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Frequent Irrigation Under Increasing Doses of Stabilized Sewage Sludge in The Soil Increases the Yield and Quality of Silage Maize

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A B S T R A C T

Achieving higher efficiency and better quality production with appropriate irrigation regimes in silage maize cultivation in soils mixed with urban sludge is a requirement of sustainable agriculture. Therefore, a two-year field study was carried out with three replicates with four different sewage sludge doses (D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, and D3: 90 t/ha), and three different irrigation regimes (S1, S2, and S3). In the S1, S2 and S3 regimes, when the sum of (Reference evapotranspiration - Effective rainfall) was 25 mm, 50 mm and 75 mm, respectively, irrigation was carried out and the soil moisture deficit was completed to the field capacity. Considering the two-year average, increasing sewage sludge dose and frequent irrigation significantly increased fresh and dry biomass yields and crude protein, while decreasing acid detergent fiber (ADF) and neutral detergent fiber (NDF). The fresh biomass yield in D3 treatment was 12.4%, 20.6%, and 42.1% higher than D2, D1, and D0, respectively. ADF in D3 was 5.6%, 2.1% and 1.7% lower than D0, D1 and D2, respectively, while NDF was 4.4%, 3.7% and 2.1% lower. D3 treatment increased the crude protein value by 27.3%, 15.5% and 7.7% compared to D0, D1 and D2 treatments, respectively. S1 provided 12.9% and 28.3% higher fresh biomass yield compared to S2 and S3. ADF value in S1 was 0.69% and 2.4% lower than S2 and S3, respectively, and NDF value was 0.86% lower compared to S3. There was a positive linear relationship with a high correlation between fresh and dry biomass yields. It could be concluded that D3-S1 treatment is the most effective practice for higher and quality yields, and followed by D3-S2 treatment.

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Introduction

The sewage sludge produced on a global scale is increasing every year due to population growth, urbanization and continuous growths in wastewater treatment. Sludge consists of water, organic matter, and inorganic components commonly known as bio-solids (Fijalkowski et al., 2017). Disposal of sewage sludge is a technically, economically, and environmentally necessary procedure (Altun & Sahin, 2021).

The use of controlled and appropriate amounts of sewage sludge in agricultural production areas stands out as one of the simplest disposal methods of sludge (Mondal et al., 2015; Çakır & Çimrin, 2018). Stabilized sewage sludge is an important nutrient storage in addition to being a source of organic matter. The two main reasons for the use of sewage sludge, which is purified from pathogens and bad odor through the stabilization process, in agriculture are that they are a cost-effective fertilizer source and also serve as a good soil conditioner. Therefore, the soil is enriched in terms of macro and micro elements needed by plants with the application of sewage sludge, while the addition of organic matter to the soil provides a sustainable contribution to soil fertility (Zuo et al., 2019). Vaca et al. (2011) stated that the addition of sewage sludge to the soil does not pose an environmental threat and offers a solution to the final disposal of organic waste. Skowrońska et al (2020) stated that the carbon and nitrogen levels in the soil increased significantly with the application of sewage sludge, especially at high doses, and that these changes had the potential to be permanent in the long term, and they also emphasized that it did not pose a risk in terms of heavy metal concentrations. However, increases in heavy metal content in soils with sewage sludge added may change depend on the dose of the sludge, the duration of its stay in the soil, and the type and concentration of the metal in it.

Maize is an important agricultural plant that can be successfully grown on almost every continent except Antarctica, can adapt to different climate and soil conditions, can grow at altitudes up to 4000 m from sea level, and performs C4 photosynthesis (Özkan & Bayhan, 2022). It is one of the most produced plants in our country as well as in the world. According to 2023 plant production statistics in Türkiye, 28 653 531 tons of silage maize is produced in 524 860,9 ha of land. The total production amount of Erzurum province in 2023 is 93 649 tons in 1 901.1 ha of land (TSI, 2024). Silage maize is preferred as an important forage plant in nutrition of especially for dairy cattle due to its high dry matter content and green grass yield, and its suitability for silage production without the need for additives (Keskin et al., 2018). Çakır & Çimrin (2018) determined significant increases in dry and fresh biomass yields of maize plants with increasing sewage sludge doses. The product quality of silage maize is also important, in this context, crude protein, acid detergent fiber, neutral detergent fiber are the most known quality parameters (Ors et al., 2015).

