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Using Sewage Sludge as Alternative Fertilizer: Effects on Turf Performance of Perennial Ryegrass

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Abstract: Two years of research were carried out to evaluate the effects of various sewage sludge and nitrogen doses on the turf performance of perennial ryegrass (*Lolium perenne* L.) under Mediterranean-type climatic conditions. Four nitrogen sources (NS) [NS1: ammonium nitrate (26%), NS2: Bursa City's wastewater treatment plant's waste, NS3: biogas production plant reactor waste, and NS4: food processing and canning factory's sludge waste] were used in the research. Four different nitrogen doses (0.0, 2.0, 4.0, and 6.0 g m^{-2}) were applied. The sewage sludges were analyzed before the start of the research. It was determined that the heavy metal concentrations were below the limit values, and the plant nutrient content was high. Turfgrass color and quality observations were taken in the study, and turfgrass clipping yield was determined. The 4.0 g m^{-2} nitrogen dose provided acceptable turf color and quality values among the sewage sludges. NS4 showed the best turf performance among the sewage sludges. Despite increased turf color and quality values, sewage sludge produced a low clipping yield. Food processing and canning factories' sewage sludges can be alternatives to a nitrogen source.

Keywords: *Lolium perenne*; alternative sources of nitrogen; turf color; turf quality

Citation: Zere Taskin, S.; Bilgili, U. Using Sewage Sludge as Alternative Fertilizer: Effects on Turf Performance of Perennial Ryegrass. *Sustainability* **2023**, *15*, 13597. https://doi.org/10.3390/su151813597

Academic Editors: Domagoj Nakić and Dražen Vouk

Received: 8 August 2023
Revised: 8 September 2023
Accepted: 10 September 2023
Published: 12 September 2023

1. Introduction

Perennial ryegrass, being one of the most prevalent and extensively employed types in the establishment of turf areas globally, holds a prominent position. It is classified as a cool-season turfgrass (C3), demonstrating its optimal growth in cool and humid regions [1], and it naturally occurs in Europe, temperate Asia, and North Africa [2]. It reaches its optimum growth rate within the range of 20–25 °C [3]. Perennial ryegrasses germinate quickly and establish a green cover in a short period, and it is also cost-effective. Perennial ryegrass is utilized in the construction of parks, home lawns, sports fields, highway medians, roadsides, and general landscaping areas. It exhibits good wear resistance to foot traffic and trampling [4]. In Turkey, which falls within the subtropical climate zone, ryegrass is widely used in turf areas, either in pure or turf mixtures.

Environmental pollution and waste problems became major issues in the last century because of increased urbanization and industrialization, as well as a growing global population [5,6]. Depending on the regulations in environmental policies, the establishment and operation of sewage sludge plants became a necessary component of modern society. With the increase in sewage sludge plants, the amount of sewage sludge produced is also increasing [7,8]. The statistical information was added to the following sentence: 'Sewage sludge 14% is disposed of in landfills, 27% is incinerated, 42% is applied to agricultural areas, and 17% is reused in different industrial sectors in the European Union [9]'. The preservation of the natural environment is feasible if waste that pollutes the environment is disposed of in an ecologically sensible manner.

The nitrogen element is essential for turf quality, including turf color, the growth of plant shoots and roots, the density of shoots, the resilience of grass plants to diseases and pests, and the tolerance to hot–cold and drought conditions [10]. Turfgrass areas that are continually cut and irrigated typically necessitate the usage of additional fertilizers. However, the use of excessive nitrogen fertilizers in agriculture has negative environmental consequences and raises numerous concerns. Ensuring a nitrogen dose that preserves the root–shoot balance, avoids inducing excessive leaf growth, minimizes the necessity for frequent mowing, and keeps lawn care expenditures at a reasonable level is of paramount importance.

