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Research Article

Textile Effluent Impact on Rice (*Oryza sativa L.*) Growth Attributes in Sandy Clay Loam Soil

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ABSTRACT

The degradation of soil caused by untreated textile effluent poses a significant threat in Pakistan. Therefore, during this study, a pot experiment quantified the impact of untreated industrial effluent on the growth attributes and heavy metal concentration (Cu and Cd) in rice. Wastewater samples were collected from two different industries and the treatments were comprised of control (tape water), Rashid printing textile effluent (RPTE), RPTE (40% dilution), Mamtaz mehal textile effluent (MMTE), MMTE (40% dilution), and RPTE (50% dilution) + MMTE (50% dilution) applied as irrigation water. Samples were evaluated for various traits including heavy metals (Cu and Cd). The highest shoot length cm (28.3) was recorded in the control treatment followed by RPTE (40% dilution) treatment (26.0) having a similar trend for fresh and dry shoot weight (g). The highest root length (7.9 cm) was recorded in the control treatment followed by RPTE (40% dilution) treatment (6.9 cm) and the same trend was observed for fresh and dry root weight (g). A similar trend was observed for tillers plant^{-1}. In the case of heavy metals, the highest Cd shoot concentration (mg kg^{-1}) was recorded in RPTE while the highest Cd concentration in root was recorded in treatment MMTE, and a similar trend was observed for post-harvest soil Cd concentration. Highest shoot Cu concentration (mg kg^{-1}) was recorded for treatment MMTE and the same trend was observed for roots while the highest concentration of Cu for post-harvest soil was recorded for treatment RPTE. The results depicted that the application of contaminated effluent leads to the development of heavy metal toxicity in the soil. Furthermore, higher concentrations of effluent not only exacerbated heavy metal toxicity but also reduced the growth of rice. Therefore, regular monitoring by government agencies is recommended to ensure the production of safe and healthy food.

Keywords: Biomass, Heavy metals, Effluent, Copper, Cadmium, Soil pollution.

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INTRODUCTION

Sustainable Development Goal 6 of the United Nations emphasizes the importance of reusing treated wastewater to ensure water availability for all. Given that the agriculture sector is one of the largest water consumers, utilizing treated wastewater for crop irrigation is a practical and sustainable option (Janczukowicz and Rodziewicz, 2024). Since its independence, Pakistan's industrial sector has been growing rapidly, positioning the country as a semi-industrial nation. Key industries include textiles, vanaspati ghee, machinery, cement, fertilizers, sugar, chemicals, and paper, among others. Unfortunately, many of these industries discharge untreated effluent into drains, which are then used by farmers for irrigation.

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This practice leads to heavy metals accumulation in soils, adversely affecting soil properties, seed germination, growth of plant, human health, and the environment (Alam et al., 2023; Singh, 2021).

A significant portion of wastewater originates from the textile industry, which is a major contributor to Pakistan's economy accounting for 7.4% of the gross domestic product (GDP), 55.6% of exports, and employing 38% of the total manufacturing labor. The study also analyzed domestic rice consumption trends among major rice-exporting countries. The findings revealed that, compared to other leading global rice exporters, Pakistan holds a significant competitive and comparative advantage in rice production (Fadah et al., 2024). The textile industry is a significant contaminant of water and soil systems, with its effluent comprising high concentrations of heavy metals, acids, and dyes. Water quality degradation due to these pollutants makes it unsuitable for use (Saratale et al., 2011). Water quality decline has a severe impact on marine ecosystems and on the health of end users. Industrial zones mostly witness immature fruit dropping, and malformed, and unwanted fruit (Zebunnesa, 2012).

