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# Assessment of Physio-Chemical Properties of Bahir Dar Textile Sludge and Its Impact on The Growth of Lettuce (*Lactuca Sativa*) and Soil Nutrient Improvement

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## Abstract

Textile produces large volumes of sludge due to industrial activity, and its disposal is a serious environmental concern because it includes toxic contaminants, including heavy metals. Due to its vast volume and mass, sludge management is seen as an additional burden to the industry. This study aims to characterize solid sludge from the textile industry. The sludge's pH, organic matter (OM), nutrient elements (N, P, K), and metal content were determined using appropriate analytical techniques. Treatment consisted of 4×3 factorial combinations of nitrogen and phosphorus, i.e., full recommended (100 kg N and 50 kg P), half recommended (50 kg N and 25 kg P), control, and dried sludge at 0, 5, 10, and 20 tons per ha. The textile industrial sludge's Cu, Cr, Fe, Cd, Pb, and Zn concentrations are 511.568, 251.166, 7991.667, 67.333, and 463.00, respectively. The Cu, Cr, Fe, and Zn concentration levels exceeded the recommended upper limit for agricultural soil. Nonetheless, cadmium and lead are below WHO standards. Soil pH, % total nitrogen, % total organic content, and % organic matter increased after sludge application. Applying textile sludge to soil considerably raised the soil Cr, Fe, and Cu contents compared with the control, and lettuce growth increased from 75 g to 143.5 g per pot after applying 20 tons of sludge per ha. Therefore, textile sludge could be an alternative to organic fertilizer or soil conditioner if metals, especially Fe and Cr, are reduced by proper treatment strategies.

Keywords: plant growth, sludge, soil nutrients, heavy metal

## Introduction

Textiles are one of the most fundamental human requirements. Textile industries are very important economically because they contain the transformation of raw materials and fabric into finished cloth through numerous phases of processing and activities that use a lot of water and various chemicals and dyes (Talema and Abebaw, 2019). Textile industries have been classified as the world's most polluting industry. Textile effluents often include dissolved substances in colloidal or suspended forms, and they are commonly colored due to the presence of residual dyes (Kaur et al., 2021).

Large volumes of sludge are produced due to industrial activity, and its disposal is a serious environmental concern because it includes toxic contaminants, including heavy metals (Eriksson, 2017). Sludge is the semi-solid wastewater component separated after treatment in an Effluent Treatment Plant (ETP). Untreated industrial wastewater pollutes surface water and soil, harming crops, insect pests, and animal and human health (Das et al., 2021). Textile industries produce many polluted effluents that are usually discharged to surface water bodies and groundwater aquifers. The wastewater pollutants badly damage the terrestrial ecological system (Dhadse, 2022).

Modern industrial waste management requires that waste of various origins be recycled wherever feasible, as landfills and incineration have significant drawbacks, including high costs, a shortage of landfill space, and the disposal of the ash produced. As a result, applying some industrial sludge to the land as fertilizer and/or soil conditioner is an alternate destination (Engida et al., 2020). However, several countries have prohibited this method, primarily due to a lack of risk assessments for this option, which is case-specific regarding soil and solid waste. Due

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to their natural physio-chemical properties, several soils have relatively low crop productivity. Because of its nutritional content and soil improvement characteristics, textile sludge might be a helpful soil fertilizer/conditioner in this scenario. As a result, agricultural use of biosolids (for example, in industrial reforestation) might be a feasible disposal alternative, converting problematic waste into a valuable resource (Mabrouk et al., 2023).

Chemical analysis of textile sludge is critical to assess numerous pollutants present in high concentrations in the sludge, creating concern that sludge application to land might have negative impacts on the environment (Paul et al., 2023). Metals and organic compounds are the two main pollutants in textile waste. When sludge is utilized for agricultural purposes, metals may be responsible for disrupting the natural balance of aquatic ecosystems surrounding the treated zones (Raju et al., 2020). Textile sludge contains macronutrients (nitrogen, phosphorus, potassium, and calcium) as well as micronutrients (Ramya and Shanthakumar, 2017). So that plants can benefit from the nutrients in sludge. Textile sludge is also high in organic compounds and plant nutrients, according to certain studies (Zou et al., 2019); it can potentially enhance soil characteristics since it includes several plant nutrients, including N, P, and K. It might be used as a substitute for chemical fertilizers in agriculture. A study demonstrates that the growth, nodulation, and nitrogen fixation of soybean and cowpea were unaffected by the composted textile sludge (Addis and Abebaw, 2017).

Sludge management is becoming an urgent issue, and the situation in developing countries like Ethiopia will become even more serious. The previous investigation into the reuse potential of nutrient-containing textile sludge, i.e., N, P, K, Br, Mn, Cu, and Zn, is growing rapidly. This study aims to determine the impact of sludge on lettuce growth and associated health risks and assess the soil quality improvement after applying the textile factory sludge.