Maize is highly sensitive to water stress and shows different responses to water deficit at different developmental stages (Ors et al. 2015; Yerli et al., 2023). Therefore, considerable decreases in soil moisture content is considered a limiting factor for maize growth (Peichl, 2018). Shahrabian and Soleymani (2011) determined that increased soil water consumption in silage maize cultivation by creating different soil moisture regimes at three different stress levels (low, medium and high) significantly reduced dry matter yield.

In this study, it was aimed to increase the yield and quality of silage maize by mixing stabilized sewage sludge including domestic wastes with soil at different doses and irrigation management. Within the scope of this research carried out in Erzurum semi-arid ecology, irrigation timing was arranged according to different water consumption levels with real-time water consumption approach and different moisture stress conditions between successive irrigations were created in the soil. Therefore, the hypothesis of this study was that frequent irrigation under high dose sewage sludge in soil would increase biomass yield and product quality in silage maize.

Materials and Methods

Experimental Site and Experimental Processes

The research was carried out at Atatürk University, Plant Production Application and Research Center in Erzurum, Turkey (39.933° N and 41.236° E, 1780 m a.s.l) using four stabilized sewage sludge doses and three irrigation regimes, in a 4x3 factorial design and with three replications. Thus, a trial consisting of a total of 36 plots was established. The trial region has a semi-arid climate with an annual precipitation of 395.7 mm. Average temperature, total precipitation and evaporation values in the vegetation periods were 18.2°C, 80.1 mm and 935.1 mm in 2021, respectively, and 17.6°C, 111.2 mm and 826.2 mm in 2022. Field soil was clay loam texture in surface layer of 0-30 cm, pH, EC, organic matter content was 7.61, 0.163 dS/m, 1.73%, respectively. Each plot 25.2 m^2 (3.5 m × 7.2 m) sizes with five rows. Irrigation was applied surface drip irrigation system using groundwater.

Sewage sludge obtained from Erzurum-Ilıca municipal wastewater treatment plant was used, which was stabilized by the activities of bacteria in anaerobic and mesophilic conditions. The stabilized sewage sludge with 29.9% dry matter content was applied to the plots with the doses of D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha and D3: 90 t/ha and mixed to a soil depth of 15 cm with a hoeing machine in 22 September 2020. The field was plowed a vertical rotavator at a depth of 15 cm on May 7 in 2021 and on May 13 in 2022, and then the DKC6777 seed variety was planted with a pneumatic seeder at 15×70 cm intervals. Nitrogen and P fertilization considering region requirements to complete deficit amounts according to initial soil fertility analysis was applied in without sewage sludge plots in both years, but mineral fertilizer was not applied in the plots where sewage sludge was used. Hoeing was carried out in two stages where the plants reached 15-20 cm and 40-50 cm height.

Irrigation regimes were implemented by completing the moisture lost at the effective root depth to field capacity when the total of the (ETc – Peff) reached approximately 25 mm (S1), 50 mm (S2) and 75 mm (S3) levels. Crop evapotranspiration (ETc) values were estimated by calculation using the ETo x Kc equation. Crop coefficient (Kc) values were taken from the Evapotranspiration Guide for Irrigated Crops in Türkiye (TAGEM, 2017). Reference evapotranspiration (ETo) calculations were made with CROPWAT software according to the Penman-Monteith (FAO) method, the necessary climate data were obtained from the Erzurum Airport meteorology station close to the trial area, and the precipitation data were obtained from the pluviometer installed in the trial area. Since there was no deep flow and surface flow from precipitation, all were considered as effective precipitation (Peff). Soil moisture monitoring was performed before each irrigation using a TDR device (Trime–Pico, IPH/T3, IMKO) in the upper layer, and using the gravimetric method in the lower layers.

Crop Measurements and Statistical Analysis

Harvesting was done manually on September 9 in 2021 and on September 10 in 2022. Fresh biomass yield was calculated by weighing 30 plants selected from the center of the plots on a precision scale, and these data were converted into biomass yield per unit area (kg/ha). To determine the dry matter ratio according to the method in Kacar (2014), the fresh weight of three randomly selected plants representing the plot was determined, then the plants were left to wither in greenhouse conditions for a while and oven dried at 78°C for 48 hours, then their dry weight was measured. The dry matter ratio was obtained by dividing the dry weight by the fresh weight, and the dry biomass yield was obtained by multiplying of dry matter ratio by the fresh biomass yield (kg/ha).

Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) analyses were carried out using the Fiber Bag System (Gerhardt), which was developed by modifying the Van Soest (1963) analysis method, and using the ANKOM 200 Fiber Analyzer. Crude protein content was calculated by multiplying the nitrogen amount determined by the Kjeldahl method by the coefficient of 6.25 (Yerli et al., 2023).

