, SA, Barcelona, Spain) was used, which was dissolved in tap water in appropriate amounts. A portable conductivity meter (Hanna HI98192, Hanna Instruments Inc., Woonsocket, RI, USA) was used to verify the EC values in each solution. To prevent salinity shock to the turfgrass from irrigation with solutions of high EC (3, 6, and 9 dS m^{-1}), at the first irrigation event of this study (31 January 2020), an irrigation solution of 1.5 dS m^{-1} was used for all salinity treatments. During subsequent irrigation events, the EC of the irrigation solutions increased by 1.5 dS m^{-1} until they reached the predetermined values of either 3, 6, or 9 dS m^{-1}. Subsequently, irrigation was implemented in accordance with the experimental setup, utilizing all three salinity solutions (3, 6, and 9 dS m^{-1}). Lysimeters were hand-irrigated using a nozzle to ensure even water distribution.

Throughout this study, turfgrass sward in each lysimeter was mowed at a height of 50 mm every 6 days with a handheld electric shear mower (Bosch ISIO3). The clippings were collected for dry weight determination after oven-drying for 48 h at 75 °C. Foliar fertilization was applied every two weeks with Nutrileaf, a 20-20-20 water-soluble fertilizer, at a rate of 5 g L^{-1} m^{-2}.

2.5. Measurements

The green turf cover (GTC) percentage was calculated throughout this study by taking digital images of each lysimeter on each irrigation date, following the methodology by Ntoulas and Varsamos [20]. The GTC was assessed through digital image analysis using SigmaScan Pro Version 5.0 software (Systat Software Inc., San Jose, CA, USA), as outlined by Richardson et al. [35].

The electrical conductivity of the leachate (EC_L), collected in tanks connected to each lysimeter, was measured every two days following irrigation events. For EC_L measurements, a handheld conductivity meter (Hanna HI98192) was used, with automatic EC correction to 25 °C.

2.6. Experimental Design and Statistics

The experimental layout followed a completely randomized design, with each treatment replicated three times, resulting in a total of 24 lysimeters (2 irrigation regimes × 4 irrigation salinities × 3 replications = 24 lysimeters). Data collected on the GTC, the clippings' dry weight, and EC_L during the salinity stress period were subjected to analysis of variance using JMP® ver.11 statistical software (SAS Institute Inc., Cary, NC, USA). Repeated measures analysis was conducted, with the irrigation regime as the main plot, irrigation salinity as the subplot, and time (sampling dates) as the sub-subplot. Treatment means were separated using Fisher's protected least significant difference (LSD) at a 0.05 probability level ($p < 0.05$).

The response of GTC to EC_L during the salinity stress period was analyzed using the segmented linear regression model presented by Ntoulas and Varsamos [20]. The GraphPad Prism software, version 6.01 for Windows (GraphPad Software Inc., San Diego, CA, USA), was utilized for conducting regression analysis [36].

3. Results and Discussion

3.1. Leachate Electrical Conductivity

The statistical analysis presented in Table 2 indicates a significant impact of the irrigation water's salinity on EC_L. According to Figure 3, the EC_L started to increase 12 days after the initiation of salinity stress (DAI), corresponding to the onset of regular irrigations using all three high-salinity solutions (3, 6, and 9 dS m^{-1}), according to the experimental setup. Subsequently, from 12 DAI, a continuous increase in EC_L was observed for all three high-salinity irrigation water treatments. Significant differences between irrigation salinity treatments were noted at 18 DAI, with irrigation using water with 9 dS m^{-1} exhibiting higher EC_L values compared to the other irrigation treatments. A clear separation was evident from 34 DAI until the end of this study. Specifically, irrigation with water of 9 dS m^{-1} presented the highest EC_L values, followed by irrigation with water at 6 dS m^{-1}, while the lowest values from the high salinity treatments were recorded for irrigation with water of 3 dS m^{-1}.

Table 2. Results of analysis of variance and table of means for leachate electrical conductivity, green turf cover, and cumulative clipping dry weight of tall fescue, across two irrigation regimes (high or low) and four irrigation water salinities (tap water, 3, 6, and 9 dS m^{-1}), following the repeated measures analysis, with irrigation regime being the main plot, irrigation salinity the subplot, and time (sampling dates) the sub-subplot. Means derived from pooled data over the whole salinity stress period (31 January–30 May 2020).

