SULFATES FROM TEXTILE EFFLUENTS AS AN AGRICULTURAL RISK: A CASE STUDY ON BASIL

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ABSTRACT: *Sulfate contamination of textile wastewater (TWW) is a growing concern in water reuse strategies for agriculture. In this study, the effects of untreated TWW with different sulfate concentrations on basil (Ocimum basilicum) were investigated. Two wastewater samples were used: one with high sulfate content (240.8 mg/L) and one with low (21.58 mg/L). No visible phytotoxic effects were observed, but basil irrigated with the high sulfate sample showed reduced shoot height (13.2 cm) compared to 17.8 cm in the low sulfate treatment. The sulfur concentration in the soil was significantly higher in the low sulfate irrigation (11357 mg/kg) than in the high sulfate irrigation (4600 mg/kg). This unexpected result could be due to differences in wastewater composition, sulfur speciation, microbial activity, or plant uptake dynamics. While basil proved resilient to elevated sulfate levels, the study shows how untreated TWW can affect both plant growth and soil chemistry in complex and nonlinear ways. These results underscope the need for detailed characterization of wastewater prior to reuse in agricultural.*

Keywords: *Textile wastewater, Sulfates, Basil, Soil accumulation, Irrigation.*

SULFATI IZ TEKSTILNIH OTPADNIH VODA KAO RIZIK ZA POLJOPRIVREDU: STUDIJA SLUČAJA O BOSILJKU

APSTRAKT: *Onečišćenje sulfatima iz tekstilnih otpadnih voda (TOV) predstavlja sve veći problem u strategijama oporabu (ponovne primjene) vode u poljoprivredi. Ovo istraživanje procijenjuje utjecaj neobrađenih tekstilnih otpadnih voda s različitim koncentracijama sulfata na bosiljak (Ocimum basilicum). Primijenjena su dva uzorka otpadne vode: jedan s visokim sadržajem sulfata (240,8 mg/L) i jedan s niskim (21,58 mg/L). Vidljivi fitotoksični učinci nisu uočeni, ali bosiljak navodnjavan uzorkom s visokim sadržajem sulfata pokazao je smanjenu visinu izboja (13,2 cm) u usporedbi s 17,8 cm kod tretmana s niskim sadržajem sulfata. Koncentracije sumpora u tlu bile su značajno više* *kod navodnjavanja vodom s niskim sadržajem sulfata (11357 mg/kg) nego kod navodnjavanja vodom s visokim sadržajem sulfata (4600 mg/kg). Ovaj neočekivani rezultat može se pripisati razlikama u sastavu otpadne vode, specijaciji sumpora, mikrobnoj aktivnosti ili dinamici usvajanja sumpora od strane biljaka. Iako je bosiljak pokazao otpornost na povišene razine sulfata, ovo istraživanje naglašava kako neobrađene tekstilne otpadne vode mogu utjecati na rast biljaka i kemizam tla na složen i nelinearan način. Ovi rezultati podupiru potrebu za detaljnom karakterizacijom otpadnih voda prije njihove oporabe u poljoprivredi.*

Ključne reči: *Tekstilna otpadna voda, sulfati, bosiljak, akumulacija u tlu, navodnjavanje.*

1. INTRODUCTION

The increasing scarcity of freshwater resources worldwide has led to wastewater increasingly being used for agricultural irrigation [1]. Among the various industrial sectors, the textile industry is one of the largest consumers and polluters of water and generates significant amount of textile wastewater (TWW). Textile wastewater is characterized by a complex composition containing high concentrations of dyes, salts, heavy metals, and various organic and inorganic contaminants [2]. A particularly worrying component of TWW is sulfate, an anion that is essential for plant growth in trace amounts, but can be harmful in increased quantities.

Sulfates are used extensively in the textile industry, especially in reactive dyeing processes. Sulfates, especially in the form of Glauber's salt ($Na_2SO_4 \times 10H_2O$), act as important electrolytes that facilitate the exhaustion of dyes from solution onto the fiber surface by reducing the negative charge repulsion between the dye molecules and the cellulose fibers. This role is critical for uniform dye fixation, color strength, and production efficiency [3]. Without the addition of sulfates, reactive dyes would largely remain in solution and would not bind sufficiently to the textile material. Due to their extensive use, significant amounts of sulfates are released into textile effluents, leading to increased sulfate concentrations in wastewater streams [4]. When such untreated or poorly treated wastewater is used for agricultural irrigation, the high sulfate load can significantly affect soil properties and plant health, raising concerns about long-term soil sustainability and crop productivity.

