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Effects of wastewater irrigation on soil physico-chemical properties, growth and yield of tomato

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Abstract

The wastewater reuse for the purpose of irrigation may have a significant contribution to reduce water pollution, maximize water utilization and restore nutrient content of soils. An experiment was conducted at Environmental Science Field Laboratory, Bangladesh Agricultural University, Mymensingh from January to May, 2015 to investigate the effects of wastewater irrigation on soil physico-chemical properties (Soil texture, pH, electrical conductivity (EC), organic matter (OM), nitrogen (N), phosphorous (P), potassium (K), sulphur (S) and sodium (Na)) as well as yield and yield contributing characteristics of tomato crop. In this study, irrigation water, e.g., normal water, domestic wastewater, municipal wastewater and industrial wastewater was used as treatment with three replications. Soil and fruits were collected for analysis during last harvest. From the result, it is found that most of the chemical properties; OM, EC, N, K, S and Na contents were higher in wastewater treated soil compared to normal water irrigation. Among the treatments, plant height, LAI and yield were also higher in wastewater treated plot compared to normal water irrigated plot. Cost benefit analysis indicated that municipal wastewater irrigation gave more profit due to higher yield compared to domestic and industrial wastewater irrigation. From the study, it could be concluded that municipal wastewater irrigation was more profitable in respect of soil nutrient content and yield of tomato.

Key words: Wastewater irrigation, soil properties, crop yield, economic benefit

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Introduction

Wastewater is spent or used water with dissolved or suspended solids, discharged from homes, commercial establishments, farms and industries. The wastewater is rich in organic matter and also contains appreciable amounts of macronutrients and micronutrients. As urban populations in developing countries increase, and residents seek better living standards, larger amounts of freshwater are diverted to domestic, commercial, and industrial sectors, which generate greater volumes of wastewater (Lazarova and Bahri, 2005). The Economic and Social Commission for Asia and the Pacific reported that about 725 Mm^3 of wastewater is released annually from the urban areas of Bangladesh. More than 80 % of this wastewater directly discharged into the environment which degrades the soil and water environment and cause human health hazards due to lack of proper management (Tasha, 2008)**.**

The reuse of wastewater, in particular for irrigation, is a common practice at many places of the world (Erfani, 1997; FAO, 1992). Agriculture is the largest user of water at global level and currently consumes 70% of the world's freshwater supplies in developed countries

(Gleick, 2000; FAO, 2001). In some low-income countries, irrigation consumes 95% of all water uses. In Bangladesh, there is 8.3Mha (million hectare) of cultivable land of which 7.0 Mha are potential area for irrigation (Mojid *et al.*, 2010). However, only 4.48 Mha is covered by irrigation systems and 2.52Mha remains out of irrigation due to shortage of water (BBS, 2004). Shortage of surface and underground water could be partially overcome by the use of wastewater and its multiple uses are becoming more and more important to meet the increasing demand of agricultural production.

The use of wastewater for irrigation may treat an important resource because accept irrigation, it can also reduce the costs of commercial fertilizer as well as environmental hazards. The irrigation by wastewater has increased crop production, and water and nitrogen use efficiencies, and served as a source of plant nutrients (Hussain and Saati, 1999). It also alleviates the problem of the disposal of wastewater effluent (WHO, 1980). Therefore, well-planned utilization of wastewater in agriculture will increase food production by more irrigation coverage, reduce the pollution of river water and also reduce the cost of disposal of this wastewater by the municipal councils (Scott *et al.*, 2004).

In Bangladesh, although a few peri-urban farmers have started to irrigate their crops with wastewater, it is not yet well documented. Therefore, a detailed knowledge about the effects of wastewater on agricultural land is a pre-requisite for any step to move forward in using low quality wastewater for irrigation. The objectives of this study were: to evaluate the effects of wastewater irrigation on soil physico-chemical properties as well as on growth and yield of crops and to calculate the economic benefit of wastewater irrigation.

Materials and Methods

Experimental site**:** The experiment was carried out at Environmental Science Field Laboratory, Department of Environmental Science, Bangladesh Agricultural University, Mymensingh during the period of January to May 2015. Geographically the experimental area is situated at 24.75°N latitude and 90.5°E longitude and elevation is about 18 m above sea level. It belongs to the old Brahmaputra Floodplain, Agro-ecological Zone (AEZ-9) having non calcareous Dark Gray Flood Plain Soil (FAO, 2001). The experimental area is under subtropical climate characterized by moderately high temperature and heavy rainfall during Kharif season (April-September) and scanty rainfall during Rabi season (October-March).