## Materials and Methods

*Description of the Study Area*

Bahir Dar is 565 kilometers northwest of Addis Ababa, at an altitude of 1801 meters above sea level, and in the "Woina Dega" type of agroecological zone, the capital city of the Amhara National Regional State. The study area has a mean annual temperature of 26°C and average annual rainfall varies from 1200 to 1600 mm.

*Pot Experiment*

The experiment used a factorial combination and a complete randomized design. Treatments consisted of 4×3 factorial combinations of nitrogen and phosphorus: full recommended (100 kg N and 50 kg P), half recommended (50 kg N and 25 kg P), control (without N and P, and dried sludge consisted of 0, 5, 10, and 20 tons.ha$^{-1}$. The experiment was replicated three times, totaling 12 treatment combinations, which account for 36 experimental pots.

Pot-growing lettuce was 22.5 cm in diameter in the base, 16.5 cm in diameter at the top, and 18 cm in height was used for this study. Each pot contained 6 kg of soil. All plants were placed in the screen house at Adet Agricultural Research Center (11°16′N 37°29′E / 11.267°N 37.483°E / 11.267; 37.483), 2300 m above sea level, during irrigation lettuce growing season. The location's average temperature and relative humidity were 24.99ºC and 33.22%.

Lettuce seeds were sown in March and transplanted by hand in April. Each pot contained two transplanted lettuces (*Lactuca sativa)* with three to four leaves. When the pot mixes were dried, equal volumes of water were added to each pot simultaneously.

After 65 days, the plants were carefully harvested and transported to the lab for further analysis. The plants were weighed after being thoroughly cleaned with water, dried in an oven at 100°C for 24 hours, and weighed. The techniques for measuring plant morphology was according to Yimer (2024). Before planting, 0.5 kg of soil and 0.2 kg of sludge were collected for laboratory analysis. After thorough dewatering, the sludge for this investigation was removed from the sludge drying bed.

*Laboratory Experiment*

Soil and sludge samples were taken before and after planting, and tissue samples were taken at harvest. The soil and plant samples were taken to the analytical laboratory at the Adet Agricultural Research Center, where they were dried with air at room temperature. The dry soil and sludge were ground and sieved using a mortar, pestle, and mesh.

The test plant was placed in clear, acid-washed porcelain crucibles and dried in an oven at 105°C for 24 hours. The dry samples were crushed into a fine powder using an acid-washed mortar, pestle, and a 2.0 mm sieve. For further investigation, the powdered materials were stored in polyethylene packages.

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Table 1. Treatment description

| No | Treatments |
|---|---|
| 1 | No fertilizer |
| 2 | 5 tons of sludge, no fertilizer |
| 3 | 10 tons of sludge, no fertilizer |
| 4 | 20 tons of sludge, no fertilizer |
| 5 | half recommended N and P (50 kg N and 25 kg P), no addition of sludge |
| 6 | Combination of half-recommended N and P (50 kg N and 25 kg P) with 5 tons of sludge per per ha |
| 7 | Combination of half-recommended N and P (50 kg N and 25 kg P) with 10 tons of sludge per ha |
| 8 | Combination of half-recommended N and P (50 kg N and 25 kg P) with 20 tons of sludge per ha |
| 9 | Full recommended N and P (100 kg N and 50 kg P), no addition of sludge |
| 10 | Full recommended N and P (100 kg N and 50 kg P) with 5 tons of sludge per ha |
| 11 | Combination of full recommended N and P (100 kg N and 50 kg P) with 10 tons of sludge per ha |
| 12 | Combination of full recommended N and P (100 kg N and 50 kg P) with 20 tons of sludge per ha |

Notes: 100 kg of nitrogen and 50 kg of phosphorus are Ethiopia's blanket recommendations for vegetable production.

*Determination of Heavy Metals in Sludge, Soil, and Plants*

Different methods were tried to optimize digestion for each sample type (soil, sludge, and plant). The technique that needed the least quantity of reagent (acid), the quickest digestion period, and the generation of a colorless solution with no residue was chosen for the digestion of soil, sludge, and plants.

The sample of sludge was precisely weighed at 300 mg of sludge using a computerized analytical scale with 0.001 accuracies before being transferred into a hot plate digestion flask. The sample was then given a freshly produced combination of concentrated $HNO_3$ (0.5 mL) (65.0 percent Analar, BDH), $H_2O_2$ (0.5 mL), (65.0% Analar, BDH), and concentrated $HClO_4$ (6.5 mL) (Talema et al., 2020). The sample was gently stirred to homogenize the mixture before running continuous digestion on a hot plate digestion block for two hours at 400°C. Blank was prepared using the same procedure for the sludge.

The method applied for lettuce digestion follows Endalamaw and Chandravanshi (2015). A powdered sample weighing 0.50 g was introduced to the flask. 2.5 ml of $HNO_3$ and 1.5 ml of $HCLO_4$ were added. The mixture was digested on a hot plate instrument at 400°C. Blank was prepared using the same procedure.