Industrial establishments produce large volumes of sewage sludge that often contain organic compounds; nitrogen, phosphorus, acids, alkalis, metal salts, oxidizers, phenols, dyes, sulfates, oils, heavy metals such as Fe, Cu, Al, Hg, Cd, As, Co, Pb, and Cr [11]. The interest in using sewage sludge as a fertilizer in agricultural lands increased because the disposal methods cause environmental concerns [12]. The fertilizing value of wastewater sludge depends on its content of plant nutrient elements, namely nitrogen, phosphorus, potassium, calcium, magnesium, iron, and organic matter [13,14]. Using sewage sludge in agriculture has several advantages, such as the provision of macro and micronutrients, which can improve the soil, increase the soil water holding capacity, create permeable soil surfaces, and reduce the frequency of needed irrigation in arid areas. When assessing the suitability of wastewater sludge for agricultural use, important factors to consider include potential water contamination by nitrate or phosphate, environmental damage caused by the release of heavy metals, and the transportation of pathogens [15].

Biogas plants, whose activities are on the rise both in Turkey and worldwide, generate electricity through the fermentation of plant and animal organic wastes while facilitating the utilization of solid and liquid organic fertilizers formed as end products in agricultural areas [14]. The utilization of biogas production plant reactor waste as fertilizer in plant production contributes to nutrient recycling and the replacement of mineral fertilizers [16], while also reducing greenhouse gas emissions resulting from the production of synthetic fertilizers [17].

Many studies reported that applying sewage sludge had a favorable effect on the general aspect of the turfgrass [18–21]. There are very few studies on the effect of sewage sludge obtained from different sources on the color, quality, and clipping yield of perennial grasses. In today’s world, as the preservation and sustainability of the natural environment are becoming increasingly important, the environmentally friendly recycling of generated waste plays a significant role [14]. Moreover, considering the problems associated with the use of chemical fertilizers, it is necessary to investigate the application of alternative fertilizer sources in agriculture. This research aimed (i) to identify which nitrogen sources are most effective in improving turf color and quality values, (ii) to compare sewage sludge and chemical fertilizers’ effect on the perennial ryegrass growth, and (iii) to determine the optimum nitrogen dose or doses.

2. Materials and Methods

2.1. Experimental Area and Weather Conditions

The research was carried out on previously founded perennial ryegrass plots at the Agriculture Faculty, Bursa Uludag University, in Bursa (40°11′ N, 29°04′ E), during 2015–2016 and 2016–2017. The climate in the research region is Mediterranean-type and is in a transitional zone. During the study period, the average temperature (15.4 and 14.8 °C, respectively) and relative humidity (72.8% and 70.7%, respectively) were higher than the long-term average. Total precipitation was lower (660.1 mm and 620.8 mm, respectively) than the long-term average (Table 1).

Table 1. Monthly average temperature, precipitation, and relative humidity of research area.

Months	Air Temperature (°C)				Total Precipitation (mm)				Relative Humidity (%)			
	2015	2016	2017	LTA [1]	2015	2016	2017	LTA	2015	2016	2017	LTA
January	5.4	5.2	3.2	5.4	112	122.2	96.4	87.6	79.0	80.7	75.8	70.0
February	7.3	11.1	7.4	6.3	74.2	80.7	19.9	74.6	76.5	76	69.3	68.7
March	9.1	11.2	9.4	8.4	78.2	75.6	17.7	69.7	79.1	71	75.9	67.7
April	11.5	16.4	12.2	12.8	95.6	22.8	38.1	63.4	70.1	65.3	68.8	66.1
May	19.3	18.3	17.2	17.6	36	67.3	33.3	44.3	64.2	71.2	71.5	62.0
June	21.7	24.5	22.1	22.1	37.8	36.4	56.4	34.3	72.0	62.3	70.0	57.8
July	25.5	25.9	24.6	24.6	0.0	0	18.9	15.3	60.7	60.4	63.0	56.2
August	26.4	26.2	24.5	24.3	5.6	7.6	6.3	15.7	61.5	66	66.4	57.3
September	23.6	21.4	22.9	20.1	98.1	30.8	0.1	39.5	73.2	67.3	56.4	63.8
October	16.4	15.8	14.4	15.2	93.2	15.8	57.6	68.8	83.7	74.6	73.2	68.7
November	12.7	10.9	10.7	10.7	26.4	51	34.1	78.5	78.1	71.6	80.0	69.3
December	5.6	7.4	9.7	7.4	3.0	110.6	102.6	103.4	76.6	82.4	78.6	68.7
Tot./Mean	15.4	14.8	14.8	14.5	660.1	620.8	481.4	695.1	72.8	70.7	70.7	64.6

[1] LTA: Long-term average (1950–2015).