Data were analyzed with the general linear model in SPSS (ver. 22) statistics program. Duncan multiple comparison test was applied for significant differences and classification was made at 5% significance level. Binary relationships were investigated with Pearson correlation analysis.

Results and discussion

Fresh Biomass Yield

Sewage sludge and irrigation treatments had significant ($p \leq 0.01$) effects on fresh biomass yield in both trial years and in the average of trial years. The interaction of dose and irrigation regime was also determined to be significant ($p \leq 0.01$) in the second trial year only (Table 1). Increasing application dose of the sewage sludge and frequent irrigation practice provided significant increases in fresh biomass yield in both trial years. According to two-year averages, fresh biomass yield obtained with D3 treatment was 12.4% higher than D2, 20.6% higher than D1 and 42.1% higher than D0. Frequent irrigation treatment (S1) provided 12.9% higher fresh biomass yield compared to S2 and 28.3% higher biomass yield compared to S3 (Table 2). Considering the treatments interaction in the two-year average, the highest fresh biomass yield was determined as 130505.3 kg/ha in D3-S1 treatment, which provided 81% more yield than D0-S3, where the lowest value was determined. The fresh biomass yield of the D3-S1 treatment, in which the highest value was obtained (130505.3 kg/ha), corresponds to 2.39 times the 2023 silage maize Türkiye average of 54670 kg/ha, 2.51 times the Northeast Anatolia Region average of 52090 kg/ha, and 2.65 times the Erzurum province average of 49260 kg/ha (TSI, 2024).

The sewage sludge used in the experiment contained 38.6% organic matter, 4.13% total Kjeldahl nitrogen, 451.5 mg/kg NO_3-N, 1.32% P, 10.4 cmol/kg K, 41 cmol/kg Ca and 83.6 cmol/kg Mg, which could be seen as an important factor for the increase in yield at increasing doses due to increased soil fertility. Similarly, Yerli et al. (2023) stated that the increase in macro and micronutrient contents in the soil contributes the silage yield for a considerable level. Especially, the increase in soil N content caused significant increases in yield (Saracoglu, 2023; Norouzi et al., 2024). It was also reported by Motta and Maggiore (2013) that yield was increased together with increased plant N uptake. Da Silva et al. (2022) determined significant increases in maize yield in soils with sewage sludge. Černý et al. (2012) reported that sewage sludge application increased silage maize yield by 19% to 25% compared to without sludge. In addition, some other studies also have indicated that increases in N, P, K and other nutrients in the soil provide significant increases in the yield (Mousavi & Shahsavari 2014; Cakmakci & Sahin 2021; Gezer et al., 2023).

It is clear that in conditions where soil moisture is retained at low tensions, the low stress effect of both matrix and osmotic potential supports plant development by facilitating easily water and nutrient uptake by plants. Similarly, Ucak et al. (2016), Cakmakci & Sahin (2021), and Yerli et al. (2023) determined that increased durations of water stress in silage maize was obtained significant decreases in fresh biomasses yield. In addition, these findings were confirmed by many others examining the effect of water stress on yield loss (Tabatabaei et al., 2017; Zare et al., 2018; Akşit, 2020; Keten, 2020; Kamali et al., 2022; Balbaa et al., 2023).

Increasing sewage sludge doses and frequent irrigation regime supported yield by improving physiological indicators (SPAD, stomatal conductance, leaf relative water content, leaf area index, membrane damage index) in this study. The linear relationships between fresh biomass yield and leaf area index, the fresh biomass yield and the leaf relative water content, membrane damage and leaf relative water content, stomatal conductivity and fresh biomass yield, and SPAD and fresh biomass yield were found significant (Altun & Sahin, 2021, 2022, 2023). Similarly, Moreira et al. (2020) reported that sewage sludge application increased specific physiological traits such as photosynthetic activity and stomatal conductance in maize (Moreira et al., 2020). Karasu et al. (2015), Cakmakci & Sahin (2021), and Yerli et al. (2023) also reported significant correlations between the fresh biomass yield and the physiological parameters of the maize crop.

Dry Biomass Yield

It is desired that the dry matter ratio of the green feed to be silage is at least between 25% and 30%. This value can be higher in silage maize (Koca, 2020). In this study, a dry matter ratio of around 28% was determined.