The soil sample was digested using an optimal process described by Endalamaw and Chandravanshi (2015); 0.5 g of well-powdered soil sample were added to a conical flask filled with 1.5 ml $H_2O_2$, 2 ml $HNO_3$, and 4 ml $HClO_4$. The liquid was digested on a hot plate digestion device at 400°C for 180 minutes. Blank was prepared using the same procedure used for the soil. Hence, it was cooled to room temperature for 10 minutes with and without removing the condenser from the flask. Deionized water was added to the cooled solution to dissolve the precipitate that developed during cooling and to reduce the amount of digest residue that would cause the Whatman filter paper to disintegrate. Finally, deionized water was used to fill the volumetric flasks to the proper level. The digestion produced a clear, colorless solution, which was put into 50 mL plastic bottles. Heavy metal levels were analyzed at the University of Bahir Dar research laboratory using a flame Atomic Absorption Spectrophotometer (Parkin Elmer Analyst 400).

*Instrumental Calibration*

Calibration and the accepted method for preparing solutions significantly impact the quality of the results for metal analysis using flame atomic absorption spectroscopy. Five working standard series were used to calibrate the device. Each metal's standard solution was freshly prepared by diluting the intermediate standard solutions. The concentration of working standards and their coefficient values for each metal are shown in Table 3.

In this study, FAAS was used to measure the content of heavy metals (Zn, Cu, Fe, Cr, Pb, and Cd, Table 4) in soil, sludge, and plant samples. The metal concentration in each sample was described in terms of $mg.L^{-1}$. The conversion of $mg.L^{-1}$ into $mg.kg^{-1}$ is done using the following formula:

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[M]=C/W*V

where:
M: metal concentration in $mg.kg^{-1}$
W: weight of digested soil, sludge, and plant in kg
C: concentration of metal in digested soil, sludge, and plant in $mg.L^{-1}$
V: final volume of digested sample solution prepared (L)

## Results and Discussion

*Physicochemical Properties of The Textile Sludge*

This investigation discovered that the examined sludge is non-granular, black, odorous, and moist at around 9.60% (Table 5). Because the bio sludge from secondary textile wastewater treatment operations has a high concentration of organic carbon and plant nutrients, it may realistically be utilized again as a raw material for producing organic fertilizers (Tsai, 2012). However, the sludge's high levels of ammonia and $H_2S$ caused an odor issue.

*Textile Sludge pH*

The average pH value of the sludge is 6.06 (Table 6), which implies a slightly acidic or nearly neutral pH. The pH value meets the standard set by (WCCS) and is suitable for the availability of plant nutrients in the soil. The pH was in the range that most soil microorganism's environment; pH levels between 6 - 8 are ideal for methanogenic bacteria (Zaher et al., 2007). Reports on sludge pH was 6.4 in Bangladesh (Easha et al., 2015), and 8.21 in Germany (Raju, et al., 2020). Furthermore, a report from nine textile factory sludge from China shows a pH range between 3.7 to 8.9 (Liang et al., 2013).

*Organic Matter*

According to the study, the average organic matter (OM) percentage in the sludge was 15.181%. The result is the same 15.88% reported by (Islam et al., 2009). The tested sludge sample's organic matter (OM) was within the WCCS limit (Table 6). The amount of carbon-based material in the sludge is measured by organic matter (OM). It might be seen as a crucial part of soil because of its involvement in physical, chemical, and biological activities. Energy, substrates, and the biological diversity required to support a variety of soil activities are provided mainly by the organic materials in soil and organic manure (Kadam et al., 2023). According to Waste Concern, the compost-quality organic matter (OM) in the analyzed sludge was at its best.

Table 2. Measurement methods and equipment used in the experiments

| Parameter | Method | Equipment |
|---|---|---|
| pH | 1:2.5 soil water ratio | pH meter (CPI-Sol, ELMEIRON) |
| Electrical Conductivity | 1:2.5 soil water ratio | Conductivity meter (Model 860033) |
| Total Nitrogen | Kjedhal digestion method | Block digestor |
| Available Phosphorous | Olsen 1954 | Spectrophotometer (SP-MUV6000) |
| Organic Matter | Weakly and black method | |
| Soil Texture | Hydrometric Method | Hydrometer (Ertco 2512H) |
| Cation Exchange Capacity (CEC) | Ammonium acetate method | |
| Heavy Metals (Zn, Cu, Cd, Cr, Pb, Fe) | Spectroscopic method | FAAS (Parkin Elmer Analyst 400) |

Table 3. A series of working standards and correlation coefficients for the determination of heavy metals in soil, sludge, and plants using FAAS

| Analyte | Standard concentrations ($mg.L^{-1}$) | Regression equation (Y = mx + b) | Correlation coefficient |
|---|---|---|---|
| Cu | 0.29, 0.58, 1.16, 2.32 and 4.64 | Y = 25.129x + 0.0567 | 0.999 |
| Fe | 0.09, 0.27, 0.81, 2.43 and 7.29 | Y = 103.63x – 0.2262 | 0.998 |
| Cr | 0.32, 0.64, 1.28, 2.56 and 5.12 | Y = 439.39x – 0.1251 | 0.998 |
| Pb | 0.32, 0.64, 1.28, 2.56 and 5.12 | Y = 111.13x – 0.1128 | 0.998 |
| Cd | 0.16, 0.32, 0.64,1.28 and 2.56 | Y= 15.135x – 0.0462 | 0.999 |
| Zn | 0.03, 0.09, 0.027, 0.81 and 2.4 | Y = 9.1315x – 0.0945 | 0.999 |

Notes: -Y = intensity, x = concentration in $mg.L^{-1}$, m= slope, b = intercept.