2.2. Plant Materials and Experimental Design

Perennial ryegrass (*Lolium perenne* L., cv. Caddieshack) was used as plant material in this study. The experiment was conducted in a split-plot design with the main plots arranged in a randomized complete block with three replications. Main plots (24 m^{-2}) consist of nitrogen sources and sub-plots (2 m^{-2}) consist of nitrogen doses [22]. The total size of the research area was 96 m^2.

2.3. Nitrogen Sources and Analysis Methods

Four nitrogen sources (NS) including one chemical fertilizer and three different sewage sludge fertilizers were used in the research. Ammonium nitrate (26%) fertilizer (NS1) was used as the chemical fertilizer. Sewage sludge was obtained from three different facilities: Bursa City's wastewater treatment plant's waste (NS2), biogas production plant reactor waste (NS3), and food processing and canning factory's sludge waste (NS4).

The sewage sludges were subjected to sun-drying to attain adequate disinfection levels and comply with conventional sludge criteria as outlined in the EU Council Directive 86/278/EEC. It waited for 3 months before the application for the possible pathogens in the sewage sludge to end their life span. Then, the dried sewage sludges were turned into granules for ease of application. Characteristics of sewage sludges information is presented in Table 2.

Table 2. Characteristics of sludge treatment plants.

Wastewater Treatment Plant	Source of Wastewater
NS2	domestic type
NS3	milk products (cheese, yogurt, etc.)
NS4	food (canned food)

Before the start of the experiment, sewage sludges and base soil were analyzed at the Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Bursa Uludag University. Sludge pH and EC were determined in sludge extract at a 1:5 sludge-to-ultrapure-water ratio (*v/v*). The Walkley–Black technique was used to determine the organic carbon content. The indophenol blue technique was used to quantify ammonium-N content in the 2 M KCl extracts. The total nitrogen amount in the soil and sewage sludge was evaluated using the Kjeldahl method. The molybdenum blue technique was used to determine the available P. The total cations (Na, K, Ca, and Mg) were measured by an Eppendorf Elex 6361 model flame photometer and HNO_3 (MWS 2 DAP 60K, Berghof, Germany). Inductively coupled plasma optical emission spectrometry (ICP-OES) was used to evaluate the extracts for Cd, Cr, Ni, Pb, Fe, Cu, Zn, and Mn elements (PerkinElmer OPTIMA 2100 DV). The total P content was determined colorimetrically using a PG Instruments T60 Split Beam UV/VIS model spectrophotometer. Available Fe, Cu, Zn, Mn, Cd, Cr, Ni, and Pb were extracted using DTPA (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA pH 7.3) and evaluated using a Perkin Elmer 2100DV ICP OES [23].

The experiment area soil structure is clayey, and it exhibits a slightly alkaline reaction with a pH of 8.48. It is rich in phosphorus and potassium, moderately abundant in organic matter, free from salinity issues, and deficient in nitrogen content (Table 3).

Table 3. Chemical composition of the sewage sludges and soil.

