Effect of Compost and Different Types of Wastewaters on Soil Properties and Wheat Crop Production

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Composted plant residues can minimize toxic effects of wastewater and ameliorate soil properties. In most regions of Punjab, crops including wheat are irrigated with wastewater, resulting in the accumulation of heavy metal in soil and plants. A pot experiment was conducted to assess the effect of compost amendment and various sources of irrigation water on soil properties and wheat growth using a completely randomized design (CRD) with a 2 × 4 factorial arrangement (two compost levels: with and without compost, and four irrigation water sources: textile industry effluent, sewage water, canal water, and groundwater), giving eight treatment combinations, each replicated three times, conducted at the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Four sources of irrigation water (textile industry effluent, sewage water, canal water, and groundwater) were used both with and without compost (2.5%, w/w). Seeds of wheat cultivar Ujala-2016 were cultivated in pots and 5 seeds were planted in each pot. Growth and soil characteristics of wheat were greatly enhanced with the use of compost under each irrigation treatment. Compost raised the height of the plant (30.7%), spike length (6.77%), straw yield (9.97%), grain yield (11.9%), soil organ carbon (31.5%), soil water stable aggregates (38.6%), and lowered soil bulk density (2.2%). It was concluded that application of compost along with different types of wastewaters improved the soil properties and enhanced the wheat yield.

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Keywords: Compost; Wastewater; Wheat; Soil bulk density; Soil organic carbon

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INTRODUCTION

Wheat is one of the world's most important staple crops and contributes approximately 20% of the total dietary calories and protein consumed globally. (Shiferaw *et al.* 2013). Pakistan is the eighth largest wheat producing country in world, but average yield production is very low in Pakistan compared to other countries like USA, China,

India, and Bangladesh (Chandio *et al*. 2016). In Pakistan during 2020-2021, wheat was cultivated on an area of 9 million hectares, and total wheat production was recorded as 26 million tons (Ahmad *et al*. 2021). Many factors like poor soil health, soil structure, ineduquate water quantity and quality, temperature stress, and unbalanced fertilize usage affect the wheat quality (Bai *et al.* 2010). The effective handling of waste from various sources is an imperative environmental, social, and economic concern in many industrial countries and causes problems that can exist for long term when not satisfactorily addressed (Farrell and Jones 2009). Land filling conditions require that no waste should be dumped into landfill before it is properly treated to minimize its environmental footprint (Hickman and Reid 2008). The elimination approaches of heavy metal that are generally carried out in "*ex situ*" are more expensive than bio-stabilization techniques and they can cause the significant decline in soil structure and productivity (Hseu 2004; Ullah *et al*. 2025b).

Compost consists of relatively stable and decayed organic matter subsequent from enhanced biotic deprivation of organic material under controlled and well-aerated conditions (Butler *et al*. 2008). Plants and animal remnants are recycled to form compost with the objective of better crop production (Duong 2013). The disintegration practice transforms the potentially toxic organic matter into stable and less toxic forms, which improve the soil health and promote crop production (Bastida *et al*. 2010). Compost formation has many benefits as it converts the landfill waste into beneficial product, eliminates of pathogens and weed seeds, disintegrates of petroleum, herbicide, and pesticide residues, and supplies nutrients for sustainable agriculture production. Utilization of compost reduces the use of chemical fertilizer and promote the production of organic food (Bouajila and Sanaa 2011). Application of organic matter in the form of compost on agriculture land enhances the nutrient supply and improves the soil physical and chemical properties (Mohammed *et al.* 2004; Ullah *et al*. 2025c). Declines in crop yield occur when soil and crops are vulnerable to pest and disease (Madeleine *et al*. 2005; Rezapour *et al*. 2019). Soil organic matter plays a vital role in the maintenance of soil quality (Haile 2017). The application of compost as organic fertilizer improves the proportion of organic matter content in soil, which improves soil productivity. Compost also improves the water holding capacity of soil and aeration, which helps for better seed germination and root development (Edwards and Hailu 2011; Ullah *et al*. 2025a). Soil fertility depends strongly on the rate of mineralization of nutrients present in soil organic matter and release of nutrients in plant available form into soil solution (Brady and Weil 2016). Although previous studies have examined the individual effects of compost application on soil fertility and the impacts of wastewater irrigation on soil and crop performance, most of this work has addressed these factors in isolation. Limited information exists on how compost amendment interacts with different wastewater sources, particularly industrial (textile) and municipal (sewage), effluents compared with conventional canal and groundwater to jointly influence both soil physical/chemical properties and wheat growth and yield within a single controlled experiment. Consequently, it remains unclear whether compost can effectively mitigate the potential adverse effects of lower-quality irrigation water while simultaneously enhancing its beneficial nutrient contributions to wheat productivity. To the best of our knowledge, this is the first study to simultaneously evaluate the interactive effects of compost amendment and four distinct irrigation water sources (textile effluent, sewage water, canal water, and groundwater) on both soil physical/chemical properties and wheat growth and yield under controlled pot conditions. This research examined the effect of compost on soil physical and chemical properties irrigated with different types of wastewaters in wheat crop.

HYPOTHESIS and OBJECTIVES

It was hypothesized that combined application of compost with wastewater irrigation would mitigate the adverse effects of wastewater on soil properties while enhancing wheat growth and yield more than either treatment alone.

The objective of this study was to evaluate the individual and interactive effects of compost and four irrigation water sources (textile effluent, sewage water, canal water, groundwater) on soil physical/chemical properties and wheat growth and yield.

EXPERIMENTAL

Experimental Site

Experiments were carried out at research area of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. The physico-chemical properties of soil in the experimental area are listed in the Table 1.

Soil Physico-chemical Analysis

Soil texture was determined by the hydrometer method (Zhang *et al*. 2024). Soil organic matter was determined by (Yusuf *et al*. 2023). Total nitrogen, available phosphorus and available potassium were determined by the Kjeldahl method (Kalita *et al*. 2023; Thabit *et al*. 2024). Electrical conductivity of the saturation extract (ECe) and pH were determined using the saturated soil paste extract method (Zhu *et al*. 2024). Cation exchange capacity (CEC) was determined by the ammonium acetate extraction method (Mustafa *et al*. 2024).

