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EFFECTS OF DIFFERENT TREATED WASTEWATER LEVELS ON MAIZE GERMINATED IN HYDROPONIC ENVIRONMENT

Murat KARAER[1]*

[1]Bilecik Seyh Edebali University, Faculty of Agriculture and Natural Science, Department of Biosystems Engineering, 11100, Bilecik, Türkiye

Abstract: This study aimed to evaluate the effects of different treated wastewater levels on maize germination in a hydroponic system. The experiment was conducted in the plant growth chamber of Bilecik Şeyh Edebali University laboratories using a randomized complete block design. Five irrigation treatments were applied, consisting of treated wastewater levels of 0%, 25%, 50%, 75%, and 100%. The results demonstrated that higher levels of treated wastewater (75% and 100%) negatively impacted parameters such as green forage yield, shoot length, and root length. Conversely, the best outcomes were observed at the 25% treated wastewater level, which significantly enhanced plant growth metrics. The highest green fodder yield as 13745.9 g m^{-2}, dry matter yield as 1559.54 g m^{-2} and plant height as 15.99 cm were obtained from TWW25 subject. These findings indicate that moderate levels of treated wastewater can be effectively utilized in hydroponic systems to optimize maize growth while minimizing potential adverse effects associated with higher wastewater concentrations.

Keywords: Treated waste water, Germination, Hydroponic system

***Corresponding author:** Bilecik Seyh Edebali University, Faculty of Agriculture and Natural Science, Department of Biosystems Engineering, 11100, Bilecik, Türkiye
E mail: murat.karaer@bilecik.edu.tr (M. KARAER)
Murat KARAER https://orcid.org/0000-0002-1920-181X

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1. Introduction

Water is a vital, limited, and strategically important natural resource essential for the survival of all living organisms on Earth (Mengü et al., 2008). In recent years, due to population growth, global warming, climate change, and other environmental factors, the water crisis has increasingly become a significant global issue. This growing crisis has led to a rise in research on the use of alternative water resources as access to clean water sources diminishes worldwide. In this context, one of the most critical alternative water resources is treated wastewater, which is reclaimed through advanced treatment technologies. The use of treated wastewater is particularly important in the agricultural sector, the largest consumer of water. The utilization of wastewater in agriculture offers a significant opportunity for both water resource conservation and sustainable agricultural practices. Especially in regions experiencing water scarcity, treated wastewater has become a viable alternative for agricultural irrigation. Owing to its content of organic matter and nutrients, treated wastewater can support plant growth, potentially reducing the need for chemical fertilizers (Pedrero et al., 2010). However, the use of wastewater in agriculture necessitates controlling its contaminants and pathogens. When appropriate treatment methods are employed, such water not only contributes to water savings but also enhances agricultural productivity (Angelakis et al., 2018). Therefore, the utilization of wastewater for agricultural irrigation is regarded as a critical strategy in addressing global challenges such as climate change and diminishing water resources.

In our country, the inability to ensure a sufficient supply of forage throughout the year in the livestock sector leads to suboptimal animal nutrition and threatens the sustainability of economically viable livestock activities. To meet the demand for forage, roughages obtained from pastures, meadows, and forage crop cultivation areas are utilized. Additionally, alternative sources such as cereal residues (straw, hay) and industrial crop by-products (pulp, etc.) are also employed. However, the provision of forage, especially during the winter months, emerges as a significant challenge. While dry hay and silage are commonly used in winter, a limited amount of forage pelleting is also carried out for animal feeding (Kılıç, 2016). Nevertheless, these sources fall short of fully meeting the forage requirements of livestock during the winter season. In this context, alternative solutions for forage provision are becoming increasingly important. The germination method conducted in hydroponic environments stands out as a potential solution to address forage needs.