Textile effluent is also recognized as the source of essential nutrients, such as N, P, and Ca, which can positively impact crop growth (Kannan et al., 2005). The presence of these nutrients has been found to enhance various aspects of plant development, including germination, chlorophyll content, and yield-related factors (Yogi et al., 2024). Numerous studies have explored the effects of different types of industrial wastewater on seed germination in crops like maize (Choudhary et al., 1987), rice (Behera and Misra, 1982), and wheat (Nagda et al., 2006). These studies suggest that wastewater could potentially serve as an alternative irrigation source.

Treated effluent use for irrigation offers various benefits, like reduction in groundwater quality degradation, increasing aquifer recovery, and decline in seawater intrusion (Al-Juaidi, 2009). Rice is member of Graminae family, is a staple food that sustains over 3 billion people, making it essential for more than half of the world's population. Due to its significant economic value, rice has been domesticated and widely cultivated. In Pakistan, rice is the second most important cereal crop, grown over a vast area and serving as a major export commodity (Ladha et al., 1997). The crop contributes 0.4% to Pakistan's GDP, with a production of 7.322 million tons cultivated over 2,976 thousand hectares in 2013-14 (Pakistan, 2014). Globally, rice provides 21% of per capita dietary energy and 15% of per capita protein intake (Depar et al., 2011).

Rice is frequently cultivated in suburban areas near industrial cities, where farmers often face irrigation water shortages. To address this challenge, they may rely on industrial effluent as an alternative water source. However, this effluent can contain heavy metals, which can enter the food chain, adversely affect plant growth, and pose significant risks to human health (Richards et al., 2000). Given these concerns, an experiment was conducted to investigate the effects of untreated industrial effluent on heavy metal accumulation in soils, the subsequent uptake of these metals by rice plants, and the overall impact on rice growth attributes.

MATERIALS AND METHODS

Soil sampling and characterization

The study was conducted using industrial effluent at the Institute of Soil & Environmental Sciences (IS&ES), University of Agriculture Faisalabad. Soil samples were collected from the institute's research field, air-dried at room temperature, and ground into fine particles using a mortar and pestle. The experiment was carried out in cylindrical plastic pots, each measuring 25 cm in diameter and 30 cm in depth, and filled with 8 kg of air-dried soil. Recommended doses of NPK fertilizers were applied in solution form, using urea, diammonium phosphate, and muriate of potash. Twenty days after transplanting, various concentrations of industrial effluents were applied for irrigation. After the experiment, several agronomic parameters were recorded, including shoot and root length, the number of tillers, and the fresh and dry weight of shoots and roots. Following harvest, the plants were thoroughly washed with distilled water and oven-dried at 65°C ± 5°C until a constant weight was achieved. The oven-dried samples were then ground and digested using a diacid mixture (HNO_3) as described by Allen et al. (1986). The digested plant samples were analyzed for heavy metal concentrations in shoots and roots using an atomic absorption spectrophotometer.

Collection and preparation of effluent

Industrial effluent was collected from the main outlet of the RPTE and MMTE processing mill near Chack Bhawa, Faisalabad Sargodha Road. Collected samples of untreated textile effluents were used as irrigation water with or without dilutions, viz., control (only tap water), RPTE, the RPTE + 40% dilution with tap water, the effluent of MMTE, the MMTE + 40% dilution with tap water and RPTE with 50% dilution + MMTE with 50% dilution. Separate effluent samples were preserved in plastic jars and stored at 4°C for subsequent analysis.

The pre-analysis data results of effluent are presented in (Table 1)

Pre-soil analysis

Soil samples were first air-dried, then ground, and finally sieved through a 2 mm mesh. The sieved soil was thoroughly mixed and subsequently stored in a sealed plastic jar. A representative soil sample was analyzed to determine various physico-chemical characteristics. The EC and pH of the soil samples were measured following the methods described by Jackson (1964) (Table 1).

Table 1. Various properties of soil and effluent used during current study.