Experimental design and layout**:** Irrigation was used as treatment in this study. Four types of irrigation water were used as treatment with three replications. Treatments were: T0 - Normal water; T1 - Domestic wastewater; T2 - Municipal wastewater and T3 - Industrial wastewater. Thus total unit of plots were 12. The area of each plot was 4 m^2 (2m × 2m).

Collection of wastewater: Industrial wastewater was collected from Rubber Industry, Tangail and Textile Industry, Valuka. Municipal wastewater was collected from the drains of botanical garden, BAU and Jaynal Abedin Park, Mymensingh which were released into the Brahmaputra River. Domestic wastewater was collected from a multistoried building at Boundary road, Mymensingh which was released through a pipe into a drain. Normal water was collected from the pond near the experiment field.

Cultivation procedure**:** In this study, tomato is used as a test crop because it is also one of the most important vegetable in Bangladesh in terms of acreage production, yield, commercial use and consumption. Forty-five day old seedlings of variety *Roma V* F were transplanted on 19th January, 2015 after 7 days of final land preparation. Plants were irrigated immediately after transplanting according to treatment layout. Weeding, pesticides and insecticides applications were done when necessary. Irrigation was given according to the need of plant throughout the growing season.

Fruits were started to harvest when it became slightly red color. First harvest was done on 3rd April, 2015.

Harvesting was done at 2 or 3 days interval and it was continued up to 5th May 2015. Fruits were collected treatment wise and their weights were taken by digital weight machine.

***Collection, preparation and analysis of soil and plant sample*:** Soil sample was collected from each plot after last harvest. Then samples were brought to the laboratory for the analysis of soil physical and chemical properties: soil texture, moisture, soil pH, electrical conductivity (EC), organic matter (OM), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), available sulphur (S) and exchangeable sodium (Na) following standard methods.

The plant height and leaf area index (LAI) was estimated at 7-day intervals from early growing season until just prior to harvest. Plants height was measured from the bottom to the top of plants by a centimeter scale. Leaf area was measured with a digital automatic leaf area meter (LI3100; LI-COR Logan, UT, USA) and the LAI was calculated as the sum of the leaf area divided by ground area and expressed as m^2m^{-2}.

The statistical analysis of plant sample (plant height, leaf area index and total yield) was done by the programme MSTATC. The analysis of variances for different parameters was performed and the means were compared by Duncan's Multiple Range Test (DMRT).

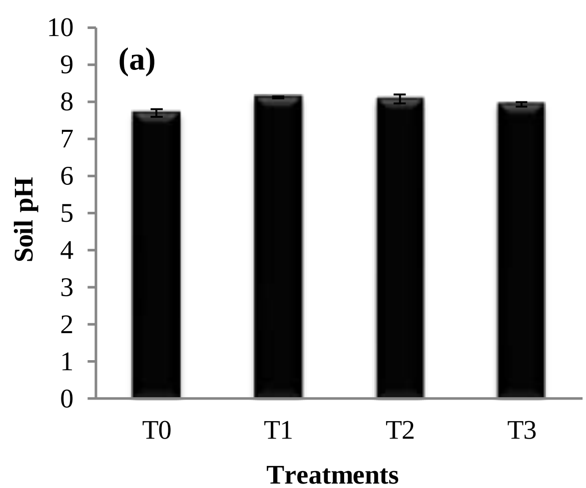
Results and Discussion

Effect of wastewater irrigation on soil physical and chemical properties

***Soil texture*:** Average sand was 12.8, 12.1, 8.8, and 15.4% in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively; silt was 72, 72, 74 and 68.6 % in treatments T0, T1, T2 and T3, respectively; and clay was 15.2, 15.8, 17.2 and 15.8% in treatments T0, T1, T2 and T3, respectively. There were no significant variations in sand, silt, and clay under different treatments.