Source of Variation	Leachate Electrical Conductivity (dS m^{-1})	Green Turf Cover (%)	Cumulative Clipping Dry Weight (g m^{-2})
Irrigation regime (I)	NS	NS	*
Irrigation salinity (S)	***	***	***
I × S	NS	NS	NS
Sampling date (T)	***	***	***
I × T	***	***	*
S × T	***	***	***
I × S × T	***	NS	NS
Treatment means			
Irrigation regime			
High	6.45 a	93.71 a	121.42 a
Low	5.98 a	92.69 a	117.13 b
LSD	0.80	1.61	2.25
Irrigation salinity			
Tap water	0.66 d	95.10 a	132.38 a
3 dS m^{-1}	4.60 c	94.26 ab	126.46 a
6 dS m^{-1}	8.17 b	92.81 b	113.42 b
9 dS m^{-1}	11.42 a	90.63 c	104.83 b
LSD	0.40	1.79	9.25

NS, *, ***: Non-significant at the 0.05 probability level or significant at the 0.05 and 0.001 probability level, respectively. Means in columns followed by the same letter are not significantly different at $p < 0.05$ using Fisher's least significant difference (LSD).

Equalization of EC_L with the salinity of the irrigation water was observed around 52–54 DAI. Subsequent high-salinity irrigation applications resulted in further increase in EC_L until 108 DAI. Afterward, the EC_L values stabilized, showing no further increase until the end of this study, with values close to 9 dS m^{-1} for irrigation with water at 3 dS m^{-1}, 16 dS m^{-1} for irrigation with water at 6 dS m^{-1}, and 22 dS m^{-1} for irrigation with water at 9 dS m^{-1}. In contrast, EC_L values for lysimeters exclusively irrigated with tap water exhibited a consistently stable pattern during this study, maintaining relatively low levels (<1 dS m^{-1}). The EC_L values observed toward the end of the salinity stress period closely matched the values predicted by the steady-state salt balance equation: $EC_{\text{drainage water}} = EC_{\text{irrigation water}}/LF$ [37], based on the irrigation water EC and the mean LF for the two irrigation regimes.

Regarding the two different irrigation regimes, during the first 78 DAI, the higher irrigation regime exhibited a more rapid rate of increase, resulting in significantly higher EC_L values compared to the lower irrigation regime from 20 DAI until 68 DAI. However, after 78 DAI, where the EC_L values of the two irrigation regimes equalized, a reversal trend was observed between the two. Specifically, when irrigation was applied at the lower regime, EC_L values continued to increase at a constant rate, while the EC_L for irrigation with the higher regime exhibited a slower increase rate, leading to significantly lower EC_L values from 88 DAI until the end of the stress period. A similar reverse response in EC_L was observed by Ntoulas and Varsamos [20] when two varieties of seashore paspalum were grown in shallow green roof substrates and irrigated with seawater at different irrigation regimes. Under the low irrigation regime of 7 mm, the EC_L exhibited a gradual and consistent rise, attributed to the ongoing accumulation of salts within both the green roof substrate and the drainage layers, reaching values significantly higher than the salinity of the seawater used as the irrigation source. Conversely, under the excessive irrigation regime of 45 mm, the EC_L experienced a sharp increase, yet it facilitated constant leaching of salts, keeping the EC_L nearly equivalent to the EC of seawater.