Sulfates in irrigation water can accumulate in the soil over time, altering soil chemistry and potentially affecting plant health. Excessive sulfate concentrations can lead to soil salinization, impair soil structure, and interfere with the uptake of other important nutrients such as calcium and magnesium [5]. In plants, elevated sulfate levels can cause osmotic stress, inhibit growth, and reduce crop yield and quality [6]. Given the increasing interest in the use of untreated or partially treated industrial wastewater for irrigation, it is important to understand the specific risks associated with sulfate accumulation.

Despite the known risks, there is little research that specifically addresses the effects of sulfate-rich TWW on agricultural soils and crops. Most studies focus on organic pollutants or heavy metals, often overlooking the cumulative and subtle effects of high sulfate levels [7]. However, since sulfate is highly mobile in soil-water systems and can persist over long periods of time, its role in soil degradation and plant physiological responses deserves greater attention.

Basil (*Ocimum basilicum*), a widely cultivated herb valued for its culinary, medicinal, and aromatic properties, provides an excellent model for studying the effects of sulfate contamination. Basil is relatively sensitive to soil salinity and nutrient imbalances [8], making it a good indicator species for assessing impacts on wastewater quality. Since basil is often consumed fresh, soil and water quality concerns translate directly into food safety issues, further emphasizing the importance of careful water management during cultivation. Previous research has shown that different crops have different tolerances to sulfate and the associated salt stress. For example, studies by Maas and Grattan (1999) established thresholds for the salt tolerance of numerous crops, but specific guidelines for sulfate concentrations remain poorly defined [9]. This knowledge gap emphasizes the need for crop-specific studies on the impact of sulfate-enriched effluents. In addition, sulfate dynamics in soil systems are influenced by numerous factors, including soil type, microbial activity, water management practices, and the chemical composition of the wastewater [10]. Sulfate can interact with soil minerals and organic matter, undergo microbial transformations such as reduction to sulfide under anaerobic conditions, and participate in complex nutrient cycling processes. These interactions make the prediction of the consequence of sulfate contamination by textile wastewater in agricultural even more complex.

In view of these considerations, this study aims to evaluate the effects of textile wastewater with different sulfate concentrations on the growth performance of basil and sulfur accumulation in the soil. By analyzing the results of irrigation with high-sulfate and low-sulfate TWW samples, we aim to provide insight into the risks and challenges associated with the agricultural reuse of textile wastewater. In addition, this research highlights the importance of comprehensive wastewater characterization, not only with respect to traditional pollutants, but also secondary pollutants such as sulfate, which can have significant ecological and agronomic consequences. Understanding the impact of sulfate contaminants on crops such as basil is critical to developing sustainable wastewater reuse strategies. It helps to establish safe guidelines for irrigation practices, soil management, and crop selection to ultimately support efforts to reduce the environmental footprint of industrial activities while safeguarding agricultural productivity and food quality.

2. MATERIALS AND METHODS

Untreated TWW samples were collected from a textile factory in Omiš, Croatia, in particular from processes dominated by dyeing activities known to contribute significantly to sulfate contamination. Two different wastewater samples were selected for the study: one with a high sulfate concentration and one with a lower sulfate concentration. The sulfate concentration in the wastewater samples was determined before irrigation started. Standard methods for the quantification of sulfate in water were used (HRN EN ISO 10304-1:2009).

The basil plants were cultivated in pots filled with a commercially available vegetable substrate (Potgrond H). Each pot was filled with about 340 cm³ of substrate. Four basil seeds were planted in each pot at a depth of about 1 cm. The plants were irrigated daily over a period of 21 days with 75 mL of one of the two collected TWW samples. Controlled environmental conditions were maintained: a temperature of 24.2 ± 0.8 °C, a relative humidity of 47.2 ± 2.3%, and 16 hours of light per day from LED lamps.
At the end of the irrigation period, soil samples were taken from each pot and analyzed for total sulfur content. The soil samples were dried and prepared according to the standard method HRN ISO 11464:2004. The sulfur content was determined using portable X-ray fluorescence spectroscopy. The shoot height of the basil plants was measured after 21 days of irrigation. Shoot height was measured recorded from the base of the stem at soil level to the apex of the main shoot using a digital ruler. Measurements were taken for all plants to evaluate the effects of different sulfate concentrations on plant growth.