***Soil pH*:** The average values of pH were 7.69, 8.12, 8.08 and 7.93 in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 1a). The highest value of pH (8.12) was found in treatment T1. All the values in different treatments were slightly higher compared to treatment T0. This slight pH change can be attributed to the release of exchangeable cations during the mineralization of organic matter (Woomer *et al.*, 1994). Kiziloglu *et al.* (2008) find out the effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower and red cabbage and found pH ranged from 6.85 to 7.52. According to Ayers and Wescot (1985), the acceptable limit of pH for tomato production ranged from 6.0- 8.4. pH values of all soil samples were less than 8.5 indicating that soil samples are free from sodicity hazards.

***Electrical conductivity (EC)*:** The average values of EC were 135.7, 172.1, 141.6 and 157.1 µS cm^{-1} in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 1b). The lowest value was recorded in treatment T0. The cause of increase of EC may be mobility of ions, their valences and their actual and relative concentration.



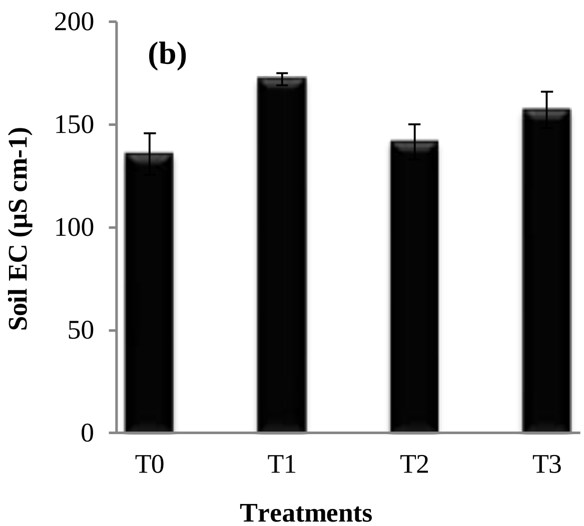


Figure 1. Effect of wastewater on (a) soil pH and (b) soil electrical conductivity (EC).

Kiziloglu *et al.* (2008) worked on effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower and red cabbage and reported that EC value was increased in untreated wastewater compared to treated wastewater.

***Soil organic matter (OM) content*:** The average values of OM were 1.05, 1.50, 1.11 and 1.26% in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2a). OM was higher in wastewater irrigated soil compared to normal water and highest was in treatment T1. It might be due to the presence of various organic substances in wastewater compared to normal water. Sonawane *et al.* (2010) assessed the impact of industrial wastewater on soil organic matter content and found that OM ranged from 0.08 to 0.698%.

***Total nitrogen (N)*:** The average values of N were 0.081, 0.107, 0.086 and 0.089% in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2b). The highest value was found in treatment T_1 and the lowest value was found in treatment T_0. It indicates that irrigation by wastewater increase the N content compared to normal water irrigation. This increase might be due to the presence of nitrate ions in the wastewater. Kiziloglu *et al.* (2008) also found an increase in N by the application of wastewater irrigation.

***Available phosphorous (P)*:** The average values of P contents were 27.86, 29.31, 35.25 and 34.18 ppm in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2c). The highest value was found in treatment T2 and the lowest value was found in treatment T0. Tabari *et al.* (2009) examined the impact of municipal wastewater on pine tree plantation soil and found the increased P content of soil.

***Exchangeable potassium (K)*:** The average values of K were found 52.96, 61.11, 55.0 and 55.68 ppm in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2d). The highest value of K was found in treatment T1 and the lowest value was found in treatment T0. Galavi *et al*. (2010) examined the effect of treated wastewater on soil properties and found K content ranged from 181-189 ppm that was much higher from the present study.

***Available sulphur (S)*:** Average values of S were 15.0, 25.47, 18.39 and 16.07 ppm in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2e). Treatment T1 showed the highest value of S and treatment T0 showed the lowest value. It indicated that by the use of wastewater, S content was increased in soil. It might be due to presence of sulfide ions in wastewater. The values recorded are within the optimum limit indicating that wastewater irrigation has no harmful effect on soil S content.

***Exchangeable sodium (Na)*:** The average values of exchangeable Na were 329.95, 363.9, 335.8 and 342.13

ppm in treatments T0 (normal water irrigation), T1 (domestic wastewater irrigation), T2 (municipal wastewater irrigation) and T3 (industrial wastewater irrigation), respectively (Figure 2f). Treatment T_1 contained the highest value of Na and treatment T_0 contained the lowest value. It indicates that by the use of wastewater irrigation, Na content was increased over normal water. Kiziloglu *et al.* (2008) investigated that effect of wastewater irrigation on chemical properties of soil and also found that wastewater irrigation increased the Na content of soil.