Table 1. Physio-chemical Properties of Experimental Soil before Experiment

Parameter	Unit	Value
Sand	%	39.12
Silt	%	27.77
Clay	%	33.11
Texture	----	Clay Loam
Organic matter	%	0.35
Available Phosphorus	mg kg^{-1}	6.17
Total nitrogen	g kg^{-1}	0.33
Available Potassium	mg kg^{-1}	277.5
ECe	dS m^{-1}	1.75
CEC	$cmol_c$/kg	12.70
pH	----	7.9

Treatments and Experimental Plan

A pot experiment was conducted in the wire house of ISES, UAF, during the season 2021-2022 to evaluate the effect of compost on soil irrigated with different types of wastewaters in wheat crop. The trial consisted of eight treatments with three replications of each treatment. The effect of compost and different types of irrigation wastewater was assessed alone and in combination. Different types of wastewaters such as ground water, canal water, sewage water, and textile water were tested for their quality, pH, and EC. Wastewater was applied to crops occasionally according to requirement of crop. Compost

was filled in pots at rate of 10 g per kg of soil. Wheat variety "Ujala 2016" was selected for this experiment, and sowing was done on 15 Oct 2021.

Collection of Data

Data relating to agronomic parameters such as plant height, spike length, and grain and straw yield was measured after the harvesting the crop. Chlorophyll content was measured during the vegetative growth of plant with the help of chlorophyll meter. Nitrogen was determined in both plant and soil sample by using the Kjheldhal apparatus (Wolf 1982). Soil organic carbon was determined in soil samples by following the method of Walkley Black method (1947). Bulk density was determined by taking the soil samples with the help of steel cores. Steel cores were placed in oven at oven at 105 °C until no loss in weigh was recorded (Blake and Hartge 1986). Bulk density of soil was calculated by Eq. 1.

$$\text{Bulk density} = \frac{\text{Weight of oven dried soil}}{\text{Volume of steel core}} \quad (1)$$

The proportion of water stable aggregates were evaluated by passing the water-soaked soil samples through series of mesh with pore sizes of 1000 µm, 750 µm, 500 µm, 250 µm, and 110 µm (Moebius *et al*. 2007). The percentage of water stable aggragate was evaluated with Eq. 2.

$$\text{Water stable aggregates (\%)} = \frac{\text{Water stable aggregates}}{\text{Total number of soil aggregates}} \times 100 \quad (2)$$

Statistical Analysis

Data relating to growth and yield obtained by all physical and chemical analysis were analyzed statistically through Fisher's method of analysis of variance (Steel *et al*. 1997) by using software Statistix-8.1. Treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Growth and Yield Parameter

The application of compost and cumulative effect of compost and various sources of irrigation water significantly affected height of plant. Sewage water resulted in maximum plant height of 85.0 cm followed by treated effluent water, which was 84.3 cm. Compost and sewage water further improved the height of plants to 92.0 cm (Fig. 1). The same applied for the length of spikes too, where the irrigation source and the compost application had a significant effect. The combined application of compost and sewage water recorded maximum spike length (9.86 cm) while sewage water alone recorded the longest spike length (9.55 cm) (Fig. 2), suggesting a synergistic effect of both compost and sewage water on wheat growth.

Various sources of irrigation and compost influenced the grain yield. The application of sewage water caused the highest grain yield of 1.48 g Pot^{-1}. The interactive effect of irrigation sources and compost application rate yielded the greatest grain yield of 1.61 g Pot^{-1} (Fig. 3). Straw yield was affected by the application various sources of irrigation and cumulative effect of compost and various sources of irrigation. Application of sewage water yielded the highest straw yield of 1.55 g Pot^{-1}. The cumulative effect of compost and sewage water resulted in the highest straw yield of 1.64 g Pot^{-1} (Fig. 4).

Various sources of irrigation and compost influenced the chlorophyll content in wheat crop leaf. Application of sewage water caused the highest grain yield of 45 SPAD. Interactive effect of sewage water and compost application rate yielded the greatest grain yield of 51 SPAD (Fig. 5).

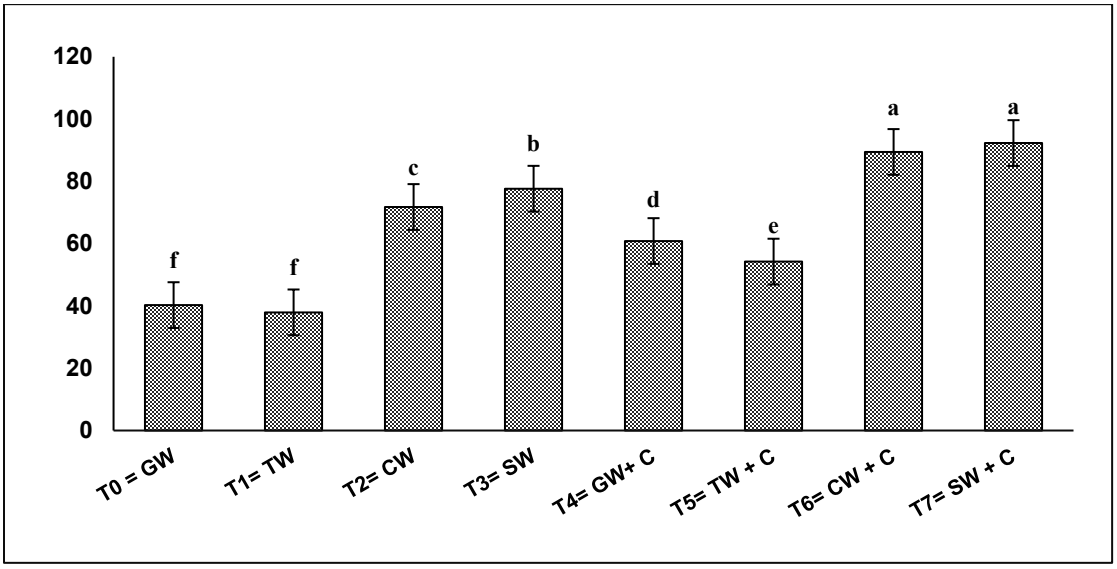


Fig. 1. Effect of compost and various source of irrigation on plant height under the plastic mulching. T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