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Table 4. Working instrument condition for metal analysis by FAAS (Anonim, 2019)

| Element | Lamp current (mA) | Wavelength (nm) | Silt (nm) | Fuel | Support |
|---|---|---|---|---|---|
| Fe | 5.0 | 284.33 | 1.0 | Acetylene | Air |
| Cd | 5.0 | 228.80 | 1.0 | Acetylene | Air |
| Cr | 5.0 | 357.87 | 1.0 | Acetylene | Air |
| Cu | 5.0 | 324.75 | 1.0 | Acetylene | Air |
| Pb | 5.0 | 283.31 | 1.0 | Acetylene | Air |
| Zn | 5.0 | 213.86 | 1.0 | Acetylene | Air |

Table 5. Physical characteristics of studied textile sludge

| Parameters | Condition | Standard condition (WCCS) |
|---|---|---|
| Physical condition | Non-granular form | Non granular form |
| Color | Dark gray to black | Dark gray to black |
| Odor | Odor present | Absence of hazardous odor |
| Moisture content | 9.60% | Maximum of 18% |

Notes: - (WCCS) Waste concern compost standard (Easha et al., 2015).

Table 6. Plant macronutrients, electrical conductivity, and pH in studied textile sludge (n = 3)

| Parameters | Mean ± SD | Standard (WCCS) |
|---|---|---|
| pH | 6.07 ± 0.15 | 6 – 8.5 |
| Electrical conductivity (µS.cm$^{-1}$) | 2.44 ± 0.03 | |
| % Organic carbon | 8.85 ± 0.28 | |
| % Organic matter | 15.18 ± 0.48 | 10 – 25 % |
| Available P (mg.kg$^{-1}$) | 5.38 ± 0.25 | |
| % Total nitrogen | 3.17 ± 0.08 | 0.5 – 4.0 % |

Notes: Waste Concern Compost Standard (WCCS). SD = standard deviation.

*Available Phosphorous*

This study discovered that sludge's average phosphorus concentration was 5.384 mg.kg$^{-1}$. The range of phosphorous reported in other textile sludge differs from this study, 873-1423 mg.kg$^{-1}$ (Islam et al., 2009). Some industry sludges in Ethiopia report 5.2% total phosphorous (Delelegn, 2018). Variations may come from factories. They may use different phosphorous-containing chemicals in their manufacturing process. Phosphorus levels in soil should be between 25 and 50 ppm. Long-term application of phosphorus-containing fertilizers often increases available P while also potentially causing P buildup. The phosphorous concentration in sludge is very low compared to other organic manure compositions (Table 7).

*Electrical Conductivity*

A crucial indication of soluble salt concentrations is electrical conductivity. In this study, the electrical conductivity values (2.44 ± 0.03 µs.cm$^{-1}$) were above the data range reported by Talema was (1.872 ± 0.003) (Talema et al., 2020). The electrical conductivity values in this study suggested that the sludge samples included small quantities of ionic constituents. According to reports, the electrical conductivity (EC) value might reach 13.4 mS.cm$^{-1}$ (Gezahegn, 2013). EC measurements in the textile sludge ranged from 2.12 to 6.63 mS.cm$^{-1}$ in other samples (Patel and Pandey, 2008).

*Total Nitrogen*

The sludge had an average total nitrogen concentration of 3.17%, and the tested sludge sample's total nitrogen level was within the WCCS limit (Table 6). Nitrogen encourages quick growth, improves the size and quality of leaves, speeds up crop maturity, and encourages the formation of fruits and seeds.

As a component of amino acids, which are needed to make proteins and other related compounds, nitrogen is involved in practically all plants' metabolic activities. According to a report (Adissie et al., 2022),

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Table 7. Organic manure and nutrient compositions

| Type of organic manure | Total nitrogen (%) | Organic carbon (%) | Available phosphorous (mg.kg$^{-1}$) | Available potassium (ppm) | Reference |
|---|---|---|---|---|---|
| Poultry manure | 2.83 | 24.73 | 49000 | 46700 | (Moe et al., 2017) |
| Cow manure | 1.05 | 13.39 | 19900 | 23400 | (Moe et al., 2017) |
| Vermicompost | 1.29 | 13.91 | 4200 | 7000 | (Moe et al., 2017) |
| Textile sludge | 3.17 | 8.80 | 5.38 | | This study |

Notes: n = 3.

nitrogen is the most yield-limiting nutrient in Ethiopia. Textile sludge with a high nitrogen content can be a good solution for unproductive soil. Textile sludge has a higher total nitrogen content than organic manure used as a fertilizer. In order: Textile sludge > Poultry manure> Vermicompost> Cow manure. Azo dye and a biological treatment unit may cause higher nitrogen concentrations during manufacture than other elements.