Parameters		Base Soil	NS2 *	NS3	NS4	EU Council **
pH		8.48	6.79	7.71	6.73	
Electrical conductivity (µS cm^{-1})		468	4100	2540	6780	
C/N			15.32	7.35	5.24	
%	N	0.106	4.76	2.46	4.66	
	Organic C	2.091	60.4	63.29	42.15	
	Total Ca	17,415	3.62	2.49	2.51	
	Total-P		0.73	1.25	1.87	
mg kg^{-1}	Available-P	30.95	2717.3	1118.6	785.9	
	Total Mn	788.3	132.6	299.6	625.6	
	Total K	5180	4437.5	4587.5	6050	
	Total Fe	36,210	8278.8	5050	9211.3	
	Total Mg	15,090	5375	8198.8	7768.8	
	Total Na	675	4150	1875	1262.5	
	Total Pb	10.42	11.8	3.6	30.3	750–1200
	Total Cd	0.148	0.8	0.5	1.4	20–40
	Total Cr	134.0	43.3	13.6	176.4	
	Total Cu	33.48	67.6	79.6	115.3	1000–750
	Total Ni	97.08	42.0	18.0	93.1	300–400
	Total Zn	54.95	273.5	596.0	578.9	2500–4000
	DTPA-Pb		3.550	0.480	3.000	
	DTPA-Cd		0.390	0.170	0.120	
	DTPA-Cr		1.120	0.310	0.510	
	DTPA-Ni		31.44	1.140	4.890	
	DTPA-Cu		55.87	23.50	19.31	
	DTPA-Zn		182.7	195.7	34.94	
	DTPA-Mn		160.4	44.98	26.98	
	DTPA-Fe		99.44	95.07	363.4	

* NS2: Bursa City wastewater treatment plant's waste, NS3: biogas production plant reactor waste, and NS4: food processing and canning factory's sewage sludge. ** EU Council Directive 86/278/EEC.

According to the analysis results, the sewage sludges analyzed in the study exhibit different chemical compositions (Table 3). The pH of the sewage sludges ranged from 6.73 to 7.71. One of the paramount factors governing the solubility of metals is pH. Sludge with a low pH (below approximately 6.5) facilitates the leaching of heavy metals, whereas sludge with a high pH (above 11.0) can lead to bacterial mortality. Additionally, when combined with neutral or highly alkaline soils, high pH sludge can impede the migration of heavy metals within the soil profile [24,25]. Perennial grass exhibits its optimal performance in fertile and well-drained soils. It demonstrates tolerance to both acidic and alkaline soil conditions within a pH range of 5.2 to 8.0, but its finest development occurs within a soil pH range of 5.5 to 7.5 [26]. EC levels varied between 2540 and 6780 µS. EC is an important factor limiting the agricultural use of sewage sludge [27]. NS4 sludge originating from the food industry had high EC values (6780 µS). An electrical conductivity (EC) value of <4.0 µS cm^{-1} suggests that the direct utilization of water in agriculture, in moderate quantities, would not pose a risk of soil salinization. The range of the C/N ratio of the sludges was 5.24–15.32. The C/N ratio of sewage sludge is a crucial factor that influences its utilization as a fertilizer or soil conditioner. A higher C/N ratio leads to a lower rate of N mineralization [28].

Sewage sludges contain different amounts of N, P, K, Ca, Mg, and Na. The total P values of wastewater sludges range from 0.73% to 1.87%, while the total K values vary between 4437.5 mg kg^{-1} and 6050 mg kg^{-1}. When the values are examined, it can be observed that the pH and nitrogen levels of the treatment sludges obtained from NS2 and NS4 are close to each other. In terms of organic matter percentages, NS2 and NS3 share similar values, while it is determined that NS4 treatment sludge has a lower organic matter percentage. NS3 treatment sludge has the highest organic matter percentage and a higher pH value compared to other nitrogen sources. However, the nitrogen percentage of NS3 treatment sludge is lower than the other treatment sludges. The results of sewage sludges' pH, EC, organic carbon, C/N ratio, nitrogen, and phosphorous properties indicate that the sludges could be useful for fertilizing turfgrass land (Table 3).

2.4. Applications of Nitrogen

The following nitrogen doses were applied: 0 (control) g m^{-2}, 2.0 g m^{-2}, 4.0 g m^{-2}, and 6.0 g m^{-2}. A full 100% of the evaporation in Class A pan evaporation was applied as daily irrigation via a rotary pop-up sprinkler system. Fertilizer applications were initiated in April and continued for 7 months until October each year. In both years, irrigation was suspended during the October to April period due to the plant's water consumption being met by rainfall in October.