Parameters	Soil	RPTE	MMTE
Textural class	Sandy clay loam	-	-
ECe (dS m^{-1})	1.68	12.1	17.1
pH	8.20	10.2	9.70
SAR ($mmol_c$ $L^{-1})^{1/2}$	2.45	8.60	11.4
Cu (mg kg^{-1})	2.20	48.7	53.7
Cd (mg kg^{-1})	0.03	0.11	0.14

Treatment plan and experimental design

The collected samples of untreated textile effluents with or without dilutions were used as irrigation water. Experiment was carried out in a completely randomized design (CRD) using six treatments with three replications. Treatments were control (Tap water), the RPTE, RPTE + 40% dilution with tap water, the MMTE, the MMTE processing + 40% dilution with tap water and RPTE with 50% dilution + MMTE with 50% dilution.

The rice variety KS-462 was selected as the test crop for the experiment. Five healthy, 40-day-old rice seedlings were transplanted into each pot and weeding was performed manually as needed. Throughout the total growing period, the plants were closely monitored for disease and pest infestations, with appropriate measures taken when necessary.

Statistical Analysis

The data obtained were statistically analyzed using the Statistix 8.1 software package. A one-way ANOVA was conducted, followed by multiple comparison analyses using an LSD test at a significance level of $P<0.05$. Means were compared by using least significant difference (LSD) test at the 0.05 level to assess the statistical significance of the treatments.

RESULTS

Industrial effluent impact on growth and chemical parameters

The shoot length, and fresh, and dry weight of rice significantly differed with the application of various treatments as compared to control in calcareous soil. Results showed that the highest shoot length was recorded for the control treatment (28.3 g) followed by RPTE with 40% dilution and RPTE while the lowest fresh shoot length was recorded in RPTE (50% dilution) + MMTE (50% dilution). The application of untreated effluents from the RPTE and MMTE significantly decreased shoot length. However, RPTE and MMTE with 40% dilution of effluent showed better shoot length compared with undiluted industrial effluent (Table 2).

In terms of fresh shoot weight, the highest fresh shoot weight (g) was recorded in the control treatment (20.7) while the lowest was noted in treatments RPTE (4.33) and MMTE (4.33). The highest shoot dry weight was also recorded in control (14.4) followed by RPTE with 40% dilution (8.16) while the lowest dry weight was observed in MMTE (3.0) and RPTE (3.5) (Table 2).

Effluent significantly affected the root length and, fresh and dry root weight of rice in all treatments as compared to the control treatment. The highest root length (cm) was recorded in the control treatment (7.9) followed by RPTE (40% dilution), and MMTE (40% dilution) while the lowest root length was recorded in MMTE (5.0). The maximum fresh and dry root weight was recorded in the control treatment at 5.11 and 3.64 cm respectively (Table 3).

Each value represents the mean of three replicates ± SD (n=3). The abbreviations used are as follows: RPTE (Textile effluent from Rashid Printing Industry Pvt. Ltd.); RPTE + 40% dilution with TW (Textile effluent from Rashid Printing

Industry diluted 40% with tap water); MMTE (Textile effluent from Mamtaz Mehal Processing Mills Pvt. Ltd.); MMTE + 40% dilution with TW (Textile effluent from Mamtaz Mehal Processing Mills diluted 40% with tap water).

Table 2: Effect of industrial effluent on shoot growth of rice crop

Treatments	Shoot length (cm)	Fresh shoot weight (g)	Dry shoot weight (g)
Control (TW)	28.3	20.7	14.4
RPTE	20.1	4.33	3.50
RPTE (40% dilution)	26.0	10.8	8.16
MMTE	19.2	4.33	3.00
MMTE (40% dilution)	25.9	9.55	6.45
RPTE (50% dilution) + MMTE (50% dilution)	16.9	4.49	2.95

Table 3: Effect of industrial effluent on root growth of rice crop

Treatments	Root length (cm)	Fresh root weight (g)	Dry root weight (g)
Control (TW)	7.9	5.11	3.64
RPTE	5.2	2.11	0.62
RPTE (40% dilution)	6.9	2.78	1.77
MMTE	5.0	1.66	0.58
MMTE (40% dilution)	5.7	2.44	1.37
RPTE (50% dilution) + MMTE (50% dilution)	3.9	1.11	0.68