In both trial years and the average of the years, significant ($p \leq 0.01$) effects of sewage sludge and irrigation treatments on dry matter yield were determined. In the second year of the trial and the average of the years, it was observed that the interaction between dose and irrigation regime was also significant ($p \leq 0.01$) (Tablo 1). According to the two-year average, the highest dry biomass yield was determined in D3-S1 treatment as 37583.4 kg/ha (Table 3). This value corresponds to an 80% increase compared to D0-S3, which provides the lowest value. The changes in dry biomass yields were parallel to the fresh biomass yields, and were supported by a positive linear relationship with a high correlation between these two variables (Figure 1). Cakmakci & Sahin (2021) and Yerli et al. (2023) also reported positive linear relationships between fresh and dry biomass yields in silage maize.

Koutroubas et al. (2023) and Özgür et al. (2023) determined that increasing the sewage sludge dose had a positive effect on dry matter yield. Increasing water stress in the soil between irrigations can negatively affect photosynthetic efficiency by decreasing the metabolic activities of the maize plant and decreasing the chlorophyll content in the leaves. Decreased photosynthetic level with the decrease in the metabolic activity and the chlorophyll content of maize in the leaves reduces dry biomass yield (Gomaa et al., 2021). Moreover, it has been reported that the effect of water stress is associated with a decrease in the leaf area index, causing a decrease in dry matter yield (Bouazzama et al., 2012). The findings of this study also showed that the leaf area index decreased with the effect of increasing stress from S1 to S3 irrigation in the soil (Altun & Sahin, 2022). Some previous studies reported that increasing the level of water stress in the soil negatively affects dry matter yield, and that changes in dry matter yield are directly related to fresh biomass yield (Ucak et al., 2016; Kale et al., 2018; Cakmakci & Sahin 2021; Demir et al., 2021; Yerli et al., 2023).

Table 1. Variance analysis

Parameter	Year	Variance Sources	df	Mean Square	F	P
Fresh biomass yield	2021	Dose	3	1662926621	64.856	.000
		Irrigation	2	2215984225	86.426	.000
		Dose × Irrigation	6	1.72E+07	0.67	.675
		Error	24	2.56E+07		
	2022	Dose	3	2094483289	242.425	.000
		Irrigation	2	1509177369	174.679	.000
		Dose × Irrigation	6	3.92E+07	4.539	.003
		Error	24	8.64E+06		
	2021-2022	Dose	3	186688.3287	196.521426	.000
		Irrigation	2	183668.1549	193.342176	.000
		Dose × Irrigation	6	1.55E+03	1.62942133	.182
		Error	24	9.50E+02		
Dry biomass yield	2021	Dose	3	119087592.2	56.511	.000
		Irrigation	2	152068196.8	72.162	.000
		Dose × Irrigation	6	1.99E+06	0.942	.484
		Error	24	2.11E+06		
	2022	Dose	3	154143052.2	661.137	.000
		Irrigation	2	117896761.6	505.673	.000
		Dose × Irrigation	6	5.53E+06	23.74	.000
		Error	24	2.33E+05		
	2021-2022	Dose	3	135978174.3	195.86	.000
		Irrigation	2	134435177.3	193.638	.000
		Dose × Irrigation	6	2.63E+06	3.788	.009
		Error	24	6.94E+05		
ADF	2021	Dose	3	4.983	12.375	.000
		Irrigation	2	1.879	4.667	.019
		Dose × Irrigation	6	9.20E-02	0.228	.964
		Error	24	4.03E-01		
	2022	Dose	3	4.92	11.799	.000
		Irrigation	2	1.874	4.496	.022
		Dose × Irrigation	6	8.70E-02	0.21	.970
		Error	24	4.17E-01		
	2021-2022	Dose	3	4.983	12.375	.000
		Irrigation	2	1.879	4.667	.019
		Dose × Irrigation	6	9.20E-02	0.228	.964
		Error	24	4.03E-01		
NDF	2021	Dose	3	9.795	27.227	.000
		Irrigation	2	1.049	2.917	.073
		Dose × Irrigation	6	5.00E-02	0.14	.989
		Error	24	3.60E-01		
	2022	Dose	3	14.806	45.518	.000
		Irrigation	2	0.427	1.314	.287
		Dose × Irrigation	6	4.00E-02	0.123	.992
		Error	24	3.25E-01		
	2021-2022	Dose	3	11.916	70.554	.000
		Irrigation	2	0.646	3.824	.036
		Dose × Irrigation	6	3.90E-02	0.232	.962
		Error	24	1.69E-01		
Crude protein	2021	Dose	3	14.046	656.627	.000
		Irrigation	2	0.092	4.295	.025
		Dose × Irrigation	6	2.00E-03	0.075	.998
		Error	24	2.10E-02		
	2022	Dose	3	6.364	58.296	.000
		Irrigation	2	0.372	3.407	.050
		Dose × Irrigation	6	2.00E-02	0.184	.978
		Error	24	1.09E-01		
	2021-2022	Dose	3	9.879	298.868	.000
		Irrigation	2	0.189	5.706	.009
		Dose × Irrigation	6	7.00E-03	0.204	.972
		Error	24	3.30E-02		