2.5. Observations and Measurements

The center of each subplot (0.5 m $\times$ 1.0 m) was clipped when grasses reached 6–8 cm in height. After clipping, the turf waste was placed in paper envelopes and dried at 72 °C for 48 h then weighed and the clipping yield was determined. Turfgrass quality was rated visually via a 1 to 9 scale (1 = dead turf, poorest, 6 = minimally acceptable, light green, thin, and 9 = dark green, dense, and uniform turf) as used in the National Turfgrass Evaluation Program (NTEP) based on a combination of turfgrass uniformity, density, texture, and color. Turfgrass color rating was carried out visually using a 1 to 9 scale (1 = completely yellow, 6 = minimally acceptable, and 9 = dark green) [29–32]. Color and quality observations were taken monthly for two years.

2.6. Statistical Analysis

All data were integrated for seasons of both years, and data were subjected to analysis of variance (ANOVA). All data were analyzed as a randomized complete block design with nitrogen sources as the main plots, and nitrogen doses as sub-plots [33]. Nitrogen sources and nitrogen doses and their interactions were separated into statistically different groups by using the least significant difference (LSD) test at the 0.05 or 0.01 probability levels in JMP 13 Pro.

3. Results and Discussion

According to the variance analysis result, mean differences in color, quality, and clipping yield under different nitrogen sources (NS) and nitrogen doses (ND) were significant on most of the evaluation dates. NS $\times$ ND interactions, except for the autumn and winter for color, were significant (Table 4).

The color stands as one of the most significant indicators that reveal the quality of grass areas. It is a desirable attribute due to its capacity to enhance the value of turfgrass areas aesthetically. It is preferred for the color of turfgrass to remain as consistent as possible throughout all seasons and ideally be a dark shade of green. The elements contributing to the quality of turfgrass plants can be listed as having a uniform structure and being free from diseases, pests, and weeds [29,34]. In our study, NS4 had the highest color average value among the sewage sludges. Moreover, NS4 surpassed the average quality value of the

NS1 fertilizer source, which was the control fertilizer (Table 5, Figure 1). The ratio of carbon to nitrogen (C/N) in the sludge could speed up the breakdown of organic material. This acceleration might result not just in the depletion of organic matter, but also in the gradual liberation of heavy metals and metalloids into the soil solution. This, in turn, could enhance their accessibility to plants [35]. The fact that the C/N ratio of NS4 is quite low compared to other sewage sludges resulted in rapid organic degradation and thus higher performance compared to other sewage sludges. Unlike chemical fertilizers, the plant nutrients in sewage sludge are not necessarily in forms that a plant can use directly. The mineralization process of the sewage sludge continues throughout the vegetation period and is not affected by washing and evaporation as much as chemical fertilizers [36]. In this study, in which color and quality values were recorded for 24 months, it was observed that the effect of sewage sludge on turf color and quality continued even when no fertilizer was applied. In this regard, sewage sludge has the advantage of being a slow-release nutrient source for turfgrass areas. Topac and Baskaya [37] highlighted that determining the concentrations of total nitrogen and inorganic nitrogen in sewage sludge and making inferences about the nitrogen fertilizer value based on these values often lead to misleading outcomes. This is because, according to the US EPA [38], 50% to 90% of the total nitrogen present in sewage sludge is in the organic form, which is slower in terms of plant availability compared to mineral forms. It was reported that 30% of the nitrogen content in sewage sludge transforms into plant-accessible forms in the first year, followed by 15% in the second year, and 5% in the third year [39,40]. In addition, phosphorus from sewage sludge has a bioavailability ranging from 40% to 80% [41], making it a renewable source of phosphorus [42].

Table 4. Variance analysis results of measurements and observations.