The data related to the numbers of total tillers showed significant differences among different treatments as shown in Table 3. The highest number of tillers (plant^{-1}) was recorded in the control treatment (9.0) followed by treatment RPTE (40% dilution) and MMTE (40% dilution) while the lowest number of tillers per plant was recorded in treatment RPTE. However, the overall trend showed an increase in the number of tillers per plant with dilution as compared to concentrated textile effluent application (Table 3).

The results of chlorophyll content are shown in Table 3. There was a non-significant relationship among the treatments. The maximum chlorophyll content (47.0) was recorded in MMTE with 40% dilution while the lowest chlorophyll content was recorded in treatment RPTE with 40% dilution (41.1) of textile effluent.

Table 4: Effect of industrial effluent on tillers per plant and chlorophyll contents

Treatments	Tillers plant^{-1}	Chlorophyll content
Control (TW)	9.0	45.8
RPTE	3.0	44.1
RPTE (40% dilution)	6.0	41.1
MMTE	4.0	46.5
MMTE (40% dilution)	5.0	47.0
RPTE (50% dilution) + MMTE (50% dilution)	3.0	43.3

Each value represents the mean of three replicates ± SD (n=3). The abbreviations used are as follows: RPTE (Textile effluent from Rashid Printing Industry Pvt. Ltd.); RPTE + 40% dilution with TW (Textile effluent from Rashid Printing Industry diluted 40% with tap water); MMTE (Textile effluent from Mamtaz Mehal Processing Mills Pvt. Ltd.); MMTE + 40% dilution with TW (Textile effluent from Mamtaz Mehal Processing Mills diluted 40% with tap water)

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Impact of textile effluent on heavy metals concentration in plants

The application of untreated textile effluent significantly impacted the shoot Cu concentration across all treatments (Figure 1a). The highest shoot Cu concentration (9.55 mg kg⁻¹) was observed in MMTE, while the lowest concentration (3.22 mg kg⁻¹) was recorded in the control treatment. A significant decrease in shoot Cu concentration was noted with the 50% dilution of industrial effluent.

The highest Cu concentration (mg kg⁻¹) in root samples was recorded in RPTE (42.7), followed by MMTE (38.5), while the lowest concentration (18.8) was observed in the control treatment (Figure 1b). A significant difference was noted among all treatments compared to the control. In soil, the highest Cu concentration (mg kg⁻¹) was also found in RPTE (2.98), with the lowest concentration (1.97) recorded in the control treatment (Figure 1c). Overall, a decreasing trend in Cu concentration was observed with the dilution of textile effluent compared to the concentrated effluent.

