

Project ID 690

Sub-Project Completion Report

on

Assessing and Mitigating the Contamination of Vegetable Crops and Soil under Irrigation with Urban Wastewater

Project Duration

June 2017 to September 2018

**Irrigation and Water Management Division
Bangladesh Agricultural Research Institute
Joydebpur, Gazipur 1701**

Submitted to

**Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215**

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Acronyms

AFI	Alternate Furrow Irrigation
BARI	Bangladesh Agricultural Research Institute
BBFI	Broad Bed Furrow Irrigation
BRAC	Bangladesh Rural Advancement Committee
CFU	Colony Forming Unit
CV	Coefficient of variation
<i>E. coli</i>	<i>Escherichia coli</i>
FC	Fecal Coliform
FS	Fecal Streptococci
g	gram
ha	hectare
ICDDR'B	International Centre for Diarrhoeal Disease Research, Bangladesh
Kg	Kilogram
LSD	Least Significant Difference
ml	millilitre
RCBD	Randomized Complete Block Design
SGS	Surveillance of General Services
SRDI	Soil Resources Development Institute
t	ton
TC	Total Coliform
TABC	Total Bacterial Aerobic Count

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Executive Summary

Proper irrigation methods and management can help farmers to harvest the benefits of wastewater irrigation while minimizing the risk of its use for crop production. This study, therefore, aims to assess the impacts of wastewater irrigation on leafy vegetables, root and salad crops in terms of safety, quality, and crop productivity and to minimize the contamination of crops through development of proper irrigation management technologies. A set of experiments were set up at the farmer's field of peri-urban areas in Terokhadia, Rajshahi and in Debidwar, Cumilla with the crops tomato, potato, spinach and Indian spinach. The management options tested for these crops were traditional furrow irrigation (TFI), alternate furrow irrigation (AFI), flood irrigation (FLI), broad bed furrow irrigation (BBFI) and drip irrigation. Not all these methods were tested for a single crop. Irrigation methods with wastewater were varied with the crops. For example, drip irrigation was not tested for leafy vegetable crops like Indian spinach, spinach, etc., but to test for tomato crop. Similarly, broad bed furrow irrigation was not used for potato. Effects of different fertilizer doses with wastewater irrigation on the yield of potato, spinach and Indian spinach were evaluated. Results showed that wastewater with 80% fertilizer dose gave the yields of spinach and Indian spinach that were identical with that obtained under fresh water irrigation with 100% RFD. Irrespective of fertilizer dose, yields under flood and broad bed furrow irrigation were almost same. The yield of potato tuber was found highest under wastewater irrigation with 100% fertilizer dose closely followed by 80% RFD and the lowest was obtained from 60% RFD with wastewater irrigation. However, tuber yield under wastewater irrigation with 80% RFD was comparable to freshwater irrigation with 100 RFD. Among the irrigation methods, drip irrigation gave the highest tomato yield and the yield under AFI, BBFI and TFI were identical and the lowest yield was obtained from flood irrigation. Application of wastewater increased, to a smaller extent, the soil chemical properties like EC, pH, organic matter, N, P, K, S, Zn and B. However, no consistence changes were observed in case of heavy metals accumulation. As the quality of wastewater-irrigated produce is concerned, it was observed that wastewater irrigation enhanced the quality of crops with an elevated concentration of N, P, K, S, B, and Zn content. But a high bacterial contamination with fecal coliforms (FC), total coliforms (TC), total bacterial aerobic counts (TABAC), fecal streptococci and *Escherichia coli* (*E. coli*) was observed in fresh spinach and Indian spinach irrigated with urban wastewater and it was observed that irrigation methods have significant role in minimizing the contamination. However, the crop was not contaminated with pathogenic bacteria of the *Salmonella* species. The bacterial contamination was found lower in BBFI than FLI system for spinach and Indian spinach. Similarly, lower count of these categories of bacteria was recorded in AFI than TFI for potato. For tomato, drip irrigation had the lowest bacterial contamination compared to other irrigation techniques. So, these irrigation techniques need to be practiced by the wastewater farmers to improve the product quality by reducing the contamination and to protect consumer health.