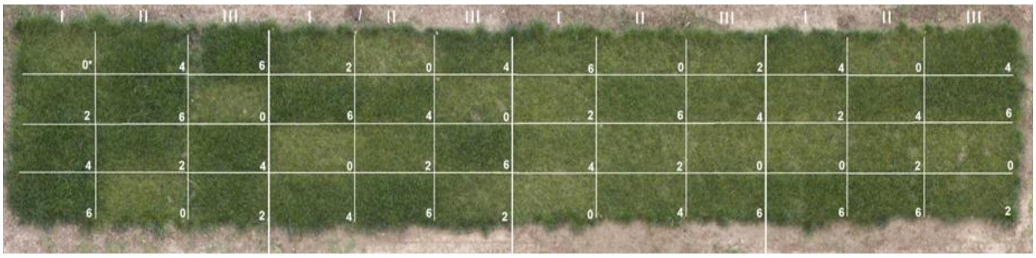
Sources of Variation	Color				Quality				Clipping Yield		
	1 ***	2	3	4	1	2	3	4	1	2	3
Nitrogen sources (NS)	**	**	**	**	**	**	**	*	**	**	**
Nitrogen doses (ND)	**	**	**	**	**	**	**	**	**	**	**
NS × ND	*	*	ns	ns	*	*	*	*	**	**	**

*: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, ns: none significant. ***: 1: spring, 2: summer, 3: autumn, and 4: winter.

Table 5. Mean turfgrass color and quality at the different nitrogen sources and doses for perennial ryegrass (1–9 scale).

Nitrogen Sources	Color					Quality				
	1	2	3	4	Mean	1	2	3	4	Mean
NS1 *	5.9 a **	5.8 a	6.6 a	6.7 a	6.3	5.5 ab	5.6 a	6.7 a	5.5 ab	5.8
NS2	5.4 b	5.2 b	6.1 b	6.1 c	5.7	5.4 b	5.4 b	6.1 c	5.4 bc	5.6
NS3	4.9 c	4.8 c	5.5 c	5.4 d	5.2	4.9 c	5.0 c	5.4 d	5.1 c	5.1
NS4	6.0 a	5.8 a	6.3 a	6.4 b	6.2	5.6 a	5.7 a	6.4 b	5.8 a	5.9
Mean	5.6	5.4	6.1	6.2	5.9	5.4	5.4	6.2	5.5	5.6
$Lsd_{0.05}$	0.280	0.220	0.250	0.166		0.208	0.216	0.147	0.300	
Nitrogen Doses										
0.0 g m^{-2}	3.8 d	3.5 d	4.1 d	3.7 d	3.8	3.5 d	3.6 d	4.2 d	3.9 d	3.8
2.0 g m^{-2}	5.4 c	5.2 c	5.9 c	5.9 c	5.6	5.3 c	5.2 c	5.9 c	5.1 c	5.4
4.0 g m^{-2}	6.3 b	6.2 b	6.8 b	6.9 b	6.6	6.1 b	5.8 b	6.7 b	6.2 b	6.2
6.0 g m^{-2}	6.8 a	6.8 a	7.7 a	7.8 a	7.3	6.7 a	6.7 a	7.6 a	6.6 a	6.9
Mean	5.6	5.4	6.1	6.1	5.8	5.4	5.3	6.1	5.5	5.6
$Lsd_{0.05}$	0.396	0.330	0.145	0.259		0.412	0.366	0.299	0.324	

* NS1: Ammonium nitrate (26%), NS2: Bursa City wastewater treatment plant's waste, NS3: biogas production plant reactor waste, and NS4: food processing and canning factory's sewage sludge. ** Various letters in columns indicate significant differences according to LSD at the 5% level.



NS1 NS4 NS3 NS2

Figure 1. Aerial view of the research area taken by a drone (6 October 2016). * g m^{-2} nitrogen doses.

In this study, all nitrogen sources showed different effects on perennial ryegrass color and quality parameters. The greatest turf color and quality values were obtained for NS1. NS4 gave high turf color and quality values after NS1, except for the summer (color) and the autumn (quality). NS2 was the next most successful after NS1 and NS4. The NS3 had ratings below the acceptable color and quality value (<6) in all seasons and showed the lowest performance. Additionally, the summer produced poor color and quality average values compared to other seasons (Table 5, Figure 1). Perennial ryegrass (cool-season grasses) is not well adapted to the Mediterranean climate's high temperatures, drought, and heat stress [43]. This difference among sewage sludges is associated with variations in the plant nutrient element contents of the sludges used in our study. Ata et al. [14] confirmed that the fertilization value of sewage sludges varies depending on the content of plant nutrient elements.