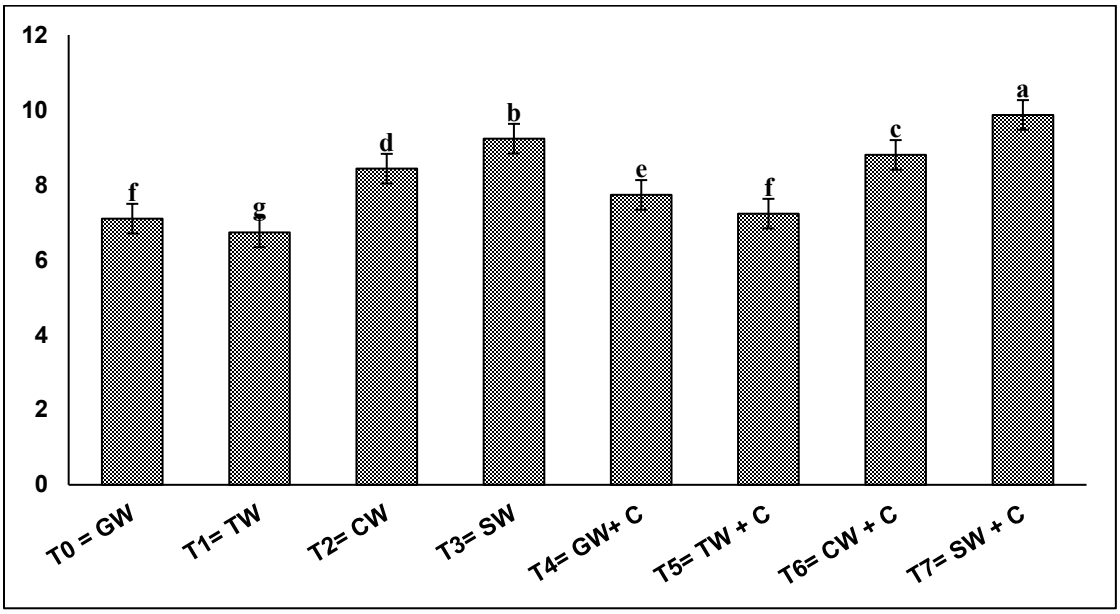


Fig. 2. Effect of compost and various source of irrigation on spike length.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

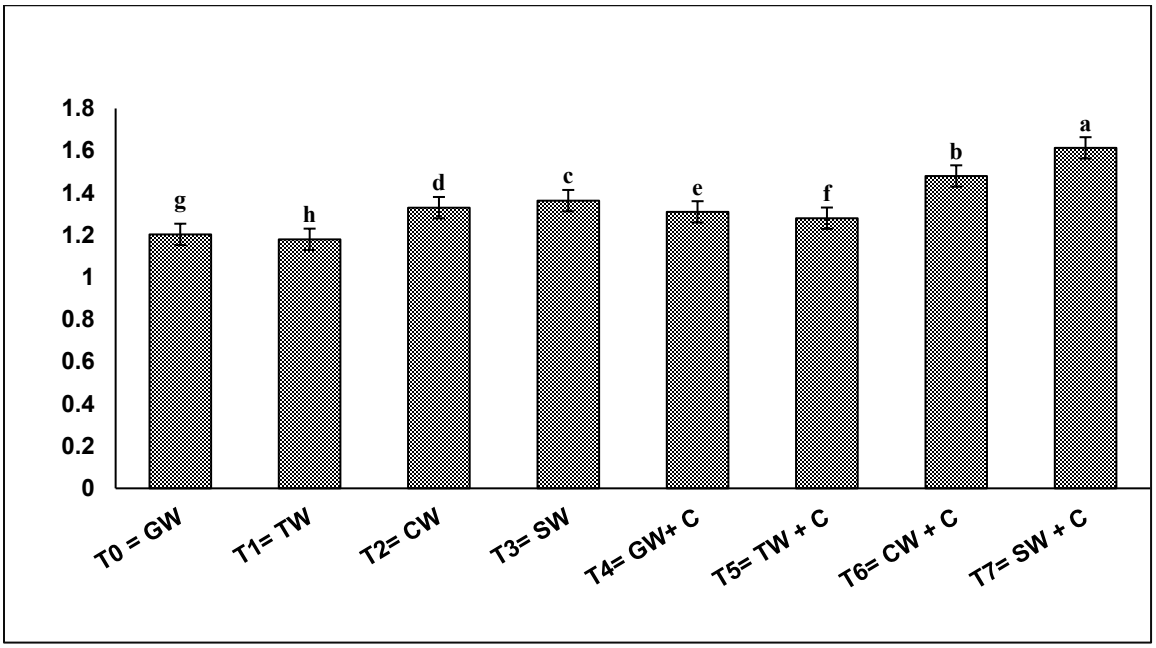


Fig. 3. Effect of compost and various source of irrigation on grain yield.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

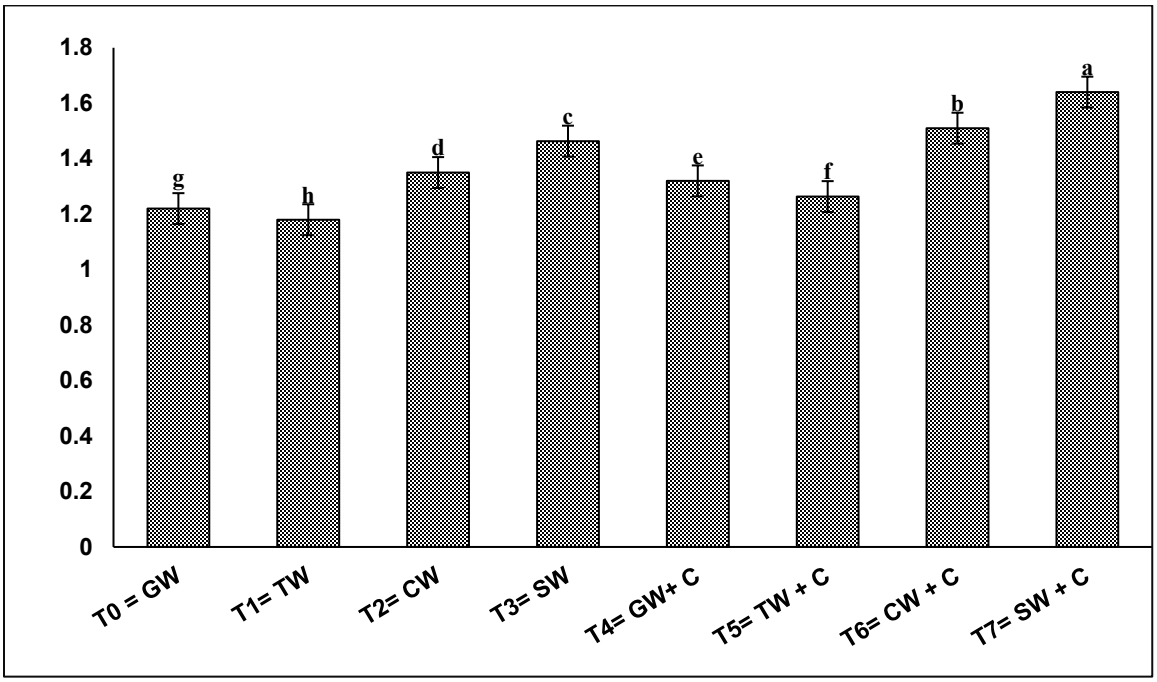


Fig. 4. Effect of compost and various source of irrigation on straw yield.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost.