Hydroponic systems are a prominent, sustainable, and efficient production technology within soilless farming methods. These systems eliminate the need for soil in agricultural production by using water-based solutions that deliver essential nutrients directly to plant roots. Hydroponic farming ensures the efficient use of water resources, reducing water consumption by up to 90% compared to traditional agriculture (Sharma et al., 2018). Furthermore, the faster access of plants to nutrients enhances growth rates and increases crop yields. Hydroponic systems also improve disease and pest control, thereby reducing the need for chemical pesticides (Resh, 2022). Consequently, hydroponic farming plays a critical role in ensuring food security, particularly in water-scarce regions and areas with high urbanization.

Hydroponic germination is of great importance as it enables the production of high-quality and sustainable feed for livestock. Through this method, water and nutrients are delivered directly to plant roots in a controlled environment, allowing for the rapid generation of dense biomass without the need for soil. Compared to traditional feed production methods, hydroponic systems require less water and land, making feed production more sustainable, especially in regions facing water scarcity and limited agricultural land (Naik et al., 2012). Additionally, hydroponic feed is highly digestible and rich in nutritional content, which can enhance the growth performance of livestock. This system contributes to the conservation of natural resources and reduces the environmental impact of livestock production (Sneath and McIntosh, 2003).

The use of treated wastewater in hydroponic germination holds significant potential for the efficient utilization of water resources. When treated wastewater meets the required hygiene and quality standards, it can be used for irrigation in hydroponic systems. Treated wastewater may contain organic matter and nutrients essential for plant growth, thereby reducing the need for fertilizers in hydroponic systems (Capra and Scicolone, 2007). However, potential risk factors such as salinity and heavy metal levels in the water must be carefully monitored and managed. With appropriate treatment techniques, these risks can be minimized, enabling the use of wastewater in hydroponic germination to conserve water and mitigate environmental impacts (Pedrero and Alarcón, 2009).

In this study, treated wastewater was diluted at different rates and used to germinate maize plants in a hydroponic system. The results indicated that treated wastewater applied at low concentrations promoted growth parameters.

2. Materials and Methods

The research was conducted in a climate-controlled chamber located at the laboratories of Bilecik Şeyh Edebali University. The plant material used in the study was the Pioneer P1551 silage maize variety. The seeds were germinated in plastic containers measuring 30×20 cm. The experiment was designed as a randomized complete block design with five different irrigation treatments and three replicates. The irrigation treatments were created by diluting treated wastewater at varying rates, as shown in Table 1.

Table 1. Experimental treatments and their descriptions

Irrigation Treatments	Description of Irrigation Treatments
TWW100	Germination with 100% Treated Wastewater
TWW75	Germination with 75% Treated Wastewater + 25% Fresh Water
TWW50	Germination with 50% Treated Wastewater + 50% Fresh Water
TWW25	Germination with 25% Treated Wastewater + 75% Fresh Water
Control	Germination with 100% Fresh Water

The treated wastewater used in the study was taken from Bilecik Şeyh Edebali University's wastewater treatment plant. The analysis results for the wastewater sample are given in Table 2.

Table 2. Analysis result of treated waste water

Parameters	Analysis Method	Analysis Result	Limit Value
pH	SM 4500H+B	7.28	6-9
Suspended Solid Matter	SM2540-D	53.350 mg/l	60
Chemical Oxygen Demand	SM5220 B	52.437 mg/l	160
Biochemical Oxygen Demand	SM 5210 D	21 mg/l	50

In all treatments, the seed density was adjusted to 4 kg m^2, and the germination process was carried out for 8 days. The room temperature was set at 24 ºC with a light cycle of 16 hours and a dark cycle of 8 hours. Before germination, the seeds were sterilized by soaking in a 10% sodium hypochlorite solution for 5 minutes. At the end of the 8 days, all materials in the containers were removed, and the necessary measurements and analyses were conducted. (Karaşahin 2014).

The properties determined in the study are as follows:

Green Forage Yield (g m^2): The harvested green forage was weighed on a precision scale after being left outside for 1 hour. The amount obtained was then scaled to the area of the container, and the green forage yield per square meter was calculated (Karaşahin 2014).