Sewage sludge was sourced NS2 from domestic, NS3 from the biogas production plant reactor, and NS4 from a food factory. Among the sewage sludge, food processing, and canning factories' sewage sludge (NS4) showed the greatest color and quality values. The lowest color, quality, and clipping yield values were obtained from biogas production plant reactor waste (NS3). Asik et al. [44], in their study conducted with different sewage sludges including sludge from biogas production reactor waste, it was observed that wastewater sludge from domestic and food industries had higher fertilization value in terms of plant nutrients and organic matter levels. Additionally, the organic composition and plant nutrient content of biogas production plant reactor waste depends significantly on the feedstock composition [45–48], as well as the management of the anaerobic digestion process [45,47].

Except for the spring season quality, a 4.0 g m^{-2} nitrogen dose provided an acceptable color and quality of perennial ryegrass. The best turf color and quality were achieved with a 6.0 g m^{-2} N dose. The 4.0 and 6.0 g m^{-2} N doses furnished green and high-quality turf throughout the growing seasons. However, nitrogen doses of 0.0 and 2.0 g m^{-2} N declined below an acceptable turfgrass color and quality. Especially nitrogen doses of 0.0 g m^{-2} N showed the poorest green color retention (Table 5). Similarly, Yilmaz [49] reported that turfgrass color rating significantly improved with an increased nitrogen application dose. Furthermore, these findings agree with the results of Bilgili and Yonter [50], who found that especially a 6.0 g m^{-2} nitrogen dose produced the highest turf color, quality, and clipping yield; in addition, generally, a 4.0 g m^{-2} nitrogen dose provided acceptable ratings.

Turfgrass quality is critical because turfgrass is an aesthetically important landscape plant [51]. Increasing the amount of sludge application had positive effects on plant growth. Sewage sludge increases the green field performance of perennial ryegrass. It is thought that the long-term nutrient requirement of perennial ryegrass can be met with sewage sludge. Grabowski et al. [52] stated that utilizing municipal sewage sludge as a cost-effective and ecological method to establish turf areas is a positive approach that significantly influences the winter survival, turf density, color, and aesthetic appearance (general appearance) of the turfgrass, particularly at the highest application rate of 31 t da^{-1}. Many other researchers' results confirm that the sludge application substantially improved the turfgrass quality characteristics, including leaf greenness and nutrient supply [53–55].

In our experiment, the highest clipping yield was produced by NS1. In contrast, fertilization with NS3 sewage sludge produced the lowest clipping yields. In every case, the control plots produced the lowest clipping yields. A 6.0 g m^{-2} N dose gave the highest clipping yield (Table 6). A low clipping yield is desirable for turfgrass areas as it reduces mowing frequency and lowers maintenance costs. Lower clipping yield values were obtained from the sewage sludges compared with the ammonium nitrate fertilizer. The organic matter in the sewage sludge can be broken down by microorganisms and transformed into beneficial forms that plants can utilize, and we believe that this situation contributes to the low clipping yield in our study [36]. Antonkiewicz et al. [56] stated that clipping yields were affected by waste treatment methods and dose of waste. Wolejko et al. [57] indicated that applying sewage sludge had a positive effect on the growth of turfgrass.

Table 6. Mean turfgrass clipping yields (g m^{-2}) at the various nitrogen sources and doses for perennial ryegrass.

Nitrogen Sources	**1**	**2**	**3**	**Mean**
NS1	100.0 a *	107.7 a	214.7 a	140.8
NS2	57.0 c	64.0 b	143.5 c	88.2
NS3	43.6 d	51.7 c	88.2 d	61.2
NS4	66.0 b	71.2 b	160.1 b	99.1
Mean	66.7	71.7	151.6	97.3
$Lsd_{0.05}$	0.145	0.145	0.145	
Nitrogen doses				
0.0 g m^{-2}	33.7 d	40.7 d	61.0 d	45.1
2.0 g m^{-2}	55.2 c	57.3 c	118.2 c	76.9
4.0 g m^{-2}	78.1 b	86.1 b	180.9 b	115.0
6.0 g m^{-2}	90.0 a	110.7 a	245.8 a	148.8
Mean	64.3	73.7	151.5	96.5
$Lsd_{0.05}$	0.173	0.173	0.173	

* Various letters in columns indicate significant differences according to LSD at the 5% level.