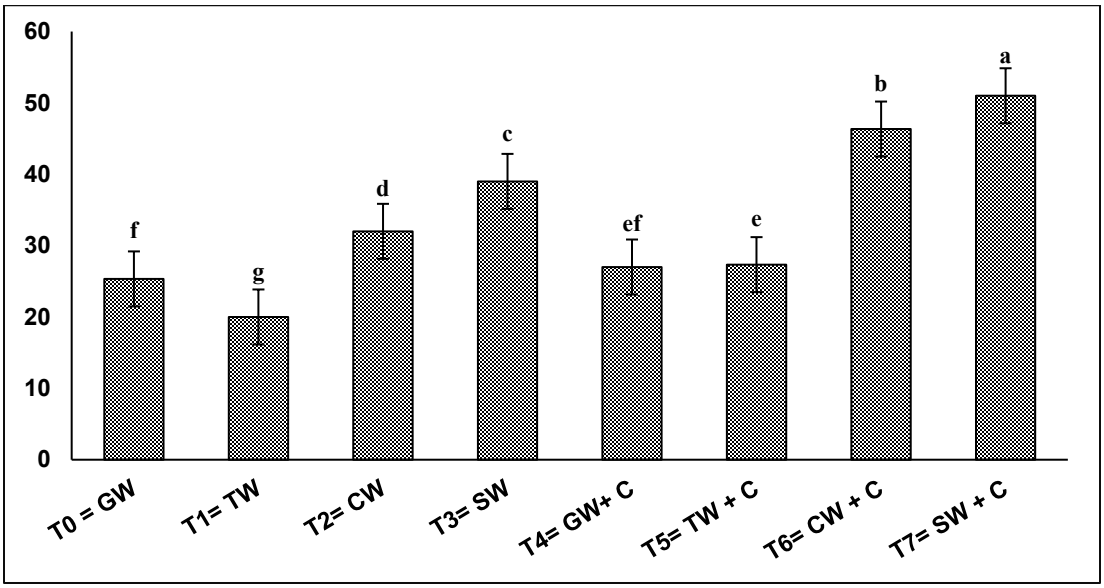


Fig. 5. Effect of compost and various source of irrigation on chlorophyll content.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

Soil Physical Properties

Soil bulk density increased as the level of heavy metals in irrigation increased. Bulk density was greater for sewage water application. The application of compost lowered the soil bulk density, and the lowest bulk density was recorded in compost treatment (Fig. 6). The proportion of water stable aggregates were affected by the application of various sources of irrigation water. The cumulative effect of sewage water and compost resulted in increased water stable aggregates (Fig. 7).

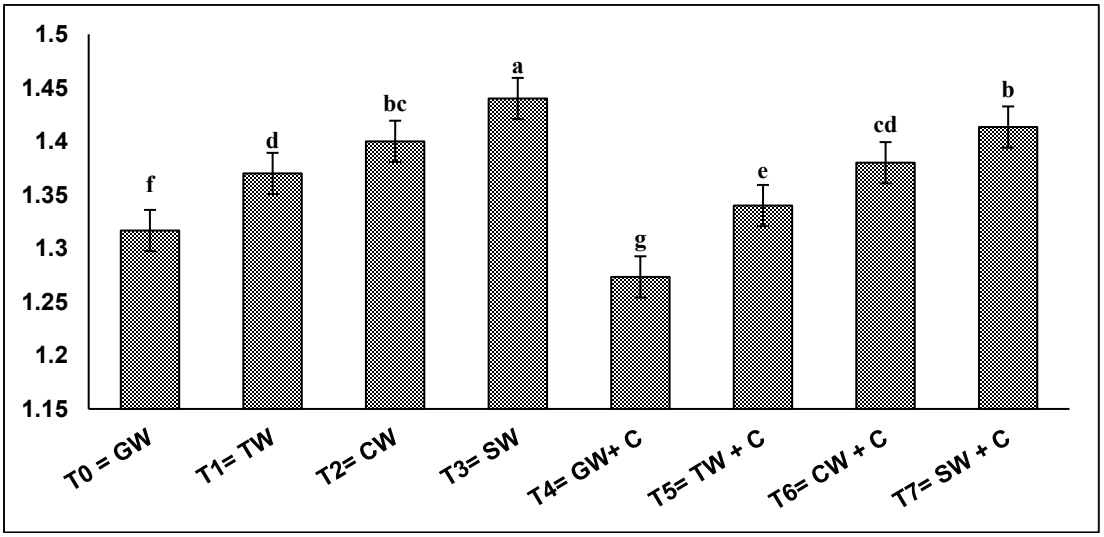


Fig. 6. Effect of compost and various source of irrigation on bulk density.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