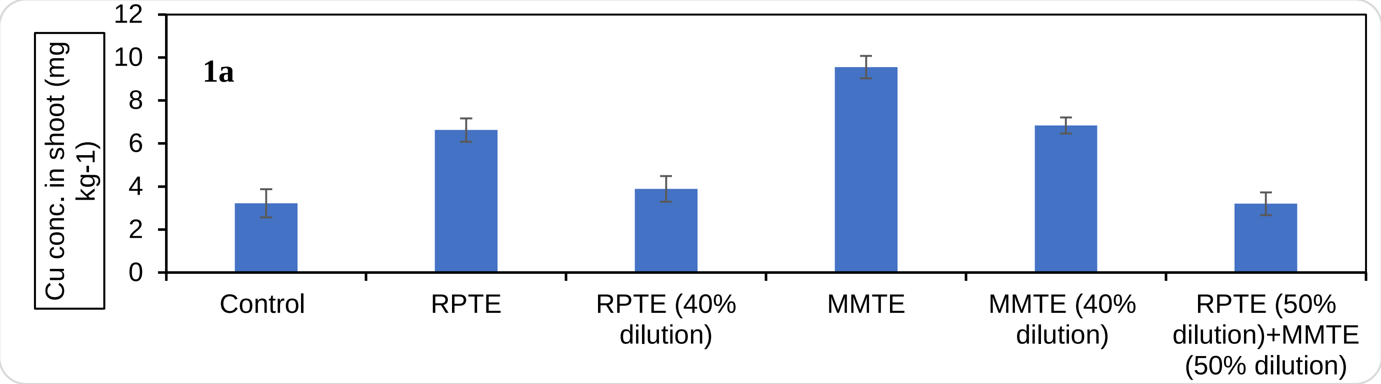

Figure 1a: Impact of textile effluent on copper concentration in rice shoots.

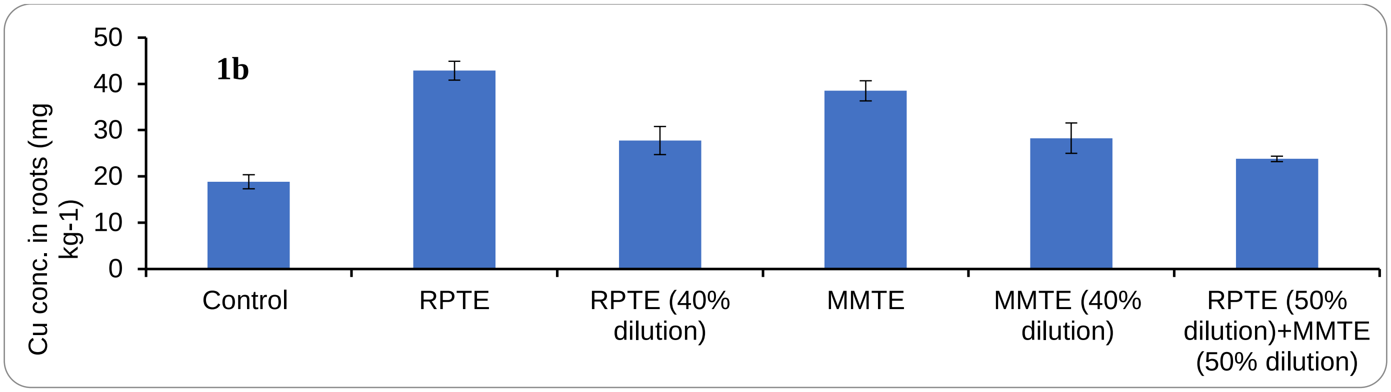

Figure 1b: Impact of textile effluent on copper concentration in rice roots.

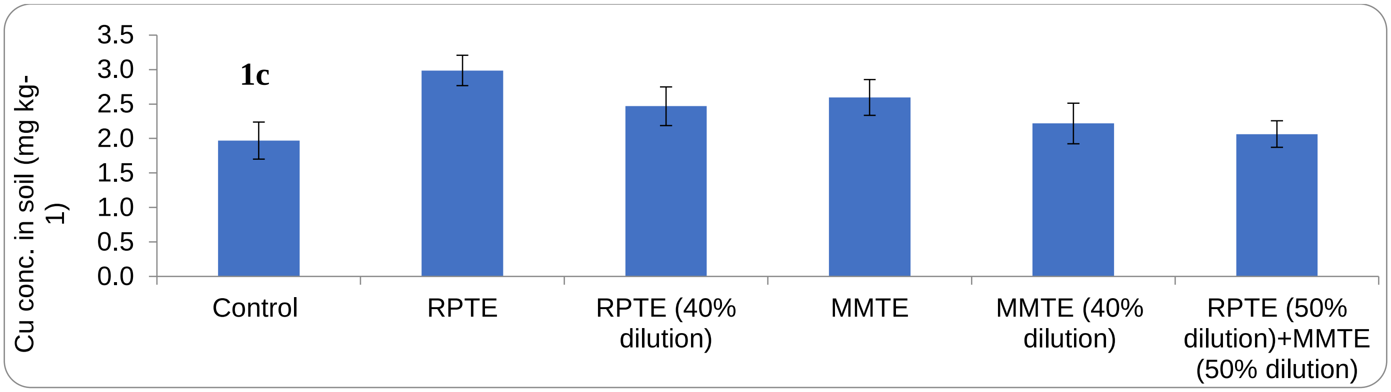

Figure 1c: Impact of textile effluent on copper concentration in post-harvest soil