*Selected Heavy Metals in the Sludge*

This study showed that the sludge sample's Fe content is 7991.667 mg.kg$^{-1}$. This finding showed that the analyzed sludge samples have relatively greater Fe levels than the FAO/WHO recommended value and agricultural soil (5000 mg.kg$^{-1}$) (Talema et al., 2020). Among the metals under study, iron has the greatest concentration. Iron from the sludge may contaminate soil over time and alter its structure, making it unsafe for agriculture. Therefore, this suggests that more treatment is required to lower the Fe concentration in the sludge under WHO law. Previous studies reported that the Fe concentration in Bahir Dar textile sludge was 2877 mg.kg$^{-1}$ (Talema et al., 2020). A study in sludge in Brazil reported the concentration of iron to be 26,646 mg.kg$^{-1}$, much larger than in this study (Rosa et al., 2007b). Furthermore, a high iron content was reported in Bangladesh (Islam et al., 2009).

The sludge samples had Cr values of 251.166 mg.kg$^{-1}$ (Table 9); according to FAO/WHO, Cr at 50 mg.kg$^{-1}$ is the acceptable maximum content for soil. The result shows a variable high accumulation of Cr in textile sludge. Chromium from the sludge may contaminate soil over time and alter its structure, making it unsafe for agriculture. Therefore, this suggests that more treatment is required to lower the Cr concentration in the sludge under the WHO limit.

A previous study reported that the concentration of Cr from Bahir Dar Bahir Dar textile sludge was 44.2 mg.kg$^{-1}$ (Talema et al., 2020). A study in Brazil (Rosa et al., 2007b) reported a sludge Cr concentration of 13.4 mg.kg$^{-1}$, whereas in Bangladesh it was 34.4 mg.kg$^{-1}$ (Islam et al., 2009). The high chromium concentrations in the studied sludge (Table 8) could be caused by high concentrations of chromium-containing chemicals or chromium used by the factory during the textile manufacturing process.

The average Pb concentration of the sludge sample was 67.33 mg.kg$^{-1}$ (Table 8). This result demonstrated that the Pb levels in the studied sludge samples were substantially lower than the FAO/WHO recommended value and agricultural soil (100 mg.kg$^{-1}$). In China's agricultural and paddy soils, the threshold background level of Pb was 50 mg.kg$^{-1}$ (Liang et al., 2013). Based on the limit, the lead concentration of this study is above the recommended safe limit set by China but below the WHO limit. When this sludge is utilized as fertilizer, its concentration might poses litle risk of soil contamination, even though a level of 25.8 mg.kg$^{-1}$ was reported in nine textile industries in China (Liang et al., 2013).

The Cd content of the sludge sample in this study was below the detection limit (Table 8). This finding showed that the investigated sludge samples had Cd levels significantly lower than the FAO/WHO recommended value and agricultural soil (3 mg.kg$^{-1}$). This qualifies or certifies the examined sludge's safety for application on land to cadmium concentration. The concentration levels of Cu (511.58 mg.kg$^{-1}$) in the textile industry sludge are above the recommended upper limit for agricultural soil. Cu, Cr, Zn, and Fe concentration levels in textile industry sludge generally exceeded the recommended upper limit for agricultural soil. Nonetheless, this study's cadmium and lead levels are below WHO standards.

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Table 8. Heavy metal concentration in (mg.kg$^{-1}$ dry weight) in the textile sludge sample

| Metals | Mean ±SD (mg.kg$^{-1}$) | WHO/FAO safe limit[a] (mg.kg$^{-1}$) | China safe limit [b] (mg.kg$^{-1}$) |
|---|---|---|---|
| Fe | 7991.66 ± 838.33 | 5000 | NA |
| Cr | 251.16 ± 41.85 | 50 | 90 |
| Cu | 511.58 ± 5.3 | 100 | 35 |
| Cd | - | 3 | 20 |
| Pb | 67.33 ± 10.38 | 100 | 50 |
| Zn | 463 ± 43.01 | 300 | 200 |

Notes: - = not detected, NA: not analyzed. a: WHO/FAO safe limit for agricultural soil; b: China Limit safe limit for agricultural soil; n=3.