Table 2. Fresh biomass yields (kg/ha) in silage maize at different sewage sludge doses and irrigation treatments

Year	IT	D0	D1	D2	D3	Mean
2021	S1	94606.4±4713.0	107513.3±2293.1	113932.3±3755.3	124142.9±1675.4	110048.7±3527.1A*
	S2	76804.2±3089.6	98211.7±1420.0	100095.2±3447.2	114555.5±1385.3	97416.7±4202.7C
	S3	67608.5±2432.6	79359.8±1463.0	85624.3±3372.5	98976.7±3658.6	82892.3±3624.0D
	Mean	79673.0±4340.4D	95028.2±4234.5C	99883.9±4450.9B	112558.4±3866.9A*	
2022	S1	95214.8±1835.2d	110333.3±1138.3c	115772.5±851.1b	136867.7±2220.6a*	114547.1±4552.3A*
	S2	81391.5±1057.5ef	99922.8±1739.3d	108012.7±1328.0c	116470.9±1828.0b	101449.5±1828.4B
	S3	76571.4±1479.6f	84888.9±3330.0e	99000.0±963.4d	108460.3±885.8c	92230.2±3808.8C
	Mean	84392.6±2891.4D	98381.7±3862.7C	107595.1±2481.2B	120599.6±4316.5A*	
2021-2022	S1	94910.6±2591.8	108923.3±1707.2	114852.4±1979.0	130505.3±1472.4	112297.9±3940.4A*
	S2	79097.9±1918.0	99067.2±1458.9	104054.0±1603.4	115513.2±677.3	99433.1±4020.5B
	S3	72089.9±1931.4	82124.3±1465.6	92312.2±1562.8	103718.5±2263.2	87561.2±3628.9C
	Mean	82032.8±3544.7D	96705.0±3988.8C	103739.5±3366.7B	116579±3957.9A*	

IT: Irrigation treatment; D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, D3: 90 t/ha. S1, S2, and S3: irrigation when ∑ (estimated evapotranspiration – effective precipitation) equals to 25 mm, 50 mm and 75 mm, respectively; *: $p < 0.05$

Table 3. Dry biomass yields (kg/ha) in silage maize at different sewage sludge doses and irrigation treatments

Year	IT	D0	D1	D2	D3	Mean
2021	S1	26605.3±826.5	29021.7±440.2	31789.7±650.8	35810.7±1128.9	30806.8±1087.0A*
	S2	22254.3±202.5	27097.0±340.2	28301.0±1565.2	30379.0±812.3	27007.8±979.0B
	S3	19659.0±602.9	22451.0±667.9	24227.0±1312.9	28433.7±233.9	23692.7±1019.7C
	Mean	22839.6±1057.0D	26189.9±1006.9C	28105.9±1255.8B	31541.1±1176.4A*	
2022	S1	27099.9±100.2e	30796.2±173.5c	32341.7±76.4b	39356.2±366.6a*	32398.5±1343.5A*
	S2	23880.4±224.9f	28549.3±333.0d	30450.2±299.9c	33090.7±239.0b	28992.7±1021.0B
	S3	22102.9±421.4g	24028.3±487.0f	28402.8±75.1d	30016.7±152.8c	26137.7±974.6C
	Mean	24361.1±744.6D	27791.2±1010.8C	30398.2±576.1B	34154.6±1380.5A*	
2021-2022	S1	26852.6±363.2ef	29908.9±216.0c	32065.7±292.7b	37583.4±707.9a*	31602.7±1196.1A*
	S2	23067.4±24.2g	27823.2±336.6de	29375.6±912.2c	31734.9±520.1b	28000.2±984.4B
	S3	20880.9±482.5h	23239.6±275.0g	26314.9±672.0f	29225.2±187.6c	24915.2±967.8C
	Mean	23600.3±889.4D	26990.6±994.8C	29252.1±896.7B	32847.8±1264.9A*	