CRG Sub-Project Completion Report (PCR)

A. Sub-project Description

- 1. Title of Sub-Project :** Assessing and mitigating the contamination of vegetable crops and soil under irrigation with urban wastewater
- 2. Implementing organization:** Bangladesh Agricultural Research Institute (BARI)
- 3. Principal Investigator (Full address with phone and e-mail):**
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- 4. Sub-project budget (Tk):**
 - 4.1 Total: 29,40,500/- (Twenty nine lac forty thousand and five hundred only)
 - 4.2 Revised (if any)
- 5. Duration of the sub-project:**
 - 5.1 Start date: June 2017
 - 5.2 End date: September 2018

6. Justification of undertaking the project:

In Bangladesh, about 66 per cent of the cultivated area is under irrigation with nearly 80 per cent of the water resources being used for agricultural production are coming from ground water. Recently, over exploitation of ground water for intensive boro rice cultivation have caused a rapid depletion of GW table threatened the sustainability of water resources and thereby the agricultural productivity (Draft Water Policy, 2004). Thus, the agriculture of Bangladesh is started facing problems due to decreasing availability of ground water resources in dry season. Climate change effects will escalate the problem as the availability of water will decrease. The shortage of water resources of good quality calls for use of water of marginal quality such as drainage water, saline

water and wastewater as an alternative. Urban wastewater is an important alternative source of water for irrigation. Like the farmers of most developing countries, the cities of Bangladesh discharging about 7.25 Mm³ (UNESCO, 2004) wastewater and the peri-urban farmers are using this wastewater without any restrictions. The agricultural use of this wastewater, if planned and managed properly, can alleviate the problems of local water shortages, reduce fertilizer costs and protect the local environment. A well planned use of urban wastewater can thus contribute to food security by increasing food production in the peri-urban areas.

Wastewater is a nutrient-rich water resource that may be constantly supplied for the mitigation of irrigation water imbalances in agricultural sites in arid and semi-arid areas around the world (Chu et al., 2004). An estimated 20 million hectares worldwide are irrigated with wastewater, more of it with untreated than treated wastewater (Scott et al., 2004). Currently, in developing countries, approximately 80% of urban wastewater is used for irrigation contributing to 70-80% food security and the livelihoods of urban and peri-urban communities (Mara and Cairncross, 1989; Cooper, 1991). In general, wastewater flows through channels into rivers and farmers' owning land along canal diverted it to irrigate different cereals, vegetables, salad and root crops. However, wastewater should be reused with caution and regularly monitored, as it may contain chemical and biological contaminants and pollutants that may pose negative environmental and health impacts (Singh et al., 2004). Crops irrigated with raw wastewater or insufficiently treated or industrial wastewater have been found to absorb and accumulate heavy metals in their edible parts beyond the maximum permissible limits (MPLs) (Mapanda et al., 2005; Singh et al., 2010; Hashem et al., 2013), evoking concerns of potential negative impacts on public health. Moreover, the reuse of raw wastewater predominance with domestic wastewater i.e., municipal wastewater with improper agricultural practices, may result to the contamination of agricultural produce with microbial and other anthropogenic pathogens, such as *Escherichia coli*, *Salmonella* spp, *Listeria* spp, *Giardia* spp, etc. (Pettersson et al., 2001; Palese et al., 2009; Bernstein, 2011; Cirelli et al., 2012). Vegetables, especially leafy vegetables grown in heavy metal-contaminated soils, accumulate higher amounts of metals than those grown in uncontaminated soils because they absorb these metals through their leaves (Al Jassir et al., 2005). Despite this adversity, the increasing global scarcity of good-quality water will turn wastewater irrigation from an undesirable phenomenon into a necessity wherever agricultural water demand is not met by supply. This is not only the case in drier regions, but anywhere where farmers seek land and water to address market demand. Common examples are urban and peri-urban areas in most developing countries where clean water sources are hardly sufficient even to meet domestic demand.

Application of wastewater on agricultural land might be an effective and sustainable strategy in arid and semi-arid countries where fresh water resources are under great pressure, as long as potential harmful effects on the environment including soil, plants, and fresh water resources, and health risks of humans are minimized. The presence of pathogenic microorganisms in wastewater can pose a significant problem for agricultural use if the crops are consumed uncooked and leads to hygienic problems. Controlling fecal coliform content is important because these organisms live in a

broad range of environmental conditions, mainly due to their ability to grow and survive under adverse conditions, and can often be found in soil, food, water and a wide variety of animals (Kayser, 2003).