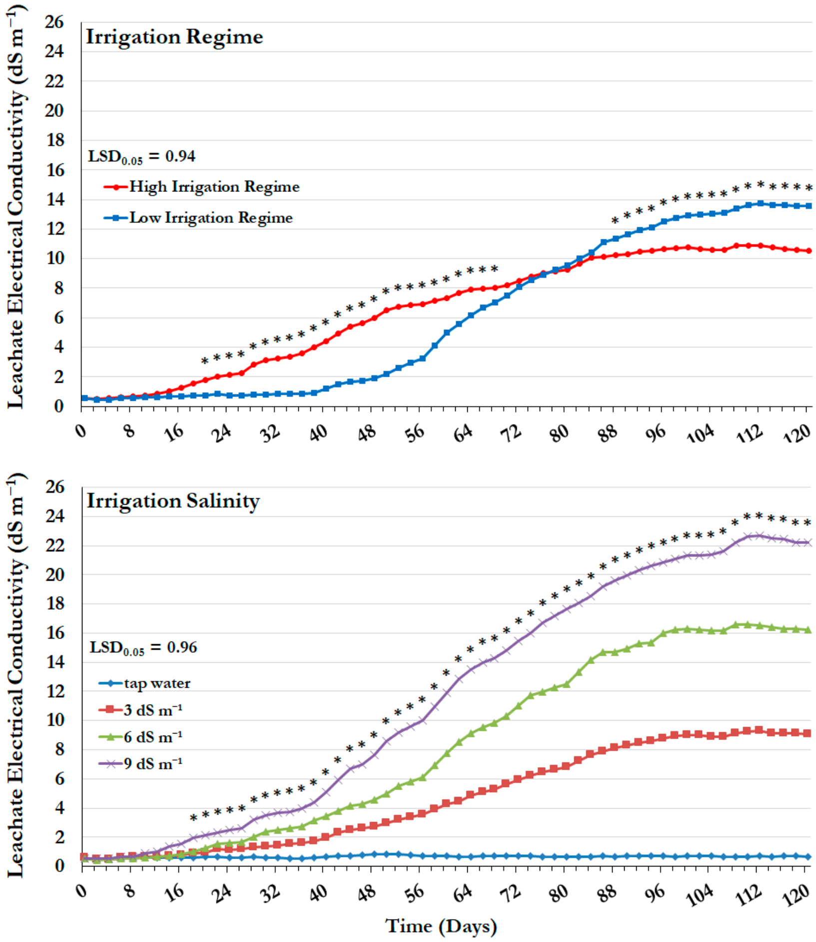

Figure 3. Leachate electrical conductivity (dS m^{-1}), as affected by irrigation regime (high or low) and irrigation water salinity (tap water, 3, 6, and 9 dS m^{-1}) during the stress period (31 January–30 May 2020). Values are the mean of 3 replications. Asterisks (*) indicate significant differences in between treatment means on a single sampling date.

3.2. Green Turf Cover

Salinity stress can lead to damage in plant tissues, resulting in a reduction of green turfgrass coverage [38–40]. In this study, the GTC of tall fescue was significantly influenced by the salinity of the irrigation water while remaining unaffected by the irrigation regime (Table 2). The GTC remained relatively stable, maintaining levels close to 95% for all salinity treatments, from initiation until 70 DAI (Figure 4). According to Figure 3, within the initial 70 days, the EC_L reached values of 14.8 dS m^{-1}, 10.3 dS m^{-1}, and 5.9 dS m^{-1} for irrigation with water at 9 dS m^{-1}, 6 dS m^{-1}, and 3 dS m^{-1}, respectively. However, a decline in GTC below the 90% threshold was observed at 80 DAI with irrigation water at 9 dS m^{-1} and at 92 DAI with 6 dS m^{-1}, coinciding with an EC_L exceeding 15 dS m^{-1}. In contrast, irrigation with tap water and water at 3 dS m^{-1} maintained the EC_L at lower levels and retained a GTC above 90% throughout the stress period.

These results demonstrate the ability to irrigate tall fescue turf when grown in extensive green roof systems with water of electrical conductivity up to 9 dS m^{-1} for extended periods without significantly reducing the turfgrass green coverage. This ability is attributed to the increased tolerance of this specific cool-season turfgrass species to soil salinity [30,33,41]. In a greenhouse study by Alshammary et al. [42], conducted in plastic containers 20 cm in depth with sand and isolite as the growing substrate, and where tall fescue was irrigated with water at 9.4 dS m^{-1} for six weeks with a leaching fraction of 0.15, it was observed that the turf quality remained acceptable, and coverage decreased by only about 20%. When the irrigation water had an electrical conductivity of 4.7 dS m^{-1}, leaf firing was observed to be less than 10% at the end of the six-week study. Uddin et al. [43] and Uddin and Juraimi [32] also classified tall fescue as tolerant to salinity levels of the growing substrate up to 10 dS m^{-1}.