The application of untreated textile effluent significantly impacted shoot Cd concentration across all treatments. The highest shoot Cd concentration (8.67 mg kg⁻¹) was observed in RPTE, followed by MMTE (7.26 mg kg⁻¹), with the lowest concentration (4.31 mg kg⁻¹) recorded in the control treatment (Figure 2a). The maximum root Cd concentration (18.8 mg kg⁻¹) was found in MMTE, while the lowest (7.91 mg kg⁻¹) was recorded in the control treatment (Figure 2b).

Cd concentration in post-harvest soil is presented in Figure 2c. Significant differences were observed across all treatments compared to the control. The highest Cd concentration (0.44 mg kg⁻¹) was recorded in RPTE, followed by MMTE, while the lowest concentration (0.37 mg kg⁻¹) was found in the control treatment. However, a decreasing trend in Cd concentration was noted in post-harvest soil samples with the dilution of industrial effluent.

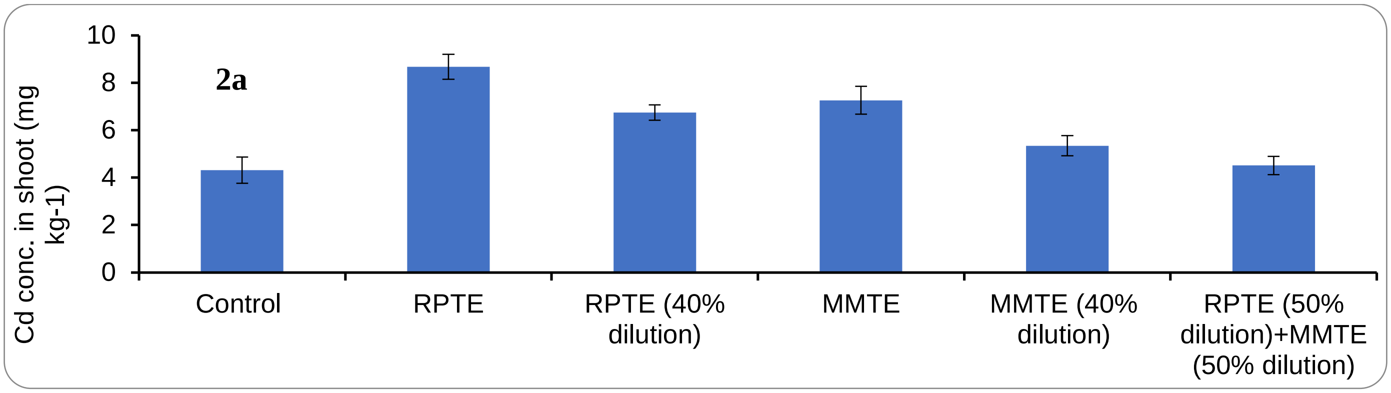

Figure 2a: Impact of textile effluent on Cadmium concentration in rice shoots

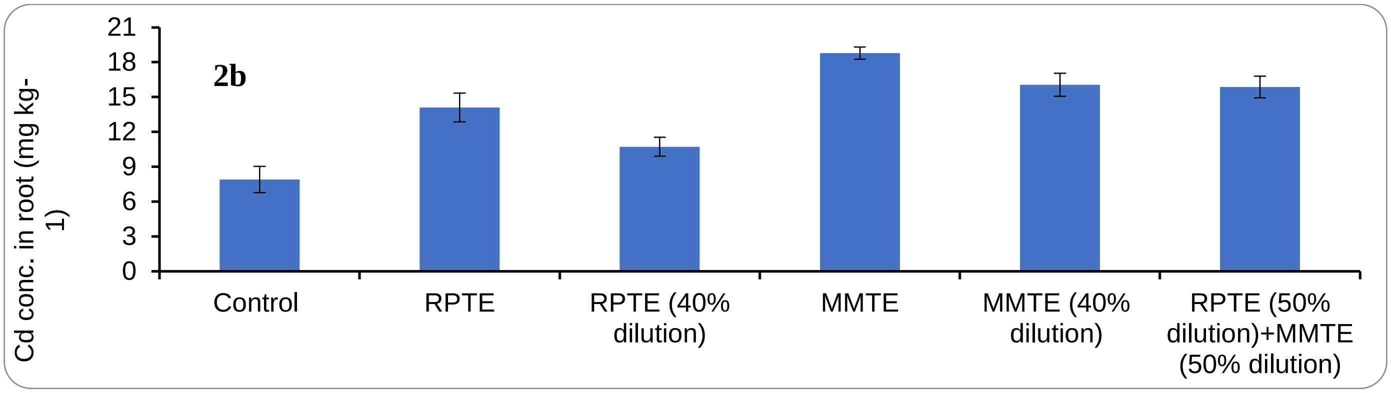