Like the farmers of most developing countries, the peri-urban farmers of Bangladesh using untreated wastewater without any restrictions for growing vegetables for a variety of reasons, such as it gives higher yields of most crops, reduces the need for chemical fertilizers that eventually results in net cost savings, and also it is more reliable or cheaper than other water sources (Keraita and Drechsel, 2004; Scott et al., 2004). But most of them, irrigating by wastewater, possessed inadequate insight into fertilizer value of wastewater as well as microbial contamination. Usually, they use excessive amount of fertilizers that are accumulated in the soil and may cause unfavorable effects on productivity and quality of crops, and soil as well as ground water by leaching. Mojid et al., (2010) demonstrated the necessity of adjustment of fertilizer. Besides, the irrigation methods (mainly flood irrigation) they followed contributing to the pathogenic hazards to the wastewater-irrigated produce. Vegetables and root crops are the major concern for pathogenic contamination when grown with untreated raw wastewater especially urban wastewater as it contains predominance level of pathogenic organisms. So, to ensure sustainable and safe wastewater use for food production in urban and peri-urban areas, it needs to explore safe wastewater use and management options.

Wastewater can be reused for the irrigation of all crops if the code of good agricultural practice is implemented. A well-managed and controlled use of wastewater can mitigate or even eliminate of all possible hazards from excreta-related pathogens and some toxic elements due to wastewater reuse in agriculture. Health protection measures that have an impact on wastewater-irrigated produce or to the consumers include wastewater treatment procedures, wastewater application techniques, etc. Special care in respect of irrigation techniques and management need to be taken for growing leafy vegetables, salad and root crops that are coming in direct contact with wastewater or eaten raw and leads to hygienic problems. Proper irrigation methods and management can help farmers to harvest the benefits of wastewater irrigation while minimizing the risk of its use for crop production. This study, therefore, aims to assess the impacts of wastewater irrigation with various irrigation techniques (drip irrigation, alternate furrow irrigation, etc.) on leafy vegetables, root and salad crops in terms of safety, quality, and crop productivity.

7. Sub-project goal:

The goal of the research project is to reduce the crop and soil contamination from wastewater irrigation and to increase safe food production through development of proper irrigation management technologies.

8. Sub-project objective(s):

The specific objectives of this study is

- To evaluate the effect of urban wastewater irrigation on the yield and contamination of vegetable crops and soil
- To determine health risk to the consumers of wastewater irrigated produce, and contribution of wastewater to nutrient requirement for the crops, and
- To develop effective management practice for the use of wastewater for growing vegetable crops to minimize the microbial and other contaminations.

9. Implementation locations: Rajshahi and Cumilla

10. Methodology

10.1 Selection of site and farmers

Selection of project sites were made based on two major criteria: a well designed and working drainage/sewerage system to collect water discharged from household, commercial establishment, industries and storm water; a peri-urban farmers community already using wastewater for irrigation to produce vegetable crops. Thus the site selected for this project was Terokhadia, a peri-urban area of Rajshahi city and Debidwar upazila under Cumilla district. In both areas, farmers are cultivating vegetable crops by using municipal wastewater for many years. So, farmers who are already using wastewater for growing vegetable crops were selected.



Fig. 1. Wastewater farmers in Terokhadia of Rajshahi municipality and Debidwar Pourshava of Cumilla

10.2 Field experiments

Field trials were set up at farmers' field of Terokhadia under Rajshahi municipality and at Debidwar upazila under Cumilla district with leafy vegetables like spinach and Indian spinach, with salad crops like tomato and with root crop like potato in order to investigate the role of municipal wastewater on yield and quality of these crops. Changes in wastewater irrigated soil and nutrient requirement of crops under wastewater irrigation were also investigated.