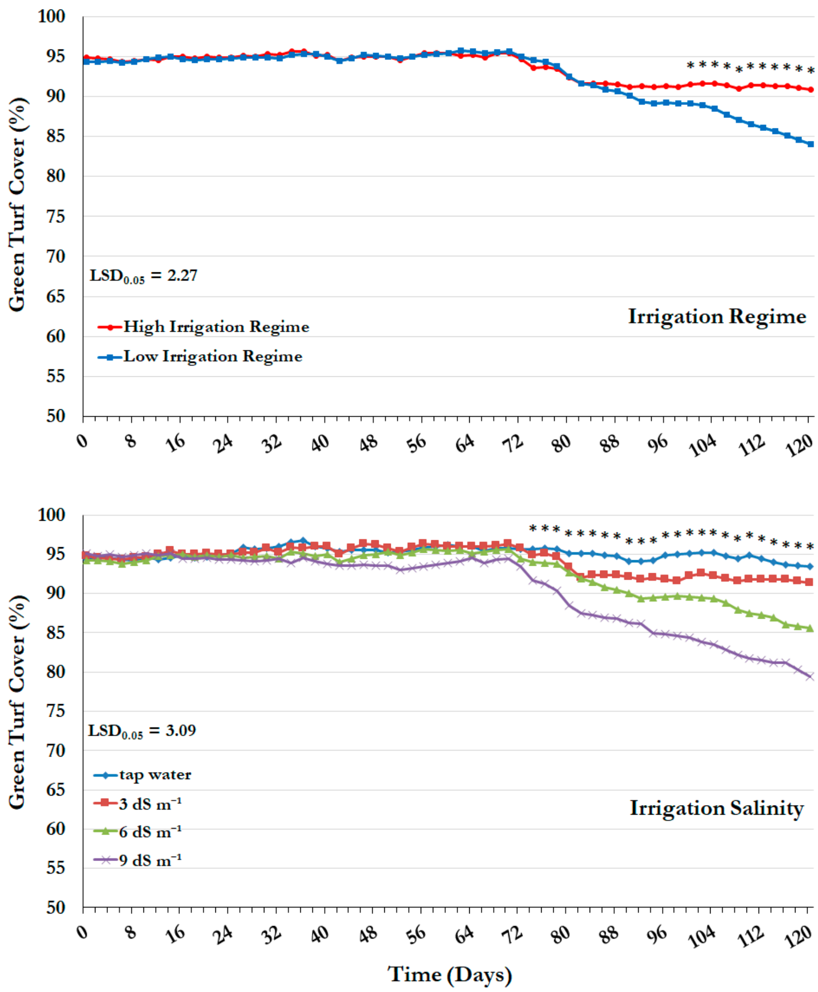

Figure 4. Green turf cover (%) as affected by irrigation regime (high or low) and irrigation water salinity (tap water, 3, 6, and 9 dS m^{-1}) during the stress period (31 January–30 May 2020). Values are the mean of 3 replications. Asterisks (*) indicate significant differences in between treatment means on a single sampling date.

Regarding the two different irrigation regimes, significant differences were observed from 100 DAI until the end of this stress study, with the higher irrigation regime showing higher GTC values compared to the lower irrigation regime. These differences were consistent with EC_L measurements, where the higher irrigation regime maintained lower EC_L values than the lower irrigation regime (Figure 3). Several researchers have emphasized the positive effect of an increased irrigation regime and, consequently, the rise in leaching fraction when irrigating turfgrass with high-salinity water [27,30,44].

3.3. Cumulative Clipping Dry Weight

Similar to the response of GTC in tall fescue to irrigation with saline water, a gradual reduction in the clippings' dry weight was observed with an increase in the salinity level of the irrigation water. The dry weight of clippings is a crucial factor in determining the response of turfgrasses to salt stress [45]. The cumulative clipping dry weight of tall fescue was significantly affected by the salinity of the irrigation water and, to a lesser extent, by the irrigation regime (Table 2).

Significant differences between the four irrigation treatments were observed from 52 DAI, with water at 9 and 6 dS m^{-1} exhibiting lower dry weight compared to the other irrigation treatments, while a clear separation was evident from 88 DAI until the end of this study (Figure 5). Specifically, irrigation with tap water recorded significantly higher cumulative clipping dry weight, followed by irrigation with 3 dS m^{-1} then irrigation with 6 dS m^{-1}, and the lowest weight was recorded for irrigation with 9 dS m^{-1}. On the last sampling date, the cumulative clipping dry weight was decreased by 7%, 18.5%, and 24.5% for irrigation with water of 3, 6, and 9 dS m^{-1}, respectively, compared to the control. In a lysimeter study, Manuchehri and Salehi [46] reported a significant reduction in the clipping dry weight of tall fescue when the salinity of irrigation water increased from 3 to 9 dS m^{-1}. Zhang et al. [47] found that shoot growth of tall and fine fescues was reduced as the salinity level of irrigation water increased from 3 to 12 dS m^{-1}.