Dry Matter Content (%): After weighing the green forage, 100 kg samples were taken and dried in a drying oven at 70 °C until a constant weight was achieved, after which they were weighed on a precision scale. The resulting values were expressed as a ratio to the green forage weight (Karaşahin 2014).

Dry Matter Yield (g m^2): This was obtained by multiplying the green forage yields by the dry matter content percentages (Karaşahin 2014).

Plant Height (cm): After harvest, five plants were randomly selected from each replicate and measured from the root region using a ruler (Daud et al., 2016).

Root Length (cm): After harvest, five plants were randomly selected from each replicate, and the root length was measured from the seed region using a ruler (Daud et al., 2016).

Fresh Weight of Root and Stem: The samples taken to determine root and stem lengths were weighed to determine their fresh weight (Atak et al., 2006).

Dry Weight of Root and Stem: The fresh weight samples were dried in a drying oven at 70 °C until they reached a constant weight, and then weighed to determine their dry weight (Atak et al., 2006).

The obtained data were subjected to analysis of variance (ANOVA) using the Minitab 19 software, and Tukey's multiple comparison test was used to compare the means.

3. Results and Discussion

To evaluate the usability of treated wastewater in hydroponic cultivation, a hydroponic germination trial was conducted using maize plants at different treated wastewater levels. At the end of the germination process, it was determined that the treated wastewater levels had statistically significant effects on the measured parameters.

The green fodder yield ranged from 13745.9 to 3713.5 g m^{-2}, with the highest green fodder yield observed in the TWW25 treatment and the lowest in the TWW75 treatment (Table 3). When the treated wastewater concentration exceeded 50%, significant decreases in yield were observed. This indicates that high TWW concentrations can negatively impact plant growth (Daifi et al., 2015). Specifically, the green fodder yields for the TWW75 and TWW100 treatments decreased to 3713.5 g m^{-2} and 4215.7 g m^{-2}, respectively. As the concentration of treated wastewater increased, a rise in dry matter content was observed. While the control group had a dry matter content of 11.5%, the TWW75 group reached the highest value at 14.9%. This increase suggests that plants under higher stress conditions may reduce water uptake (Tüfenkçi et al., 2023). The control and TWW25 groups exhibited the highest dry matter yields, at 1419.35 g m^{-2} and 1559.54 g m^{-2}, respectively. In contrast, significant decreases in dry matter yield were observed in the TWW50, TWW75, and TWW100 treatments, reflecting the restrictive effects of high TWW concentrations on plant growth. The results indicate that low concentrations of treated wastewater (TWW25) could serve as a suiTable irrigation source for maize plants, whereas higher concentrations adversely affect plant growth. Similar findings have been reported in studies on other plant species. It has been emphasized that treated wastewater at specific concentrations positively impacts germination and seedling development, thereby enhancing biomass and green fodder yields. However, excessive application of treated wastewater has been observed to negatively affect plant growth (Daud et al., 2016; Ramana et al., 2002; Yousaf et al., 2010; Rusan et al., 2007; Kardes et al., 2020).

These results are supported by the study of Pedrero et al. (2014), which suggested that the use of treated wastewater at low concentrations not only conserves water in agricultural production but also enhances yield.

Table 3. Effects of different treated wastewater levels on green fodder yield, dry matter content, and dry matter yield

	Green Fodder Yield ** (g m^{-2})	Dry Matter Content ** (%)	Dry Matter Yield** (g m^{-2})
Control	12329.4^{ab}	11.5^{c}	1419.35^{a}
TWW25	13745.9^{a}	11.3^{c}	1559.54^{a}
TWW50	5588.7^{bc}	12.7^{bc}	725.61^{b}
TWW75	3713.5^{c}	14.9^{a}	555.57^{b}
TWW100	4215.7^{c}	13.7^{ab}	581.1^{b}