The reasons for limiting the use of sewage sludge relate to the possibility of the sludge containing toxic elements, pathogenic microorganisms, or eggs that may cause harm to the environment [58]. It should not be overlooked that sewage sludge contains not only organic matter and plant nutrients, but also toxic elements harmful to the environment, pathogenic microorganisms, and eggs of parasitic organisms. Cd, Cr, Cu, Pb, Hg, Ni, and Zn are the heavy metals important in the application of sewage sludge to the soil and whose critical values are specified. In particular, cadmium has a toxic effect even at low concentrations [59]. To ensure safer use of sewage sludge, it is necessary to stabilize the sewage sludge before application. The stabilization procedure usually reduces the organic matter and water content, the emission of unpleasant odors, and the concentrations of pathogenic microorganisms [60]. Stabilization should result either in a final product containing pathogens below detection limits (Class A), or alternatively in sludge (Class B), where pathogen counts were reduced but are still detectable. Common stabilization approaches include anaerobic (mesophilic or thermophilic) and aerobic digestion, lime stabilization, composting, and heat drying [61,62]. In our study, heavy metal contents of sludges were within the suggested limit values [63,64]. Therefore, the sewage sludges used in this research were deemed to not cause environmental harm or to represent any health risk concerning heavy metals. The previous study [54] indicated that sun-dried sewage sludge collected from a food processing company's wastewater system can be utilized as an N fertilizer for turfgrass without raising the risk of heavy metal in the soil. Researchers found that fecal coliform regrowth was not observed in sludge-amended soil samples that were examined monthly. Similarly, Cheng et al. [18] reported that sewage sludge did not affect the heavy metal and soluble salt content in the soil by increasing the required nutrient content as fertilizer. However, Duan et al. [65] reported that using sewage sludge resulted in ecological and human health risks. Wang et al. [66] found that the application of sewage sludge on different turfgrass species increases the heavy metal content, especially Cd, in the soil and should not be used in agricultural areas. It was reported that it can be used in forest and turfgrass areas where Cd content will not spread through the food chain.

When considering the agricultural applications of sewage sludge, it is important to consider factors such as the quantity of sludge applied, the characteristics of the sludge itself, the properties of the receiving soil, the potential impact on soil salinity and heavy metal levels, the specific type of plant to be cultivated, and the potential risk of groundwater pollution [67]. Although the heavy metal contents of the treatment sludge used in our research were within the limit values, we recommend that it be used in grass areas where people do not use it intensively (highway medians, roadsides) for safer use in terms of human health.

4. Conclusions

Experimentally demonstrating whether sewage sludge can be used as a fertilizer in turfgrasses is undoubtedly of great importance. The application of sewage sludges as fertilizer in agriculture can contribute to the recycling of nutrients, while potentially reducing the application of synthetic fertilizers. In this study, fertilization applications were carried out based on the nitrogen content of sewage sludges used as a nitrogen source. Furthermore, important nutrient elements such as potassium and phosphorus present in these nitrogen sources also had significant effects on the growth of perennial ryegrass. This study revealed that the 4.0 g m^{-2} nitrogen dose of all sewage sludges provided acceptable turf color and quality ratings. The 4 g m^{-2} nitrogen dose is recommended for acceptable turf quality to prevent environmental pollution due to excess nitrogen use and reduce maintenance costs. Despite increased turf color and quality ratings, sewage sludge provided a low clipping yield. This is a desirable situation when considering the clipping disposal problem. Food processing and canning factories' sludge produced the greatest color and quality values among the sewage sludges. As a result, sludge from food processing and canning factories' can be used in place of chemical fertilizers to fertilize the turf.

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

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are presented in this manuscript. This article is based on the Master's thesis titled 'Effects of different sewage sludge and nitrogen doses on growth and turf quality of perennial ryegrass (*Lolium perenne* L.)' submitted by Sinem ZERE at Bursa Uludag University.

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

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