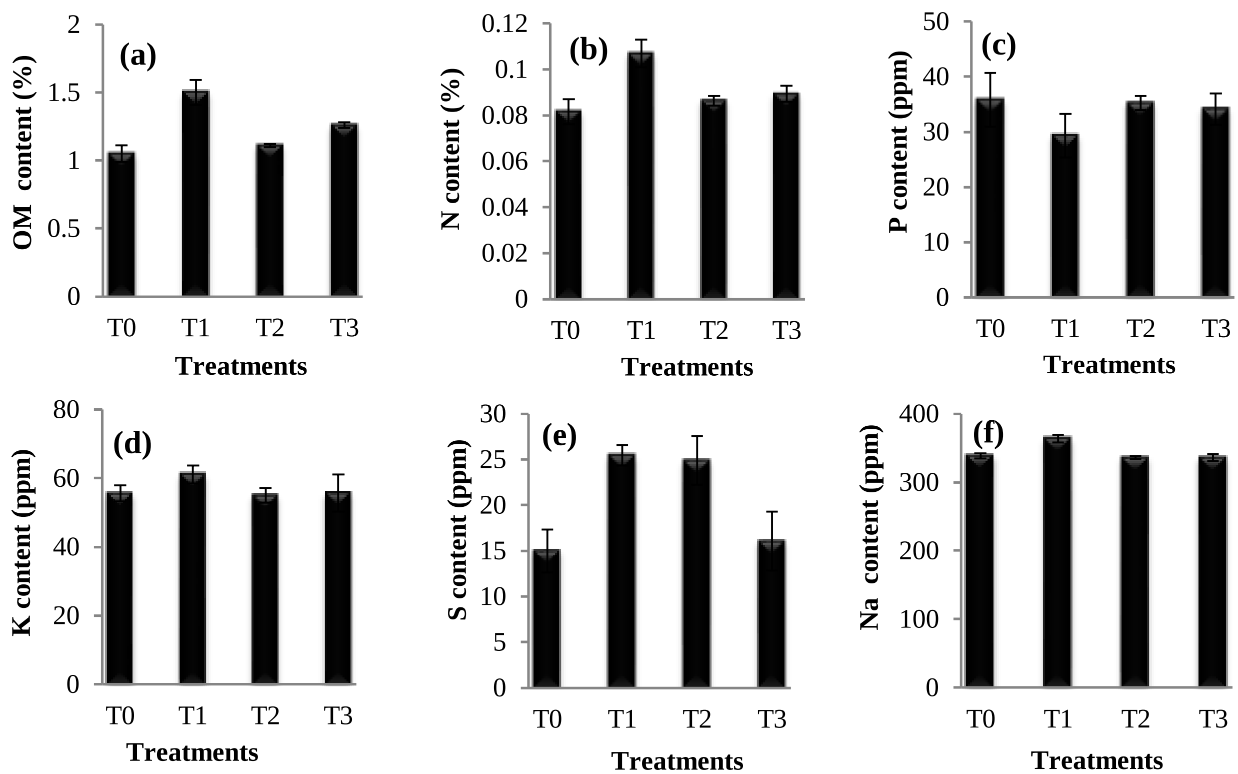


Figure 2. Effects of wastewater irrigation on soil organic matter and nutrient contents: (a) organic matter (OM), (b) Nitrogen (N), (c) Phosphorous (P), (d) Potassium (K), (e) Sulphur (S) and (f) Sodium (Na) content.

Effect of wastewater irrigation on crop performance

Plant height: The plant height was recorded at 45, 52, 59, 66, 73, 80, 87 and 94 DAT (Table 1). Among the treatments, the highest plant height was observed (50.29 cm) in treatment T2 (municipal wastewater irrigation) and the lowest was observed (25.65 cm) in treatment T1 (domestic wastewater irrigation) although most of the nutrient content was higher in T1 treatment. It might be happened due to the presence of more readily available nutrients in T2 compared to T1. Gatta *et al.* (2015) also reported that plant growth was increased due to use of wastewater irrigation.