IT: Irrigation treatment; D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, D3: 90 t/ha. S1, S2, and S3: irrigation when ∑ (estimated evapotranspiration – effective precipitation) equals to 25 mm, 50 mm and 75 mm, respectively; *: $p < 0.05$

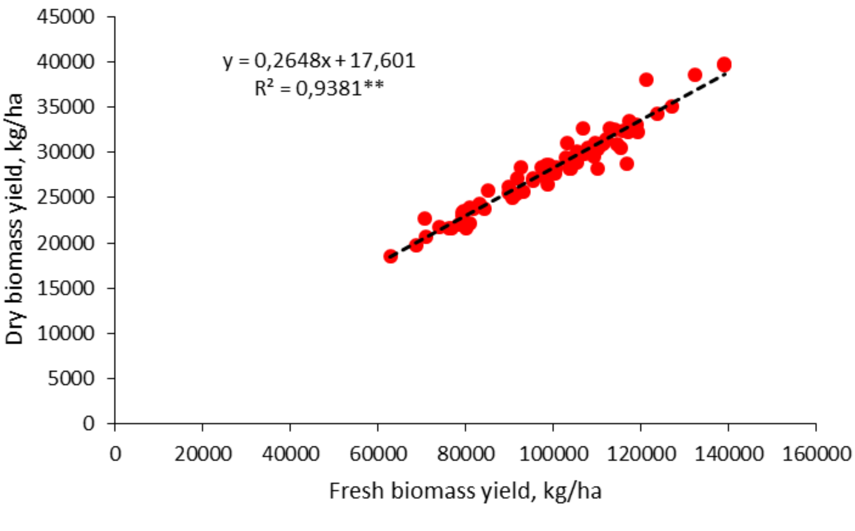

Figure 1. Relationship between fresh and dry biomass yields ($n = 72$, **: $p < 0.01$)

Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), And Crude Protein Content

ADF and NDF are important quality parameters that allow the evaluation of digestibility and energy intake. High ADF indicates an excess of cellulose and lignin that are difficult to digest, high NDF indicates an excess of cellulose and fibrous carbohydrates of the cell wall such as hemicellulose, lignin, some proteins and silicon (Yerli et al., 2023). Therefore, it is reported that ADF is an indicator of the digestibility of the plant, and NDF is an indicator of its uptake by animals (Mese & Gulumser, 2021).

While significant ($p \leq 0.01$) effects of sewage sludge treatments on ADF and NDF were determined in both trial years, significant ($p \leq 0.05$) effect of irrigation regimes was determined only on ADF. However, significant effects of both sewage sludge doses ($p \leq 0.01$) and irrigation regimes ($p \leq 0.05$) were determined in the average of the trial years (Tablo 1).

Table 4. Acid detergent fiber (ADF) values (%) in silage maize at different sewage sludge doses and irrigation treatments

Year	IT	D0	D1	D2	D3	Mean
2021	S1	29.1±0.32	28.2±0.59	28.0±0.08	27.7±0.41	28.3±0.23B
	S2	29.6±0.37	28.3±0.41	28.3±0.35	27.8±0.26	28.5±0.25B
	S3	30.2±0.37	29.0±0.38	28.8±0.46	28.0±0.08	29.0±0.28A*
	Mean	29.6±0.24A*	28.5±0.27B	28.4±0.21B	27.9±0.15B	
2022	S1	30.1±0.32	29.2±0.59	29.0±0.08	28.7±0.41	29.3±0.23B
	S2	30.6±0.37	29.3±0.41	29.3±0.35	28.8±0.26	29.5±0.25B
	S3	31.2±0.37	30.0±0.38	29.8±0.46	29.0±0.08	30.0±0.28A*
	Mean	30.6±0.24A*	29.5±0.27B	29.4±0.21B	28.9±0.15B	
2021-2022	S1	29.6±0.32	28.7±0.59	28.5±0.08	28.2±0.41	28.8±0.23B
	S2	30.1±0.37	28.8±0.41	28.8±0.35	28.3±0.26	29.0±0.25B
	S3	30.7±0.37	29.5±0.38	29.3±0.46	28.5±0.08	29.5±0.28A*
	Mean	30.1±0.24A*	29.0±0.27B	28.9±0.21B	28.4±0.15B	

IT: Irrigation treatment; D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, D3: 90 t/ha. S1, S2, and S3: irrigation when ∑ (estimated evapotranspiration – effective precipitation) equals to 25 mm, 50 mm and 75 mm, respectively; *: $p < 0.05$