Table 9. Comparison of sludge metal mean concentration from this study with different threshold values for use and disposal

| Metals | This study (mg.kg$^{-1}$) | EU[a] (mg.kg$^{-1}$) | USEPA[b] (mg.kg$^{-1}$) | China pH<6.5[c] (mg.kg$^{-1}$) | China pH>6.5[c] (mg.kg$^{-1}$) |
|---|---|---|---|---|---|
| Fe | 7991.66 | NA | NA | NA | NA |
| Cr | 251.16 | - | - | 600 | 1000 |
| Cu | 511.58 | 1750 | 13000 | 800 | 1500 |
| Cd | ND | 20 | 85 | 5 | 20 |
| Zn | 463.00 | 3000 | 7500 | 2000 | 3000 |
| Pb | 67.33 | 1200 | 810 | 300 | 100 |

NB: NA: not analyzed, ND: not detected.

a: EU. 86/278. Council directive of June 1986 on protecting the environment, particularly soil, when sewage sludge is used in agriculture,1986.
b: USEPA. 40 CFR part 503. Standard for the use or disposal of sewage sludge,1992.
c: Environmental Protection Administration (EPA), PR China, Ministry of Rural and Urban Construction, PR China. Discharge standard of pollutants for municipal wastewater treatment plant (GB 18918-2002, 2002).

*Effect of Sludge and Fertilizers on the Lettuce Leaf Length, Plant Height, and Fresh Weight*

ANOVA shows that the interaction between fertilizer and sludge significantly affects leaf length (p<0.05). Therefore, the full dosage of the recommended N and P fertilizer produced the most considerable leaf length (21.70 cm), even though it is not statistically different from half N and P with 20 tons of sludge, full N and P with 0 tons, full N and P with five tons, and full N and P with 10 tons. Meanwhile, the control treatment produced the lowest (13.2 cm). Applying textile sludge alone increases the leaf length (13.2 cm) to 17.83 cm in 20 tons of sludge (Table 10). Half of the recommended fertilizer with 20 tons of sludge gives a comparable result with the fully recommended fertilizer application.

Fertilizer and sludge interacted in influencing plant height (p<0.05). Applying 20 tons of sludge and the full recommended amount of N and P fertilizer resulted in the maximum plant height (23.30 cm). The control pot resulted in the lowest plant height (12.23 cm) (control). Applying textile sludge alone significantly increases the plant height (12.23 cm) to 15.63 cm in 20 tons of sludge (Table 10).

The analysis of variance for the interaction effect of fertilizer and textile sludge showed a significant change in the overall fresh yield (p <0.05). Lettuce yields gradually increased when the combination level was raised from the control to the full recommended N and P and control to 20 tons of textile sludge. The pots that received a combined application of 20 tons of textile sludge and the full recommended amount of N and P produced the maximum lettuce yield (190.86 g per pot). It statistically differed between full N and P with 5 tons of sludge and N and P with full N and P with 10 tons. The report noted that increased nitrogen dosages and farmyard manure helped plants develop more vegetatively, leading to better yields (Yeshiwas et al., 2018). Nitrogen fertilizer and textile sludge have high nitrogen content. The pots that received a control produced the lowest yield of lettuce 75.20 g per pot. which, according to statistics, varied from the levels of 5, 10, and 20 tons of sludge. It demonstrates

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Table 10. Lettuce growth at different sludge rates and nitrogen and phosphorus fertilizer dosages

| Sludge rates ($tons.ha^{-1}$) | 0 | | | Half N and P dosages | | | Full N and P dosages | | |
|---|---|---|---|---|---|---|---|---|---|
| | Leaf length (cm) | Plant height (cm) | Fresh weight (g) | Leaf length (cm) | Plant height (cm) | Fresh weight (g) | Leaf length (cm) | Plant height (cm) | Fresh weight (g) |
| 0 | $13.20^{f}$ | $12.23^{h}$ | $75.20^{f}$ | $19.03^{bc}$ | $16.03^{ef}$ | $151.90^{cd}$ | $21.70^{a}$ | $21.83^{c}$ | $182.68^{ab}$ |
| 5 | $15.30^{e}$ | $13.50^{g}$ | $111.30^{e}$ | $20.13^{ab}$ | $17.13^{e}$ | $154.31^{cd}$ | $21.60^{a}$ | $21.93^{bc}$ | $182.41^{ab}$ |
| 10 | $16.56^{de}$ | $14.26^{g}$ | $123.71^{e}$ | $20.60^{ab}$ | $18.76^{d}$ | $160.86^{c}$ | $21.50^{a}$ | $23.03^{ab}$ | $186.37^{ab}$ |
| 20 | $17.83^{cd}$ | $15.63^{f}$ | $143.61^{d}$ | $21.06^{a}$ | $21.26^{c}$ | $176.89^{b}$ | $21.33^{a}$ | $23.30^{a}$ | $190.86^{a}$ |

Notes: values with different letters show significant differences according to the Tukey test at $\alpha$ = 0.05.

how yield was considerably impacted by applying textile sludge from 75.20 g per pot to 143.61 g per pot. Lettuce yield increased by 90.9% by 20 tons of textile sludge, and the total yield increment by fertilizer was recorded by 140%.