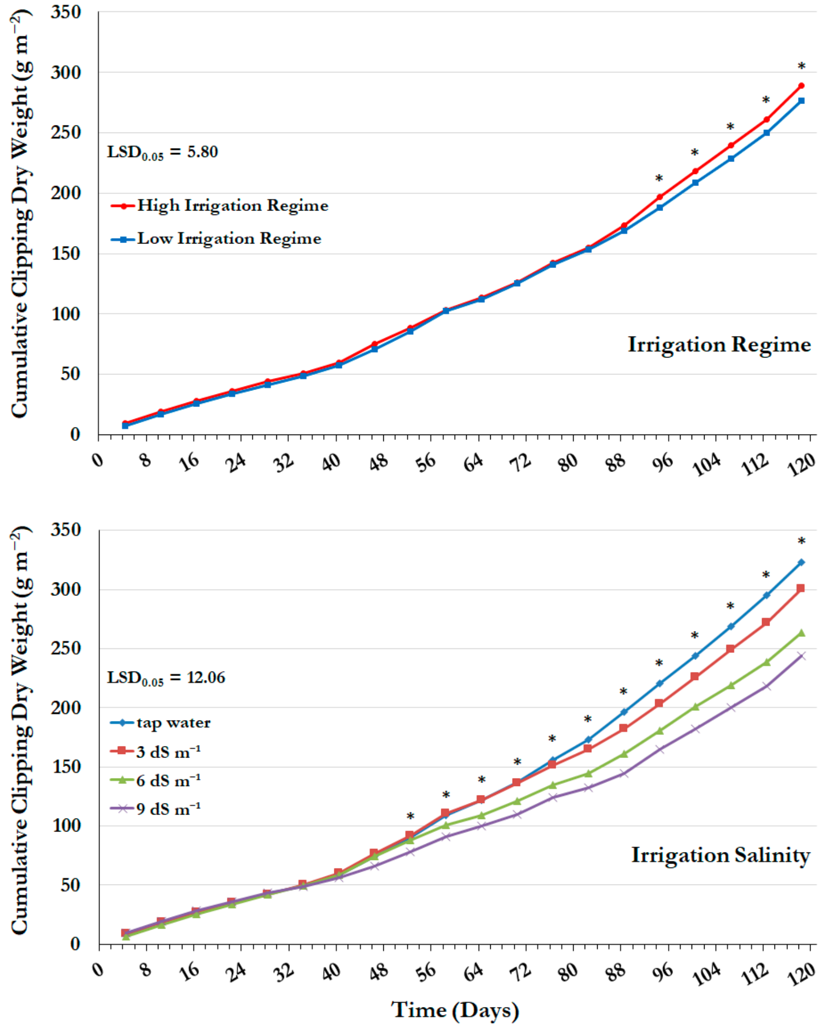

Figure 5. Cumulative clipping dry weight (g m^{-2}) of tall fescue, as affected by irrigation regime (high or low) and irrigation water salinity (tap water, 3, 6, and 9 dS m^{-1}) during the stress period (31 January–30 May 2020). Values are the mean of 3 replications. Asterisks (*) indicate significant differences in between treatment means on a single sampling date.

In the initial 94 days of this study, the two irrigation regimes showed similar cumulative clipping dry weight, as both had EC_L levels below 12 dS m^{-1}, regardless of any significant differences between them (Figure 3). However, from 94 DAI until the conclusion of this study, the higher irrigation regime, characterized by consistently lower EC_L values than the lower irrigation regime, demonstrated a significantly greater cumulative clipping dry weight. These findings align with the observations of Leskys et al. [48], who investigated the impact of leaching fraction on tall fescue's response to saline water and reported an increase in yield dry weight with higher leaching fractions.

3.4. Response of Green Turf Cover to Leachate Electrical Conductivity

A regression between GTC and EC_L was performed to determine the threshold EC_L value that impacts the GTC of tall fescue. Similar to the study of Ntoulas and Varsamos [20], it was found that the relationship between GTC and EC_L was adequately described by a two-segment linear regression model, resulting in an R^2 value equal to 0.62 when data from all irrigation regimes and salinity treatments (3, 6, and 9 dS m^{-1}) were pooled for the stress period (Figure 6). This regression model bears a similarity to the yield response curve proposed by Maas and Hoffman [49] for crops in response to soil salinity. The breakpoint between the two linear segments, indicating a change in the rate of GTC reduction, was determined to be 12.5 dS m^{-1}. Beyond this EC_L threshold, GTC exhibited a more rapid decline, with a slope value for the second segment line equal to −1.206.

The generated regression curve, illustrating the GTC response to drainage water salinity, can serve as a decision-making tool for green roof managers [20]. The identified threshold EC_L value, marking the onset of GTC decline in tall fescue when grown on extensive green roofs and irrigated with saline water, can be employed to estimate leaching requirements.