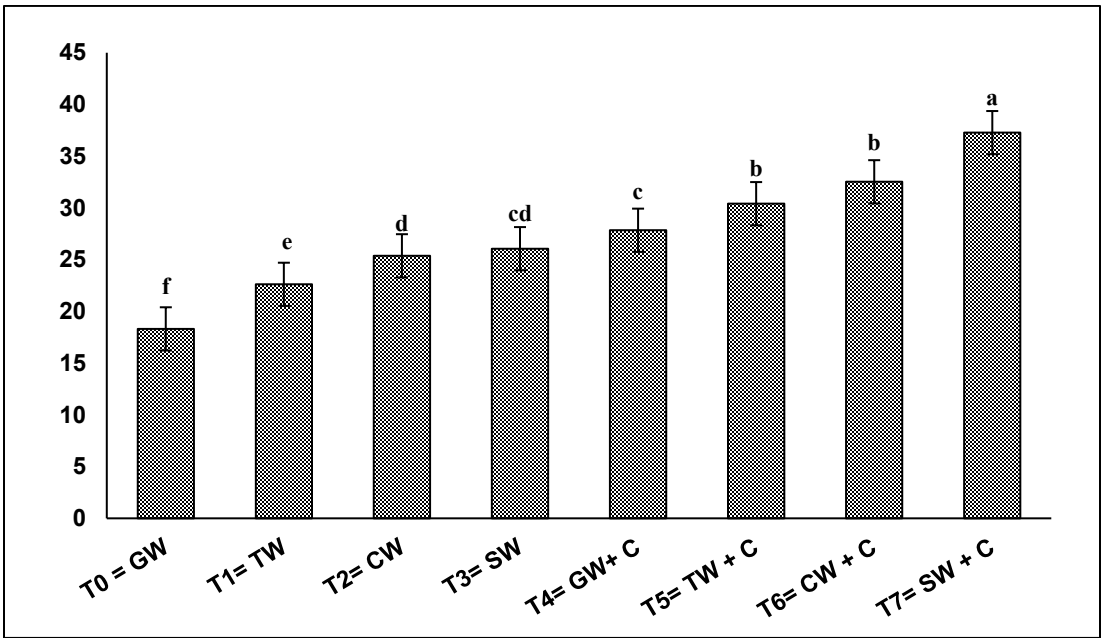


Fig. 7. Effect of compost and various source of irrigation on water stable aggregate.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

Soil organic carbon was affected by the application of compost and cumulative effect of compost and phosphorous sewage water. The application of sewage water caused the highest soil organic carbon of 0.46%. The cumulative effect of compost and sewage water resulted in the highest soil organic carbon of 0.53% (Fig. 8).

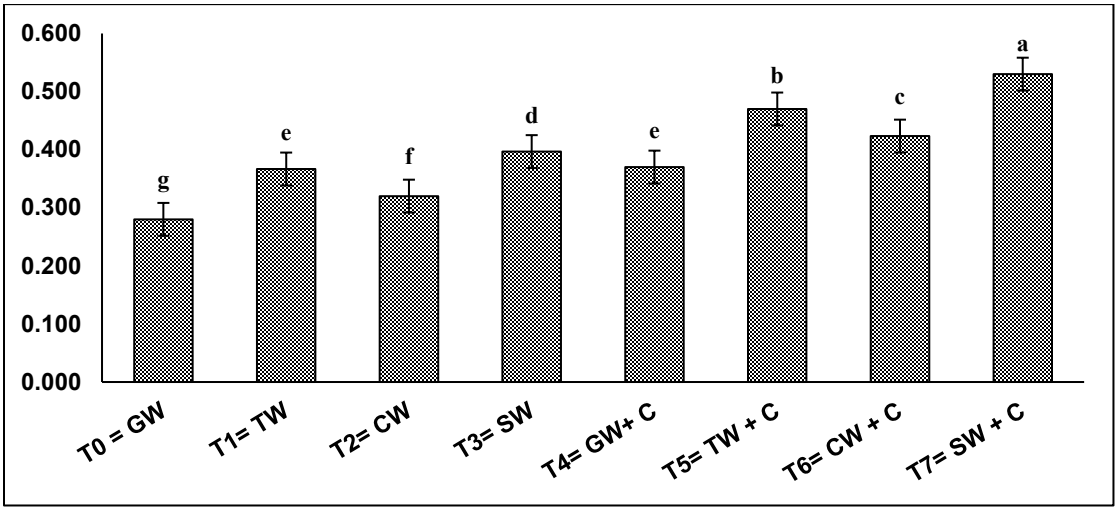


Fig. 8. Effect of compost and various source of irrigation on soil organic carbon.
T_0 = Ground Water, T_1 = Textile Water, T_2 = Canal Water, T_3 = Sewage Water, T_4 = Ground Water + Compost, T_5 = Textile Water + Compost, T_6 = Canal Water + Compost, T_7 = Sewage Water + Compost. Bars sharing the same letter are not significantly different from each other according to Tukey's HSD test ($p \leq 0.05$).

The application of compost in agriculture field is one of the most important factors for sustainable agriculture production. The low soil organic matter reduces soil fertility that results in poor soil health and increased exposure of plants to diseases and pest attacks (Hua *et al*. 2020). Use of compost not only improves the growth and production of crop, but it also improves the quality of product (Abedi *et al*. 2010). Due to shortage of fresh water for irrigation, wastewater is used for crop irrigation, which imparts beneficial impacts such as improvement in soil organic carbon, nitrogen, phosphorous, and potassium (Rai *et al*. 2011). In addition to beneficial effect of the use of wastewater as irrigation source, it also causes some harmful effects such as root and shoot growth inhibition and reduction in the yield of crop due to accumulation of heavy metal (Singh *et al*. 2009). Using wastewater for crop irrigation causes the accumulation of heavy metals in soil and plant parts, which is dangerous for human health (Singh *et al*. 2010). The results showed that cumulative effect of compost and different sources of water had an effect on soil properties, crop physiology, and yield parameter. The chlorophyll content was higher in the treatments where compost and different sources of water were used collectively in comparison to treatment where only the various source of water were used as treatment. The increased chlorophyll content may be due to higher availability of nitrogen and other nutrients. Similarly, Kaushik *et al*. (2005) described that application of sewage and canal water enhanced the physiological activity in plant due to more availability of nutrients. According to Adugna (2018), there are numerous beneficial effects of compost on the physical, chemical, and biological properties, as the application of compost enhances the physiological activity in crops. Wastewater irrigation has also been reported to enrich soil with nitrogen and phosphorus. This can improve productivity of several agronomic crops, although wheat has shown comparatively inconsistent yield responses depending on wastewater quality (Saleh *et al*. 2025).