Leaf area index (LAI): The variation of LAI was statistically significant at 45, 52, 59, 66, 73, 80, 87 and 94 DAT under different treatments of wastewater irrigation at 1% and 5% level of probability (Table 2). Among the treatments, the highest LAI was observed (9.730) in treatment T3 (Industrial wastewater irrigation) at 59 DAT and the lowest LAI was observed (1.420) in treatment T0 (normal water irrigation) at 94 DAT.

Table 1. Effect of wastewater irrigation on plant height.

Treatments	Plant height (cm) at different days after transplanting							
	45 DAT	**52 DAT**	**59 DAT**	**66 DAT**	**73 DAT**	**80 DAT**	**87 DAT**	**94 DAT**
T0	28.49 c	30.22 b	30.75 bc	35.83 c	42.67 b	41.40 b	42.67 b	43.43 b
T1	25.65 d	27.63 c	28.77 c	31.59 d	37.84 b	37.33 b	37.84 b	38.60 c
T2	30.98 b	31.75 b	33.02 b	40.36 b	50.03 a	49.53 a	50.03 a	50.29 a
T3	36.83 a	38.37 a	42.92 a	45.44 a	49.27 a	48.51 a	49.27 a	49.53 a
LSD(0.05)	1.459	2.543	3.341	3.202	5.463	4.756	5.463	4.48
CV (%)	2.39	3.98	4.94	4.18	3.81	5.39	6.08	4.93
Level of significance	**	**	**	**	**	**	**	**

** = Significant at 1% level of probability

Table 2. Effect of wastewater irrigation on leaf area index.

Treatments	Leaf area index at different days after transplanting							
	45 DAT	**52 DAT**	**59 DAT**	**66 DAT**	**73 DAT**	**80 DAT**	**87 DAT**	**94 DAT**
T0	4.950 ab	4.730 b	6.480 b	7.530 a	5.300 c	2.343 c	1.680 d	1.420 d
T1	4.830 bc	4.980 a	5.230 c	5.310 c	5.330 c	3.110 b	2.830 c	2.590 c
T2	4.730 c	4.970 a	5.400 c	6.320 b	7.500 a	5.880 a	4.730 b	3.840 b
T3	5.030 a	5.070 a	9.730 a	6.480 b	6.950 b	6.500 a	5.650 a	5.130 a
LSD(0.05)	0.1895	0.1895	0.3518	0.2605	0.3518	0.7035	0.9134	0.619
CV (%)	1.96	1.94	2.61	2.01	2.89	7.88	12.29	9.54
Level of significance	*	*	**	**	**	**	**	**

**= Significant at 1% level of probability; *= Significant at 5% level of probability

***Total yield*:** The variation in yield was statistically significant due to use of different treatments of wastewater irrigation (Table 3). Among the treatments, the highest yield was observed (15.87 t ha^{-1}) in treatment T2 (municipal wastewater irrigation) and the lowest yield was observed (10.38 t ha^{-1}) in treatment T0 (normal water irrigation). It indicates that due to use of wastewater irrigation, yield was increased compared to normal irrigation water. Jamal *et al.* (2011) reported that by the use of wastewater irrigation, yield of tomato was increased significantly due to the presence of higher amount of nutrient in wastewater.

***Costs-benefit analysis*:** From the Table 4, it is observed that the highest profit was gained in treatment T_2 (municipal wastewater irrigation) due to higher yield and the lowest profit was gained in control T_0 (normal water irrigation) due to lower yield.

Table 3. Effect of wastewater on total yield of tomato.

Treatments	Total Yield (t ha^{-1})
T0	9.72d
T1	12.48c
T2	15.37a
T3	14.12b
LSD (0.05)	0.4853
CV (%)	1.85
Level of significance	**

**= Significant at 1% level of probability

The costs included price of seedling, fertilizer, wastewater collection cost and others and income included the price of tomato. Baddesha *et al*. (1997) also found that wastewater irrigation increases the level of soil fertility and yield and profit.

Table 4. Effect of wastewater on economic benefit.

Treatment	Cost (Tk)	Income (Tk)	Profit (%)
T_0	175.0	291.69	66.68
T_1	200.0	374.46	87.23
T_2	225.0	461.1	104.0
T_3	250.0	423.6	69.55

This study revealed that there were no significant negative effects of wastewater on soil physical and chemical properties as well as on crop performance. In addition, nutrient content of soil and yield and yield contributing characters were higher in wastewater irrigated plot compared to normal water.

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