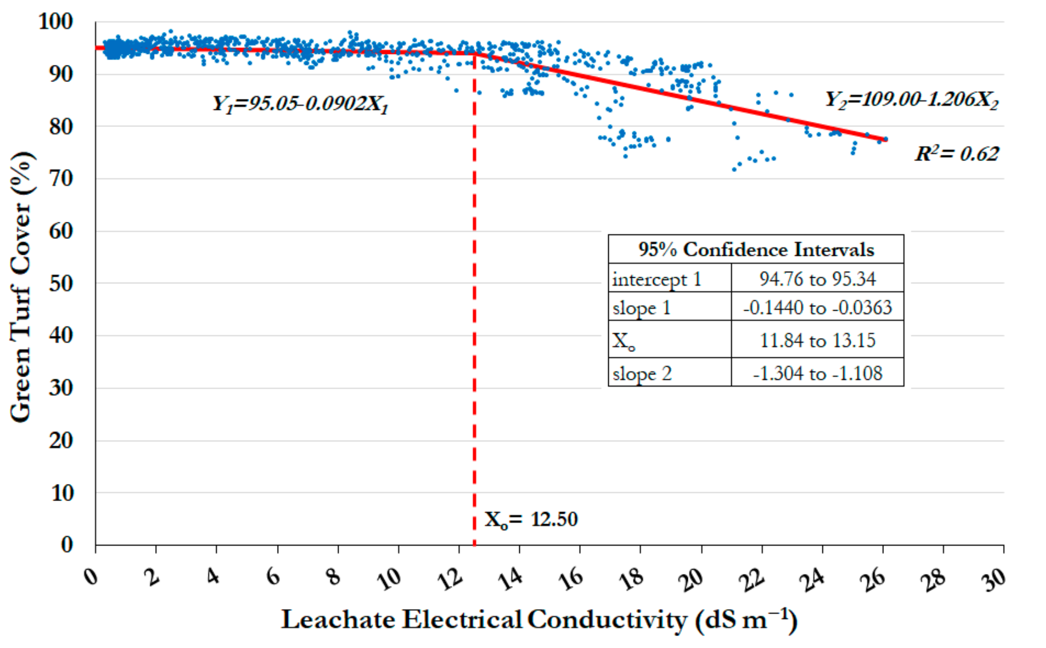

Figure 6. Two-segment linear regression model to determine green turf cover (%) reduction in tall fescue resulting from leachate electrical conductivity (dS m^{-1}) increase, when data from all irrigation regimes and salinity treatments (tap water, 3, 6, and 9 dS m^{-1}) were pooled for the whole stress period (31 January–30 May 2020).

4. Conclusions

It was determined that tall fescue, when grown on an extensive green roof, can tolerate irrigation with saline water up to 9 dS m^{-1} for approximately three months without reducing its green coverage below 90%, as long as a minimum leaching requirement of 30% is fulfilled. However, the irrigation with water at 9 dS m^{-1} resulted in a notable reduction of 24.5% in cumulative clipping dry weight over the four-month study period. A critical leachate salinity threshold of 12.5 dS m^{-1} was identified, indicating the point beyond which the green coverage of tall fescue begins to decline.

Considering the salinity and turfgrass limits established by the current study, it is concluded that the utilization of saline water could provide an alternative irrigation source, contributing to the conservation of essential drinking water resources. However, it is crucial to acknowledge that leachate salinity may reach elevated levels close to 20 dS m^{-1}, emphasizing the necessity for specialized green roof drainage systems capable of efficiently collecting and safely disposing of high-salinity leachate to prevent contamination of the urban environment.

Under greenhouse conditions, increasing the leaching fraction from 30% to 50% was found to be beneficial only if the duration of saline water application exceeds 3 months. Green roof administrators considering the duration of drought periods as well as the forecasted natural precipitations can establish an irrigation schedule favoring salt leaching to minimize adverse effects on turfgrass growth.

To ensure leachate salinity remains below the critical threshold of 12.5 dS m^{-1}, it is recommended to implement a continuous monitoring system for EC_L as an integral part of the urban green roof infrastructure. This involves installing conductivity meters at the outlets of the green roof for real-time measurement of leachate salinity. Regular monitoring will enable timely adjustments in saline water irrigation to maintain leachate salinity within the desired range.

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

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to thank HellaSod S.A. for donating the tall fescue sod.

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

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