The results showed that the application of compost and sewage water together yielded the greatest plant height and spike length. Improvement in plant height and spike length may occur due to availability of plant-needed nutrients in proper amount. Application of compost as organic fertilizer improves the proportion of organic matter content in soil because of which plant growth improves (Edwards and Hailu 2011). Wastewater is always enriched with many plant-needed nutrients such as organic carbon, nitrogen, phosphorous, potassium and magnesium as compared to clean water (Singh and Agrawal 2012). Grain yield and straw yield improved due to application of compost in combination with various sources of irrigation water. This increment in grain yield and straw yield may be due to improvement in spike length, grain size and height of plant. The results are similar to the findings to Usman (2013), who concluded that plant height and spike length increases when plant needed nutrient are supplied in balance quantity. The results are supported by Abdul Mojid and Wyseure (2014), who reported that due to application of wastewater in field nutrient including N, P, K, and organic matter accumulates in soil that is taken by plant due to mineralization because of wheat yield increased. However, irrigation with industrial or municipal wastewater can also introduce toxic metals into soil, which may reduce crop productivity and compromise food safety (Haider *et al.* 2025), a concern that is particularly relevant to the textile effluent and sewage water treatments used in the present study and is addressed further in the Future Work section. These findings are consistent with (El-Sharkawy *et al*. 2022), who reported that compost application improved soil physicochemical properties, plant growth, and yield components of durum wheat under saline irrigation conditions. The improvement in chlorophyll content with compost application observed in the present study agreed with

recent findings that compost and biochar amendments alleviated reductions in chlorophyll content (SPAD), straw yield, and grain yield under stressed irrigation conditions (Shaaban *et al*. 2024). However, irrigation with industrial or municipal wastewater can also introduce toxic metals into soil, which may reduce crop productivity and compromise food safety.

Compost improves soil structure by decreasing the soil bulk density. Porosity is an important soil property that determines the water and air movement in soil and root development. Compost reduces soil hardness and increases nutrient availability. The results are similar to Cogger *et al*. (2008), who showed that application of compost increased the infiltration rate of soil by increasing the total pore space in soil. Similarly, Curtis and Claassen (2009) found that compost increased the saturated hydraulic conductivity of soil. Water stable aggregate is an important physical property of soil that plays a vital role in soil fertility and yield of crop. The results indicated that water stable aggregate increased due to application of compost as amendment. Similarly, compost amendment has recently been shown to lower soil bulk density while increasing soil aggregation, water-stable aggregates, and soil organic carbon in semi-arid agricultural systems (Kang *et al*. 2021). The results are similar to findings of Wortmann and Shapiro (2008), who showed that application of compost increased water stable aggregates by consolidating the micro-aggregates into macro-aggregates. Bipfubusa *et al*. (2008) found that application of compost promotes the diffusion of humic acid within the soil aggregates as a result soil aggregate become stable due to cohesion. However, recent evidence that organic amendments increased the stability of water-stable aggregates in the surface soil layer, which was attributed to higher organic carbon content promoting organo-mineral bonding (Jiang *et al*. 2025). Soil organic carbon is a very important component of soil health and plays a vital role in crop production. The results illustrated that soil organic carbon increased due to application of wastewater and compost. This increase in soil organic carbon was due to presence of organic matter in wastewater and compost. The results are similar to those of Bipfubusa *et al*. (2008), who showed that application of compost and sewage water increased the soil organic carbon due accumulation and sequestration of carbon in soil. Wuest and Gollany (2013) found that application of compost increased the soil organic carbon after the decomposition by soil microbes.

Future Work

The present study did not include an analysis of heavy metal accumulation in soil or wheat tissue following the different wastewater and compost treatments. Since industrial wastewater (textile effluent) and municipal wastewater (sewage water) can carry heavy metals such as cadmium, lead, nickel, and chromium, future studies should quantify metal accumulation in soil and its uptake by wheat grain and straw to assess food-safety implications before these irrigation and compost combinations are recommended for widespread field application. In addition, the present study evaluated only one type of compost; future work should compare multiple compost sources (e.g., animal manure-based, municipal solid waste-based, and plant-residue-based composts) to determine whether compost type influences the mitigation of wastewater-related contaminants and the enhancement of soil properties and crop yield.

CONCLUSIONS

1. Wheat growth and yield parameter improved owing to cumulative effect of compost and various sources of irrigation water.
2. Compost improved the availability of nitrogen and minimized its losses by improving the soil physical properties such as water stable aggregate and total porosity, and lowers the bulk density of soil.
3. Application of compost was found to be very beneficial along with various sources of irrigation water for increasing the wheat yield and improving the soil nitrogen availability.
4. However, since textile effluent and sewage water may carry heavy metals, future studies should quantify metal accumulation in soil and wheat tissue to confirm the food-safety of these treatments before recommending them for field-scale adoption.

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Competing Interests

The authors declare that there are no conflicts of interest.

Availability of Data and Material

All the data generated in this research work has been included in this manuscript.

REFERENCES CITED

Abdul Mojid, M., and Wyseure, G. C. L. (2014). "Fertility response of potato to municipal wastewater and inorganic fertilizers," *Journal of Plant Nutrition* 37(12), 1997-2016. https://doi.org/10.1080/01904167.2014.920365

Abedi, T., Alemzadeh, A., and Kazemeini, S. A. (2010). "Effect of organic and inorganic fertilizers on grain yield and protein banding pattern of wheat," *Australian Journal of Crop Science* 4(6), 384-389.

Adugna, G. (2018). "A review on impact of compost on soil properties, water use and crop productivity," *Agricultural Science Research Journal* 4, 93-104. https://www.academicresearchjournals.org/ARJASR/PDF/2016/March/Adugna.pdf

Ahmad, T. I., Khan, R. E. A., Soharwardi, M. A., Shafiq, M. N., and Gillani, S. (2021). "Socio-economic and agronomy of wheat yield in cotton-wheat Punjab (Pakistan): A quality-quantity assessment," *International Journal of Agricultural Extension* 9(1), 69-78.

Bai, W., Zhang, H., Liu, B., Wu, Y., and Song, J. (2010). "Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles," *Soil Use and Management* 26(3), 253-260. https://doi.org/10.1111/j.1475-2743.2010.00271.x

Bastida, F., Kandeler, E., Moreno, J., Ros, M., Garcia, C., and Hernandez, T. (2010). "Soil degradation and rehabilitation: Microorganisms and functionality," in: *Soil Biology and Agriculture in the Tropics*, Springer, Berlin, Germany, pp. 253-270. https://doi.org/10.1007/978-3-642-04043-6_13

Bipfubusa, M., Angers, D. A., N'Dayegamiye, A., and Antoun, H. (2008). "Soil aggregation and biochemical properties following the application of fresh and composted organic amendments," *Soil Science Society of America Journal* 72(1), 160-166. https://doi.org/10.2136/sssaj2007.0055

Blake, G. R., and Hartge, K. H. (1986). "Bulk density," in: *Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods* (2nd Ed.), A. Klute (ed.), ASA and SSSA, Madison, WI, USA, pp. 363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13

Bouajila, K., and Sanaa, M. (2011). "Effects of organic amendments on soil physico-chemical and biological properties," *Journal of Materials and Environmental Science* 2(5), 485-490.