Table 5. Neutral detergent fiber (NDF) values (%) in silage maize at different sewage sludge doses and irrigation treatments

Year	IT	D0	D1	D2	D3	Mean
2021	S1	57.6±0.42	57.5±0.52	56.7±0.16	55.1±0.56	56.7±0.36
	S2	57.7±0.18	57.5±0.32	56.8±0.35	55.4±0.34	56.8±0.30
	S3	58.1±0.20	57.9±0.13	57.1±0.43	56.0±0.21	57.3±0.27
	Mean	57.8±0.16A*	57.7±0.19A	56.9±0.18B	55.5±0.24C	
2022	S1	60.2±0.26	59.7±0.22	58.2±0.23	57.2±0.57	58.8±0.39
	S2	60.3±0.24	59.7±0.36	58.5±0.34	57.7±0.30	59.1±0.34
	S3	60.6±0.28	59.8±0.21	58.7±0.55	57.7±0.21	59.2±0.36
	Mean	60.4±0.15A*	59.8±0.14B	58.5±0.21C	57.5±0.21D	
2021-2022	S1	58.9±0.32	58.6±0.29	57.5±0.09	56.2±0.04	57.8±0.34B
	S2	59.0±0.12	58.6±0.33	57.7±0.28	56.5±0.13	57.9±0.31AB
	S3	59.3±0.19	58.9±0.17	57.9±0.37	56.9±0.19	58.3±0.30A*
	Mean	59.1±0.13A*	58.7±0.14A	57.7±0.15B	56.5±0.13C	

IT: Irrigation treatment; D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, D3: 90 t/ha. S1, S2, and S3: irrigation when ∑ (estimated evapotranspiration – effective precipitation) equals to 25 mm, 50 mm and 75 mm, respectively; *: $p < 0.05$

The lowest ADF and NDF values were determined in D3 treatment among sewage sludge doses and S1 treatment among irrigation regimes in both trial years (Tables 4 and 5). When the two-year average is considered, in D3 treatment, ADF value was found to be 5.6%, 2.1% and 1.7% lower compared to D0, D1 and D2 treatments, respectively; NDF value was found to be 4.4%, 3.7% and 2.1% lower. For S1 treatment, ADF value was found to be 0.69% and 2.4% lower compared to S2 and S3, respectively, and NDF value was found to be 0.86% lower compared to S3.

Crude protein value was significantly affected by both sewage sludge doses ($p \leq 0.01$) and irrigation regimes ($p \leq 0.05$) in both experimental years and the average of the years ($p \leq 0.01$) (Tablo 1). According to two-year averages, D3 treatment increased the crude protein value by 27.3%, 15.5% and 7.7% compared to D0, D1 and D2 treatments, respectively (Table 6). In the S1 treatment, the increase was 3.0% compared to the S3 treatment. It was evaluated that the main reason for the increase in the crude protein value with the ratio of sewage sludge application was due to the high nitrogen content of the sewage sludge. Kale et al. 2018 and Yerli et al. (2023) reported that there was an increase in the crude protein value in silage maize as the content of nitrogen in the soil and therefore in the plant increased. Therefore, in the S3 treatment, it was evaluated that the increased stress between irrigations caused lower crude protein value with less plant N uptake compared to more frequent irrigations. Previous studies have reported that as water stress increases in silage maize, the protein content decreases because the plant cannot get enough nutrients (Aydınsakir et al., 2013; Cakmakcı, 2018, Yerli et al., 2023).

Yerli et al. (2023) indicated that lower ADF and NDF values in silage maize are associated with the higher crop N content, so crude protein content. Therefore, it was evaluated that the lower ADF and NDF values in D3 treatment were associated with the increase in crude protein values from the increase in sewage sludge dose (Table 6). Correlative relationships between crude protein and ADF and NDF also show that the increase in crude protein leads to a significant decrease in ADF and NDF values (Figures 2 and 3). Many previous studies have shown that increasing the protein content in silage maize via increasing N content reduces the ADF value (Kaplan et al., 2016; Kale et al., 2018; Cakmakcı, 2018; Yerli et al., 2023). Nitrogen is an essential nutrient for plant growth and development. Plants with high nitrogen content can increase their photosynthetic activity by remaining active for longer periods of time. This delays the maturation process of the plant and can therefore positively affect the health and productivity of the plant. Therefore, Safdarian et al. (2014) reported that the delay in the maturation process of the plant due to the effect of nitrogen caused the decrease of ADF and NDF, and indicated the negative relationship of N with ADF and NDF.