*Application of Sludge Impact on the Composition of the Soil at Lettuce Harvest*

Soil pH decreases with increased applied textile sludge (Table 11). This is due to the lower average pH of textile sludge, 6.067. Slightly acidic pH characteristics of textile sludge are suitable for basic characteristics of soil that are affected by high salt accumulation. Electrical conductivity increases as the amount of textile sludge in the soil increases. A lower soil pH means that there are more hydrogen ions present. The level of electrical conductivity can be impacted by the presence of hydrogen ions in the soil environment, which can occur in variable amounts. Higher electrical conductivity will produce higher soil hydrogen ion concentrations and low pH.

The relationship between soil pH and electrical conductivity is inverse, not linear, since other factors such as soil mineral content, porosity, texture, moisture, and temperature affect soil electrical conductivity (Mohd-Aizat et al., 2014). Soil organic matter increased from 0.56% to 2.14% after application of 20 tons of textile sludge. This is due to the high amount of organic matter in textile sludge (15.18%, Table 4). According to many reports, applying organic fertilizer increases soil organic matter. Although organic fertilizers are frequently less cost-effective as nutrient sources than inorganic fertilizers, their large-scale applications can raise quantities of organic matter. When used rarely, they probably will unlikely affect organic matter levels (Yeshiwas et al., 2018).

The application of sludge had no significant effect on the phosphorous concentration in the soil. This is due to sludge's lower average phosphorous concentration (5.38 ppm), but nitrogen content increases after sludge application. This study found that textile sludge improved crop yield and the soil's physio-chemical properties.

*Accumulation of Heavy Metals after Applying Sludge to Lettuce-growing Soil*

The application of textile sludge considerably raised the Cr, Fe, and Cu contents in the pot soils concerning the control pot ($p < 0.05$). Applying textile sludge at a rate of 5 tons per hectare considerably increased the amount of Fe in the pot soils ($p < 0.05$, Table 12). The 10-ton sludge application treatment had the highest amount of Fe (5653.33 $mg.kg^{-1}$), whereas the control treatment had the lowest (3075.00 $mg.kg^{-1}$). The WHO safe limit for uncontaminated soil Fe content is 5000 $mg.kg^{-1,}$ indicating that the soil's iron content exceeds the safe limit. Control soil has iron content below the safe limit, but treatments result in high iron content after applying textile sludge to the soil.

Sludge rates of 5 and 10 tons per hectare have no significant impact on the amount of Cr in the pot soil compared to the control pot. The 20-ton sludge application treatment had the highest amount of Cr (136.20 $mg.kg^{-1}$), whereas the control treatment had the lowest (92.76 $mg.kg^{-1}$). World Health Organization safe limit of Cr content of uncontaminated soil is 50 $mg.kg^{-1}$. This indicates that the chromium content of the soil is above the safe limit. All treatments, including the control, show a high chromium content after applying textile sludge to the soil. However, the control treatment had the highest amount of Pb (36.70 $mg.kg^{-1}$), while the 20-ton sludge application treatment had the lowest (10.70 $mg.kg^{-1}$). This result is due to the %OM increase after applying textile sludge. Lead forms complexes with organic matter, decreasing the availability of lead in the soil. The WHO safe limit for Pb content in uncontaminated soil

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Table 11. Soil physical and chemical properties after application of textile sludge

| Sludge rates (ton.ha$^{-1}$) | pH | EC (μS/cm) | Available P (ppm) | %OC | %OM | %TN | CEC (meq per 100 g soil) |
|---|---|---|---|---|---|---|---|
| Control | 7.4±0.04 | 52.2±1.31 | 5.04±0.52 | 0.38±0.01 | 0.65±0.03 | 0.10 ±0.01 | 40.86±4.27 |
| 5 | 7.2± 0.01 | 54.3±1.68 | 7.67±0.30 | 0.93±0.13 | 1.62±0.23 | 0.11±0.018 | 35.53±5.79 |
| 10 | 7.1±0.03 | 61.2±1.71 | 5.59±0.21 | 0.99±0.23 | 1.71±0.40 | 0.12±0.014 | 39±2.27 |
| 20 | 7.0±0.01 | 94.5±0.56 | 6.43±0.08 | 1.24±0.15 | 2.14±0.27 | 0.12±0.026 | 41.53±3.25 |

Notes: values are mean ± standard deviation; n = 3

Table 12. Soil heavy metal content after application of textile sludge

| Sludge rates (ton.ha$^{-1}$) | Fe (mg.kg$^{-1}$) | Cr (mg.kg$^{-1}$) | Pb (mg.kg$^{-1}$) | Cd (mg.kg$^{-1}$) | Cu (mg.kg$^{-1}$) | Cu (mg.kg$^{-1}$) |
|---|---|---|---|---|---|---|
| Control | 3075.00 | 92.76 | 36.70 | - | 59.30 | 87.90 |
| 5 | 5653.33* | 121.70 | 33.00 | - | 57.63 | 82.33 |
| 10 | 8746.66* | 92.76 | 29.30 | - | 58.46 | 77.66 |
| 20 | 35721.66* | 136.20* | 10.70* | - | 51.30* | 113.06* |
| SD | 13693.60 | 26.99 | 11.47 | | 4.06 | 15.25 |
| CV | 103.00 | 24.40 | 41.80 | | 7.20 | 16.9 |

Notes: * mean difference is significant at p<0.05 level compared to the control. SE= standard deviation, CV = coefficient of variation, - = undetected. n=3.