Brady, N. C., and Weil, R. R. (2016). *The Nature and Properties of Soils*, 15th Ed., Pearson Education, Upper Saddle River, NJ, USA.

Butler, T., Han, K., Muir, J., Weindorf, D., and Lastly, L. (2008). "Dairy manure compost effects on corn silage production and soil properties," *Agronomy Journal* 100(5), 1541-1545. https://doi.org/10.2134/agronj2008.0033

Chandio, A. A., Jiang, Y., Joyo, M. A., and Rehman, A. (2016). "Impact of area under cultivation, water availability, credit disbursement, and fertilizer off-take on wheat production in Pakistan," *Journal of Applied Environmental and Biological Sciences* 6, 10-18.

Cogger, C., Hummel, R., Hart, J., and Bary, A. (2008). "Soil and redosier dogwood response to incorporated and surface-applied compost," *HortScience* 43(7), 2143-2150. https://doi.org/10.21273/HORTSCI.43.7.2143

Curtis, M. J., and Claassen, V. P. (2009). "Regenerating topsoil functionality in four drastically disturbed soil types by compost incorporation," *Restoration Ecology* 17(1), 24-30. https://doi.org/10.1111/j.1526-100X.2007.00329.x

Duong, T. (2013). *Compost Effects on Soil Properties and Plant Growth*, Ph.D. Dissertation, School of Agriculture, Food and Wine, The University of Adelaide, Adelaide, Australia.

El-Sharkawy, M., Mahmoud, E., Abd El-Aziz, M., and Khalifa, T. (2022). "Effect of zinc oxide nanoparticles and soil amendments on wheat yield, physiological attributes and soil properties grown in the saline – sodic soil," *Communications in Soil Science and Plant Analysis* 53(17), 2170-2186. https://doi.org/10.1080/00103624.2022.2070635

Edwards, S., and Hailu, A. (2011). *How to Make and Use Compost*. (https://www.fao.org/4/i2230e/i2230e14.pdf), Accessed June 17, 2026.

Farrell, M., and Jones, D. L. (2009). "Critical evaluation of municipal solid waste composting and potential compost markets," *Bioresource Technology* 100(19), 4301-4310. https://doi.org/10.1016/j.biortech.2009.04.029

Haider, B., Imran, M., and Ashraf, M. (2025). "Wheat growth, yield and metal uptake from a cadmium and lead contaminated soil following pressmud and phosphate fertilizer application," *Journal of Plant Nutrition and Soil Science* 188, 324-333. https://doi.org/10.1002/jpln.202400217

Haile, W. (2017). *Review of Soil Fertility Interventions in Ethiopia*, Research Finding Report Submitted to Fertile Ground Initiative, Ethiopia. https://doi.org/10.13140/RG.2.2.27550.64322

Hickman, Z. A., and Reid, B. J. (2008). "The co-application of earthworms (*Dendrobaena veneta*) and compost to increase hydrocarbon losses from diesel contaminated soils," *Environment International* 34(7), 1016-1022. https://doi.org/10.1016/j.envint.2008.03.004

Hseu, Z. Y. (2004). "Evaluating heavy metal contents in nine composts using four digestion methods," *Bioresource Technology* 95(1), 53-59. https://doi.org/10.1016/j.biortech.2004.02.008

Hua, W., Luo, P., An, N., Cai, F., Zhang, S., Chen, K., Yang, J., and Han, X. (2020). "Manure application increased crop yields by promoting nitrogen use efficiency in the soils of 40-year soybean-maize rotation," *Scientific Reports* 10, article 14882. https://doi.org/10.1038/s41598-020-71932-9

Jiang, W., Li, T., Ma, J., Wang, X., Cheng, Y., Gong, L., Zhang, J. and Chen, G. (2025). "Organic materials input promotes the soil aggregate sequestration through changing soil aggregates structure and stability," *Journal of Environmental Management* 393, article 127027. https://doi.org/10.1016/j.jenvman.2025.127027

Kalita, L., Singh, N. J., Ray, L. I., and Singh, A. K. (2023). "Incubation study of kinetics and mineralization rate of nitrogen in organic sources of Ultisol," *Current Science* 125(7), 765-770. https://doi.org/10.18520/cs/v125/i7/765-770

Kang, S. W., Yun, J. J., Park, J. H., and Cho, J. S. (2021). "Exploring suitable biochar application rates with compost to improve upland field environment," *Agronomy* 11(6), article 1136. https://doi.org/10.3390/agronomy11061136

Kaushik, P., Garg, V. K., and Singh, B. (2005). "Effect of textile effluents on growth performance of wheat cultivars," *Bioresource Technology* 96(10), 1189-1193. https://doi.org/10.1016/j.biortech.2004.09.020

Inckel, M., de Smet, P., Tersmette, T., and Veldkamp, T. (2005). *The Preparation and Use of Compost* (Agrodok No. 8), Agromisa Foundation, Wageningen, The Netherlands.

Moebius, B. N., Van Es, H. M., Schindelbeck, R. R., Idowu, O. J., Clune, D. J., and Thies, J. E. (2007). "Evaluation of laboratory-measured soil properties as indicators of soil physical quality," *Soil Science* 172(11), 895-912. https://doi.org/10.1097/SS.0b013e318154b520

Mohammad, H. G., Denney, M. J., and Iyekar, C. (2004). "Use of composted organic wastes as alternative to synthetic fertilizers for enhancing crop productivity and agricultural sustainability on the tropical island of Guam," in: *ISCO 2004 - 13th International Soil Conservation Organisation Conference*, Brisbane, Australia, Paper No. 234.

Mustafa, A. R. A., Abdelsamie, E. A., Mohamed, E. S., Rebouh, N. Y., and Shokr, M. S. (2024). "Modeling of soil cation exchange capacity based on chemometrics, various spectral transformations, and multivariate approaches in some soils of arid zones," *Sustainability* 16(16), article 7002. https://doi.org/10.3390/su16167002

Rai, S., Chopra, A. K., Pathak, C., Sharma, D. K., Sharma, R., and Gupta, P. M. (2011). "Comparative study of some physicochemical parameters of soil irrigated with sewage water and canal water of Dehradun City, India," *Archives of Applied Science Research* 3(2), 318-325.