Figure 2b: Impact of textile effluent on Cadmium concentration in rice roots.

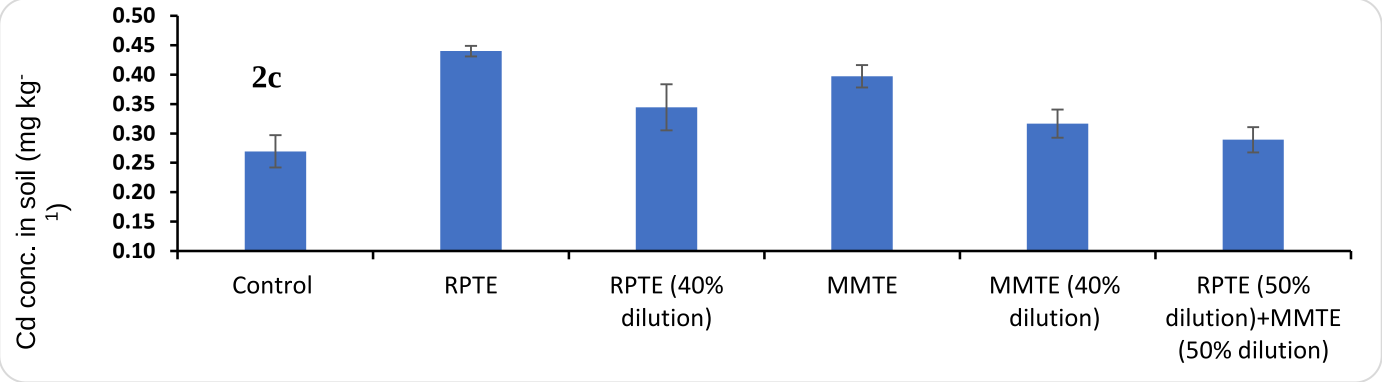

Figure 2c: Impact of textile effluent on Cadmium concentration in post-harvest soil.

DISCUSSION

The growth attributes of rice were significantly negatively affected by the application of untreated textile effluent during this study. Heavy metals present in raw effluent are non-biodegradable, leading to their accumulation in soil. Heavy metals accumulation from textile effluent into plants adversely affects the growth and development of plants (Hossain et al., 2015). In contrast, the growth parameters of rice were observed to be higher in the control treatment, in which the irrigation source was tap water. This improvement in growth is likely attributed to the use of contaminantfree water. In contrast, the use of untreated textile effluent in RPTE and MMTE as irrigation sources resulted in a decrease in crop growth and development. However, the application of diluted textile effluent yielded better growth attributes than untreated effluent.