*= $P\leq0.05$; **= $P\leq0.01$

Figure 1 and 2 illustrates the plant height values of maize germinated under different treated wastewater (TWW) levels. In the TWW25 treatment, plant height reached the highest value of 15.99 cm, indicating that low concentrations of treated wastewater promote plant growth. The plant height in the control group (10.84 cm) was statistically similar to the TWW50 (11.22 cm) and TWW100 (11.56 cm) treatments. However, the TWW75 treatment recorded the lowest plant height at 9.76 cm. This suggests that a moderate level of TWW may have an inhibitory effect on plant growth. The promotion of plant growth by low concentrations of TWW, due to increased nitrogen and other nutrients in the irrigation water, is supported by the literature (Smith et al., 2021). However, the toxic effects observed at higher concentrations, particularly due to salinity and the accumulation of heavy metals, can negatively impact plant metabolism (Brown and Wong 2018). The low plant height observed in TWW75 aligns with previous studies, which indicate that high ion accumulation or salinity induces osmotic stress, thereby limiting plant growth (Lopez et al., 2019).

Regarding root length, the control group exhibited the highest value of 9.84 cm. However, root length decreased under all treated wastewater applications. In the TWW25 group, root length was measured at 7.07 cm, which, while lower than the control, was statistically similar. In contrast, other TWW levels exhibited a significant reduction in root length. This decrease is likely attribuTable to the increased levels of salts, heavy metals, or other toxic compounds in the wastewater, which adversely affect root development. Similarly, studies by Rusan et al. (2007) and Yadav et al. (2002) have highlighted the negative effects of high levels of treated wastewater on plant growth parameters. These results indicate that treated wastewater should be applied at low concentrations when used for irrigation, as higher doses negatively impact plant growth. The findings suggest that low-level TWW applications optimize maize growth, whereas moderate and high levels increase the risk of toxicity.

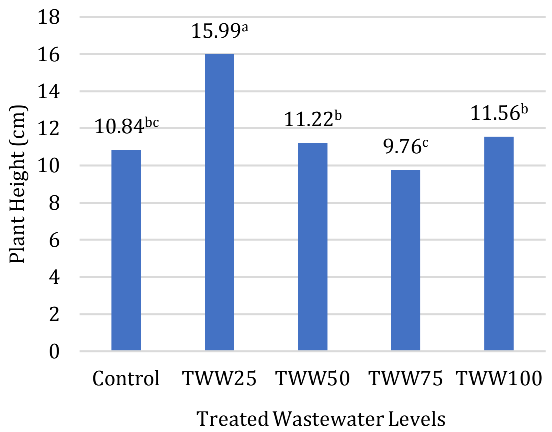

Figure 1. Effects of different treated wastewater levels on plant height.

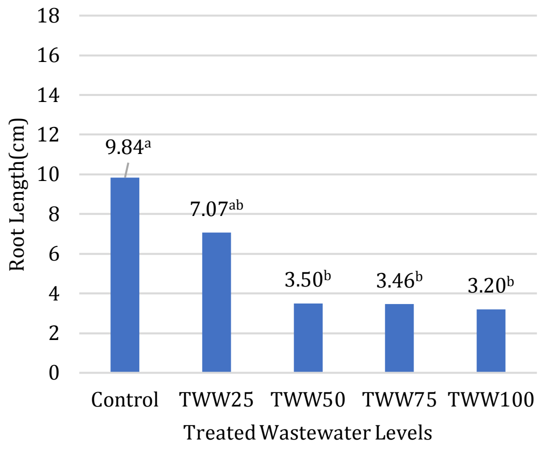

Figure 2. Effects of different treated wastewater levels on root length values.

When examining the effects of treated wastewater applications on the stem development of maize plants, it was determined that fresh weight values ranged between 2.04–1.30 g, while dry weight values varied between 0.14–0.23 g (Table 3). The highest stem fresh weight (2.04 g) was observed in the TWW25 treatment, indicating that low levels of treated wastewater could promote stem development. However, in the TWW75 (1.86 g) and TWW100 (1.76 g) treatments, fresh weight values were higher compared to the control group but lower than the TWW25 group, suggesting that increasing concentrations of treated wastewater might negatively affect stem growth.