Table 13. at different sludge rate treatments

| Sludge rates (ton.ha$^{-1}$) | Dry weight (mg.kg$^{-1}$) | | | | | | Fresh weight (mg.kg$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fe | Cr | Pb | Cd | Zn | Cu | Fe | Cr | Pb | Cd | Cu | Zn |
| 0 | 924.66 | 63.80 | - | - | 121.10 | 10.50 | 151.72 | 10.46 | - | - | 1.85 | 22.37 |
| 5 | 4567.00* | 150.70* | - | - | 140.33 | 12.23 | 880.98* | 29.07* | - | - | 2.28 | 26.14 |
| 10 | 3192.66* | 121.70* | - | - | 152.76 | 13.90 | 598.46* | 22.81* | - | - | 2.56 | 28.17 |
| 20 | 2711.00* | 121.70* | - | - | 197.76* | 11.40 | 485.02* | 21.77* | - | - | 2.03 | 35.38* |
| SD | 1367.82 | 36.27 | | | 34.37 | 2.66 | 274.03 | 7.51 | | | 0.448 | 6.21 |
| CV | 48.0 | 31.7 | | | 22.5 | 22.2 | 51.8 | 35.7 | | | 20.5 | 22.2 |
| WHO Limit | 425.5 | 2.3 | 0.3 | 0.2 | 99.4 | 73.30 | 425.5 | 2.3 | 0.3 | 0.2 | 73.30 | 73.30 |

Notes: * significantly different 0.05 level to control. SD = standard Deviation, CV = coefficient of variation, - = not detected. n=3.

is 100 mg.kg$^{-1}$, indicating that the soil's lead content is below the safe limit. All treatments, including control, show a minimum lead content after applying textile sludge to the soil. The application of textile sludge decreased the content of lead in the soil.

Cadmium content is not detected in soil, plants, or soil after applying textile sludge (Table 13). This indicates that applying textile sludge as fertilizer is not likely to cause problems associated with cadmium content.

*Lettuce Shoot Heavy Metal Content*

Different sludge treatments considerably affected several lettuce plant sections' Fe and Cr concentrations (p <0.05, Table 13). Generally, the higher the rate of textile sludge is applied, the more heavy metals accumulate in soils and enter the food chain. Among the various heavy metals examined in this study, Fe and Cu are also crucial micronutrients. The amount of textile sludge applied increased, but the uptake of the elements did not always coincide with or follow the same trends. A report by Guha et al. (2015) shows that the uptake of metals is not correlative with increasing effluents on rice.

The application of textile sludge considerably increased lettuce' Cr, Fe, and Cu contents compared with the control pot (p <0.05). The 5-ton sludge application had the highest amount of Fe (4567.0000

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mg.kg$^{-1}$), whereas the control treatment had the lowest (924.6667 mg.kg$^{-1}$). The WHO safe limit for the Fe content of vegetables is 425.5 mg.kg$^{-1}$. This indicates that the iron content of lettuce plants is above the safe limit, including the control pot, but on a fresh weight basis, the iron content in lettuce is below the safe limit (151.72 mg.kg$^{-1}$). The 5-ton sludge application treatment had the highest amount of Cr (150.70 mg.kg$^{-1}$), whereas the control treatment had the lowest (63.80 mg.kg$^{-1}$). The WHO safe limit for Cr content in vegetables is 2.33 mg.kg$^{-1}$, indicating that the chromium content of lettuce is higher than the safe limit. All plant samples, including the control, show a high chromium content after applying textile sludge to the soil. On a wet basis, the chromium content, including the control pot, was above the WHO's safe limit. This was due to the high chromium concentration in the initial soil and the high sludge chromium content. Cadmium and lead content are not detected in the lettuce plant sample. This indicates that application of textile sludge as fertilizer is not associated with problems associated with cadmium and lead content.

## Conclusion and Recommendation

The studies demonstrated that when significant volumes of textile sludge were applied as an organic fertilizer, Cu, Fe, and Cr in lettuce increased. In contrast, the lead concentration was lowered when the textile sludge load increased. Applying textile sludge improved the soil pH, % total nitrogen, % organic matter, and % organic carbon above the control concentrations and impacted the plant growth rate. The Cu, Cr, and Fe levels in the textile industry sludge exceeded the recommended upper limit for agricultural soil. However, Cd and Pb levels are below WHO standards, and these concentrations are below the safe limit regulation of residue use for agricultural purposes and waste disposal strategies recommended by different organizations. Further studies should focus on removing the metals from the sludge, mainly trace metals like Cr and Pb, the molecular mechanism of plants exposed to textile sludge, and the impact of other organic pollutants on soil microorganisms and crops.

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