Rezapour, S., Atashpaz, B., Moghaddam, S. S., and Damalas, C. A. (2019). "Heavy metal bioavailability and accumulation in winter wheat (*Triticum aestivum* L.) irrigated with treated wastewater in calcareous soils," *Science of The Total Environment* 656, 261-269. https://doi.org/10.1016/j.scitotenv.2018.11.288

Saleh, M., Salehi, M., Khanaki, S., Ebrahimian, H., Liaghat, A., Mousavi, S. M., Pashapour, S., and Ashrafi, A. (2025). "Effects of treated wastewater irrigation on soil properties, nutrient uptakes, and crop yields of agronomic crops under different crop rotations," *Agricultural Water Management* 316, article 109585. https://doi.org/10.1016/j.agwat.2025.109585

Shaaban, A., Hemida, K. A., Abd El-Mageed, T. A., Semida, W. M., AbuQamar, S. F., El-Saadony, M. T., Al-Elwany, O. A., and El-Tarabily, K. A. (2024). "Incorporation of compost and biochar enhances yield and medicinal compounds in seeds of water-stressed *Trigonella foenum-graecum* L. plants cultivated in saline calcareous soils," *BMC Plant Biol.* 24, 538. https://doi.org/10.1186/s12870-024-05182-6

Shiferaw, B., Smale, M., Braun, HJ., Duveiller, E., Reynolds, M., and Muricho, G. (2013). Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Sec* 5, 291-317. https://doi.org/10.1007/s12571-013-0263-y

Singh, A., and Agrawal, M. (2012). "Effects of wastewater irrigation on physical and biochemical characteristics of soil and metal partitioning in *Beta vulgaris* L.," *Agricultural Research* 1(4), 379-391. https://doi.org/10.1007/s40003-012-0044-4

Singh, A., Sharma, R. K., Agrawal, M., and Marshall, F. M. (2010). "Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India," *Food and Chemical Toxicology* 48(2), 611-619. https://doi.org/10.1016/j.fct.2009.11.041

Singh, A., Sharma, R. K., Agrawal, M., and Marshall, F. (2009). "Effects of wastewater irrigation on physicochemical properties of soil and availability of heavy metals in soil and vegetables," *Communications in Soil Science and Plant Analysis* 40(21-22), 3469-3490. https://doi.org/10.1080/00103620903327543

Steel, R. G. D., Torrie, J. H., and Dickey, D. A. (1997). *Principles and Procedures of Statistics: A Biometrical Approach*, 3rd Ed., McGraw-Hill Book Co., New York, NY, USA, pp. 172-177.

Shiferaw, B., Smale, M., Braun, H.-J., Duveiller, E., Reynolds, M., and Muricho, G. (2013). "Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security," *Food Security* 5, 291–317. https://doi.org/10.1007/s12571-013-0263-y

Thabit, F. N., Negim, O. I., AbdelRahman, M. A., Scopa, A., and Moursy, A. R. (2024). "Using various models for predicting soil organic carbon based on DRIFT-FTIR and chemical analysis," *Soil Systems* 8(1), article 22. https://doi.org/10.3390/soilsystems8010022

Ullah, S., Vogel-Mikus, K., Naeem, A., Ahmad, I., and Barcauskaite, K. (2025a). "Differential response of buckwheat growth, physiology, and elements distribution to copper and zinc toxicity in hydroponics," *Water, Air, & Soil Pollution* 236(6), article 360. https://doi.org/10.1007/s11270-025-07950-y

Ullah, S., Naeem, A., Praspaliauskas, M., Vaskeviciene, I., Hosney, A., and Barcauskaite, K. (2025b). "Comparative toxicity of copper and zinc contaminated wastewater irrigation on growth, physiology, and mineral absorption of wheat," *Water Environment Research* 97(1), article e70001. https://doi.org/10.1002/wer.70001

Ullah, S., Naeem, A., Praspaliauskas, M., Vaskeviciene, I., Hosney, A., Drapanauskaite, D., and Barcauskaite, K. (2025c). "Compost application modulates growth, physiology and metal uptake by *Pisum sativum* grown in two different pH soils irrigated with contaminated wastewater," *Plant and Soil* 513(2), 3041-3059.

https://doi.org/10.1007/s11104-025-07366-x

Usman, K. (2013). "Effect of phosphorus and irrigation levels on yield, water productivity, phosphorus use efficiency and income of lowland rice in northwest Pakistan," *Rice Science* 20(1), 61-72. https://doi.org/10.1016/S1672-6308(13)60109-2

Walkley, A. (1947). "A critical examination of a rapid method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents," *Soil Science* 63(4), 251-264.

Wolf, B. (1982). "A comprehensive system of leaf analysis and its use for diagnosing crop nutrient status," *Communications in Soil Science and Plant Analysis* 13(12), 1035-1059. https://doi.org/10.1080/00103628209367332

Wortmann, C. S., and Shapiro, C. A. (2008). "The effects of manure application on soil aggregation," *Nutrient Cycling in Agroecosystems* 80(2), 173-180. https://doi.org/10.1007/s10705-007-9130-6

Wuest, S. B., and Gollany, H. T. (2013). "Soil organic carbon and nitrogen after application of nine organic amendments," *Soil Science Society of America Journal* 77(1), 237-245. https://doi.org/10.2136/sssaj2012.0184

Yusuf, Y. M., Madukwe, D. K., and Kebede, F. (2023). "Establishing phosphorus critical values for tomato (*Solanum lycopersicum*) fertilization with phosphate fertilizers on the Sudan savanna soils using three soil phosphorus extraction methods and field experimentation in Kano State, Nigeria," *Frontiers in Agronomy* 5, article 1181045. https://doi.org/10.3389/fagro.2023.1181045

Zhang, X., Warren, C. J., Spiers, G., and Voroney, P. (2024). "Comparison of the integral suspension pressure (ISP) and the hydrometer methods for soil particle size analysis," *Geoderma* 442, article 116792. https://doi.org/10.1016/j.geoderma.2024.116792

Zhu, W., Gu, S., Jiang, R., Zhang, X., and Hatano, R. (2024). "Saline–alkali soil reclamation contributes to soil health improvement in China," *Agriculture* 14(8), article 1210. https://doi.org/10.3390/agriculture14081210

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