In terms of dry weight, the TWW75 (0.22 g) and TWW100 (0.23 g) treatments achieved the highest stem dry weights compared to the control group (0.14 g) and the TWW25 treatment (0.21 g), indicating that medium and high levels of treated wastewater could enhance stem biomass density. Previous studies have reported that moderate levels of wastewater can stimulate plant growth through increased nutrient availability and nitrogen accumulation (Smith et al., 2021), while higher concentrations may exert toxic effects (Brown and Wong 2018). Additionally, the elevated dry weight values in the TWW100 group suggest structural density increases in stem cells (Lopez et al., 2019). Overall, the data indicate that low TWW levels (TWW25) provide optimal conditions for stem fresh weight, whereas the increase in stem dry weight at higher TWW levels (TWW75 and TWW100) may be associated with structural changes.

When the effects of treated wastewater applications on maize root development were examined, fresh weight values ranged between 0.67–0.39 g, while dry weight values varied between 0.13–0.06 g (Table 4). The TWW75 treatment provided an optimal environment, achieving the highest root fresh weight (0.67 g) and dry weight (0.13 g). This indicates that moderately diluted treated wastewater can enhance root biomass and density, thereby promoting root development. Although the control group exhibited a relatively high root fresh weight (0.58 g), it lagged behind the TWW75 group in terms of dry weight.

In the TWW100 treatment, significant reductions in both root fresh weight (0.39 g) and dry weight (0.06 g) were observed, suggesting that high concentrations of treated wastewater may hinder root development due to toxic effects such as salinity or heavy metal content. The literature highlights that moderate levels of wastewater increase nutrient availability and water retention in the root zone, whereas higher concentrations result in toxic effects (Brown and Wong 2018). High salinity levels, in particular, are known to induce water stress and adversely affect root growth (Lopez et al., 2019). These findings suggest that TWW75 could serve as an ideal irrigation strategy for root development in maize, although pretreatment technologies may be necessary to mitigate the toxic ions present at higher TWW levels.

Previous studies have also reported that low concentrations of treated wastewater positively impact plant growth, while increasing wastewater concentrations negatively affect plant development. Çatak and Korkmaz (2024) observed that the application of dye wastewater at concentrations of 25% or higher inhibited the growth of both tomato and pepper seeds, with adverse effects not only on seed germination but also on root and hypocotyl formation and development. Similarly, Gassama et al. (2015) found that low concentrations (<25%) of wastewater exhibited low phytotoxicity on crop growth and development, while higher concentrations (50%–100%) demonstrated significant phytotoxicity, reducing growth and development during the rice germination process

Table 4. Effects of different treated wastewater levels on fresh and dry weights of stems and roots

	Treated Wastewater Levels				
	Control	TWW25	TWW50	TWW75	TWW100
Fresh Weight of Root**(g)	0.58[ab]	0.46[ab]	0.49[ab]	0.67[a]	0.39[b]
Dry Weight of Root**(g)	0.07[b]	0.06[b]	0.07[b]	0.13[a]	0.06[b]
Fresh Weight of Stem**(g)	1.30[b]	2.04[a]	1.61[ab]	1.86[a]	1.76[ab]
Dry Weight of Stem**(g)	0.14[b]	0.21[ab]	0.20[ab]	0.22[a]	0.23[a]

*= P≤0.05; **= P≤0.01

4. Conclusion

This study was conducted to evaluate the effects of different levels of treated wastewater on maize seeds germinated in a hydroponic environment. The results revealed that the 25% treated wastewater level (TWW25) provided the most favorable conditions in terms of germination parameters. However, when the treated wastewater level exceeded 25%, significant reductions were observed in parameters such as germination rate, root development, and shoot growth. This indicates that high levels of treated wastewater have adverse effects on plant physiology. In conclusion, determining the optimal application levels is crucial for the safe and sustainable use of treated wastewater in agricultural practices.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	M.K.
C	50
D	60
S	80
DCP	60
DAI	50
L	60
W	100
CR	50
SR	100
PM	100
FA	

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

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