The application of higher concentration of textile effluent led to an increased concentration of heavy metals in experimental soil and rice roots owing to translocation effects, which subsequently transferred these metals to rice straw and grain. These findings suggest that the use of contaminated effluent can lead to the development of heavy metal toxicity in soil (Polle, 2001; Zhang et al., 2021). These metals are non-biodegradable, and their accumulation in soils facilitates their transfer from effluents to soil and plant cells, ultimately reducing rice plant growth, and resulting in lower yields (Hossain et al., 2015). Rice leaf tissues are known to accumulate >5 times more manganese (Mn) compared to other grasses (Foy et al., 1978). High soil Mn levels have also been linked to a significant decline in chlorophyll content in rice (Zhang et al., 2024).

The uptake of various metals into the roots of plants is a complex process, influenced by the dynamic interactions between plant roots, microorganisms in the rhizosphere, and soil solutions. Essential metals such as copper (Cu), and zinc (Zn) chelate with phytometallophores, making them readily available to plants (Dobermann, 2000). In this study, high concentrations of Cu, and Cd were detected in the potting soil as a result of using highly concentrated effluent for irrigation. Concentration of lead (Pb) typically ranges between 10 to 50 mg/kg in uncontaminated soils, whereas in contaminated soils Pb is around 30 to 100 mg/kg (Moreno Jiménez et al., 2024). Similarly, nickel (Ni) content in soils is generally around 5 and 150 mg/kg (Ene et al., 2024). Long-term use of effluent for irrigation leads to the buildup of heavy metals in the soil, posing a significant ecological risk (Wang et al., 2024).

Heavy metal toxicity usually does not occur in natural soils having native vegetation, even when soils naturally contain high levels of certain metals, as native plants often adapt to these conditions over time (Alam et al., 2024; Millaleo et al., 2010). However, toxicity can develop due to changes in the soil environment, such as alterations in pH, redox potential, and OM content, often resulting from anthropogenic activities like industrial effluent discharge and mining, even without additional metal inputs.

Toxicity of heavy metal arises from a complex interaction between essential and non-essential elements, potentially inhibiting the activity of enzymes such as α-amylase, RNAse, phosphatase, and various proteins (Latif et al., 2008). Cadmium phytotoxicity is particularly evident in reduced biomass (Millaleo et al., 2010). Cadmium exposure negatively impacts seed germination, seedling growth, photosynthetic activity, and transpiration rates (Vareda et al., 2019). In summary, the application of untreated textile effluent results in concentrations of Cu and Cd, in rice shoots and roots, with significant variation in metal concentrations observed across different textile wastewater treatments.

CONCLUSION

Rice growth decreased with the application of raw textile effluent due to the higher concentration of heavy metals. However, diluting the textile effluent reduced its toxic effects to some extent, leading to less severe impacts on rice growth. The study observed higher metal accumulations in the roots, shoots, and soil when untreated textile effluent was used without any dilution. The findings underscore the necessity of treating textile effluent before using it as an irrigation source. It is recommended that effluent treatment should be mandatory to minimize environmental contamination and protect soil and plant health. Additionally, government agencies should implement regular monitoring and enforcement to ensure compliance with effluent treatment regulations. This approach will help safeguard the environment, promote sustainable agricultural practices, and enhance agricultural productivity.

AUTHOR CONTRIBUTIONS

TR: Conceptualization, Formal analysis, Methodology, Investigation, Data curation. TA: Conceptualization, Visualization, Software, Data curation, Writing – review & editing. MKA: Data curation, Review & editing. MS: Review & editing. MB: Review & editing. JH: Review & editing. RS: Review & editing

COMPETING OF INTEREST

The authors declare no competing interests.

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