3. RESULTS AND DISCUSSION

The sulfate concentrations measured in the two TWW samples showed considerablr variability. The high sulfate sample contained 240.8 mg/L sulfate, while the low sulfate sample contained 21.58 mg/L. These differences reflect the variability to be expected in untreated TWW, which is influenced by the type of the processes and the amount of chemicals used in production. The measured sulfate concentrations in TWW samples and the corresponding sulfur concentrations in the soil after irrigation are shown in Table 1. Such variability emphasizes the need for regular monitoring of industrial effluents intended for agricultural reuse, as inconsistent chemical compositions can lead to unpredictable effects on soils and plant systems.
After irrigation the basil plants with the two TWW samples, differences were also found in the sulfur concentrations in the soil. Soils irrigated with the low sulfate TWW sample showed significantly higher sulfur accumulation (11357 mg/kg) than soils irrigated with the high sulfate sample (4600 mg/kg). This result was unexpected as it is generally assumed that a higher sulfate input would lead to a higher sulfur content in the soil. Several factors could explain this discrepancy, including differences in sulfur speciation, microbial activities affecting sulfur cycling, or different plant uptake rates that could have reduced the available sulfur in the soil under high sulfate conditions [11]. In addition, soil characteristics such as texture, organic matter content, and pH may have influenced sulfur retention and mobility, highlighting the complex interactions within the soil matrix when irrigated with TWW.
The height of basil plants was used as an indicator of the effects of sulfate concentration on plant growth. Plants irrigated with high sulfate TWW had an average shoot height of 13.2 cm, while plants irrigated with low sulfate TWW reached an average height of 17.8 cm. Although no visible signs of phytotoxicity were observed, the reduction in shoot height suggests that elevated sulfate concentrations may impose a form of sublethal stress on basil plants, possibly through osmotic effects that inhibit water uptake and limit cell expansion [12].

Prolonged exposure to high levels of sulfate could potentially lead to cumulative negative effects on plant biomass and yield, especially under conditions of high evapotranspiration that enhance salt accumulation. Therefore, even moderate differences in sulfate concentration in irrigation water can have significant effect on plant performance over time.

Table 1: The measured sulfate concentrations in TWW samples and the corresponding sulfur concentrations in the soil after irrigation.

Sample	Sulfate concentration in TWW (mg/L)	Soil sulfur concentration (mg/kg)
High sulfate TWW	240.80	4600
Low sulfate TWW	21.58	11357

4. CONCLUSIONS

The results of this study show that untreated TWW with varying sulfate concentrations can affect both soil chemistry and basil growth in unexpected ways. Despite higher sulfate levels in one sample, sulfur accumulation in the soil was greater when treated with the lower sulfate concentration, highlighting the complexity of soil–plant interactions. Although basil plants were resilient to elevated sulfate concentrations, the reduced shoot height under high sulfate irrigation indicates possible stress effects. These results emphasize the need for careful evaluation and monitoring of industrial wastewater prior to their application in agriculture to ensure sustainable soil management and crop health.
Textile wastewater is an increasingly attractive alternative source of water for agricultural irrigation due to it high volume and nutrient content, especially in regions where water is scarce. However, its complex composition, including high concentrations of salts, dyes, and auxiliary chemicals such as sulfates, requires thorough testing before reuse. Improper use of untreated TWW can lead to soil degradation, lower crop productivity, and potential environmental pollution. Therefore, future strategies should focus on developing appropriate treatment technologies, water quality standards, and management practices that enable safe and beneficial reuse of TWW in agriculture. Integrating wastewater reuse with sustainable agricultural practices could significantly contribute to alleviating freshwater scarcity, but only if the focus is on continuous monitoring, risk assessment, and soil-plant system management.

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