Table 6. Crude protein values (%) in silage maize at different sewage sludge doses and irrigation treatments

Year	IT	D0	D1	D2	D3	Mean
2021	S1	8.9±0.18	9.9±0.08	10.9±0.04	11.8±0.01	10.4±0.33A*
	S2	8.8±0.03	9.8±0.09	10.8±0.06	11.7±0.04	10.3±0.33AB
	S3	8.7±0.05	9.7±0.04	10.8±0.16	11.6±0.03	10.2±0.33B
	Mean	8.8±0.06D	9.8±0.05C	10.8±0.05B	11.7±0.03A*	
2022	S1	9.1±0.18	9.8±0.10	10.2±0.11	10.9±0.26	10.0±0.22A*
	S2	8.7±0.03	9.5±0.13	10.1±0.30	10.8±0.22	9.8±0.25AB
	S3	8.6±0.12	9.4±0.18	9.9±0.17	10.7±0.27	9.7±0.24 B
	Mean	8.8±0.09D	9.6±0.09C	10.0±0.11B	10.8±0.13A*	
2021-2022	S1	9.0±0.18	9.9±0.05	10.5±0.06	11.3±0.14	10.2±0.27A*
	S2	8.8±0.02	9.7±0.02	10.5±0.17	11.2±0.13	10.0±0.28AB
	S3	8.7±0.06	9.6±0.09	10.3±0.01	11.2±0.12	9.9±0.28B
	Mean	8.8±0.07D	9.7±0.05C	10.4±0.06B	11.2±0.07A*	

IT: Irrigation treatment; D0: 0 t/ha, D1: 30 t/ha, D2: 60 t/ha, D3: 90 t/ha. S1, S2, and S3: irrigation when ∑ (estimated evapotranspiration – effective precipitation) equals to 25 mm, 50 mm and 75 mm, respectively; *: $p < 0.05$

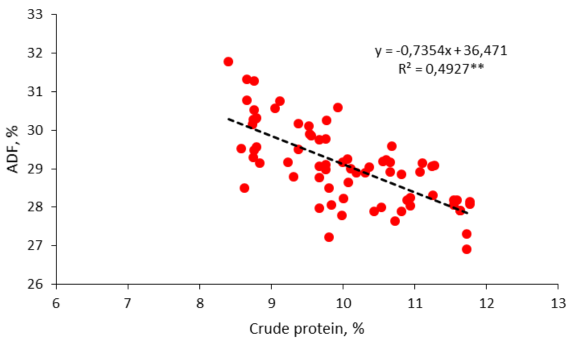

Figure 2. Relationship between crude protein and acid detergent fiber (ADF) (n = 72, **: $p < 0.01$)

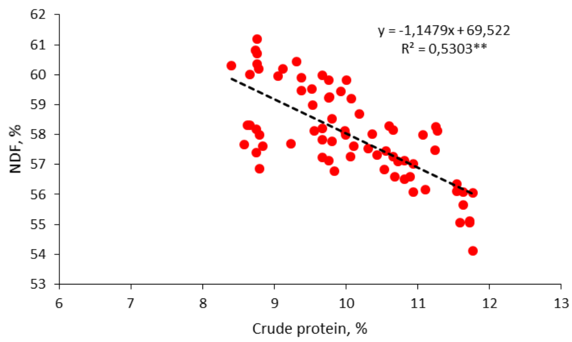

Figure 3. Relationship between crude protein and neutral detergent fiber (NDF) (n = 72, **: $p < 0.01$)

Conclusion

In this study, the effects of different doses of sewage sludge in soil on biomass yield and quality of biomass of silage maize under frequent and wider intervals irrigation regimes were investigated. Frequent irrigation and high dose of sewage sludge provided better finding for yield and quality. At 90 t /ha, 60 t/ha, and 30 t/ha sewage sludge doses, fresh and dry yields under frequent irrigation were approximately 1.4 times, 1.2 times, and 1.1 times higher than those under frequent irrigation without sewage sludge. Frequent irrigation at the highest dose decreased ADF and NDF approximately 5%, and increased crude protein 26% compared to the treatment without sewage sludge. Therefore, it can be concluded that frequent irrigation in sewage sludge dose of 90 t/ha can be the better practice to obtain higher yield and quality forage in silage maize cultivation. However, these findings need to enlargement with the findings under different climatic conditions and also higher doses.

Declarations

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Conflict of Interest

The authors declare no conflict of interest.

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