10.2.1 Experimental with leafy vegetables

Field experiment on Indian spinach and spinach has been set up at the farmer's field in Terokhadia village, which is at the outskirts of Rajshahi City Corporation. The soil was silty clay loam having a bulk density of 1.44 gm/cc and field capacity of 29.57%. The experiment was designed in a split plot with two irrigation methods as a main factor and three fertilizer doses as sub-factor that replicated thrice to identify effect of wastewater on the yield and quality of leafy vegetables (Indian spinach

and spinach), a intensively cultivated vegetable in sub-urban area of Rajshahi. The treatments were as follows:

Irrigation method

I_1 = Flood irrigation with wastewater

I_2 = Broad bed furrow irrigation with wastewater

Fertilizer dose

F_1 = 100% of recommended fertilizer dose

F_2 = 80% of recommended

F_3 = 60% of recommended

For spinach, six treatment combinations were made using two irrigation methods and three fertilizer doses. An additional treatment of freshwater irrigation with 100% fertilizer dose was kept as a control. Then these seven treatments replicating thrice were assigned in 21 elementary plots in a randomized complete block design. The standard dose of fertilizers was calculated with the help of Fertilizer Recommendation Guide (FRG, 2012) considering soil nutrient status as 92, 20, 20, and 5 kg/ha of N, P, K, and S, respectively, for spinach and 115, 20, 50, and 18 kg/ha of N, P, K, and S for Indian spinach. The entire amount of these fertilizers under specific doses, except nitrogen, were applied and incorporated into soil at the time of final land preparation. Nitrogen was applied in two equal split for spinach: half at final land preparation and rest half at 25 DAS; and for Indian spinach in three equal splits: one-third each at final land preparation, and at 25 and 45 DAP as top dressed. Seeds of spinach were sown on 7 December 2017 at a spacing of 20 cm line to line while Indian spinach were planted on 12 December 2017 with a spacing of 25 cm x 15 cm in a elementary plot of 5 m x 4 m. Each elementary plot was separated by a 0.5 m buffer to avoid any interference of fertilizers from one plot to another one.



Fig. 2. Experimental fields of leafy vegetables: Spinach and Indian spinach

10.2.2 Experimental with root and salad crops

Field experiment on a root crop potato, a popular vegetable crop to wastewater farmers, was laid out in Randomized Complete Block Design (RCBD) with seven treatments and three replications. The treatments were as follows:

T₁ = Furrow irrigation by fresh water with 100% of recommended fertilizer (standard practice)

T₂ = Furrow irrigation by wastewater with 100% of recommended fertilizer

T₃ = Furrow irrigation by wastewater with 80% of recommended fertilizer

T₄ = Furrow irrigation by wastewater with 60% of recommended fertilizer

T₅ = Alternate furrow irrigation by wastewater with 100% of recommended fertilizer

T₆ = Alternate furrow irrigation by wastewater with 80% of recommended fertilizer

T₇ = Alternate furrow irrigation by wastewater with 60% of recommended fertilizer



Fig.3a Experimental fields of potato at Rajsahi and Cumilla

Potato was irrigated four times-just after planting and at 25, 45 and 65 days after planting (DAP).

Experiment with tomato, a popular salad crop, was laid out in Randomized Complete Block Design (RCBD) with the following four irrigation methods replicated thrice.

I₁ = Traditional furrow irrigation at 10 days interval with wastewater

I₂ = Alternate furrow irrigation at 10 days interval with wastewater

I₃ = Broad bed furrow irrigation at 10 days interval with wastewater

I₄ = Drip irrigation at 3 days interval with wastewater



Fig.3b Experimental fields of tomato at Cumilla and Rajshahi

Recommended fertilizers doses was 138 kg N, 30 kg P, 90 kg K, 12 kg S, 1 kg Zn and 1 kg B/ha for potato and 140 kg N, 34 kg P, 50 kg K, 18 kg S/ha for tomato. The entire amount of these fertilizers under specific doses, except nitrogen, were applied and incorporated into soil at the time of final land preparation. Nitrogen was applied in two equal split for spinach: half at final land preparation and rest half at 25 DAS; and for Indian spinach in three equal splits: one-third each at final land preparation and at 25 and 45 DAP as top dressed. Seeds of spinach were sown on 7 December 2017 at a spacing of 20 cm line to line while Indian spinach were planted on 12 December 2017 with a spacing of 25 cm x 15 cm in a elementary plot of 5 m x 4 m. Each elementary plot was separated by a 0.5 m buffer to avoid any interference of fertilizers from one plot to other ones.

10.3 Source of irrigation water and irrigation application

Source of irrigation water was the municipal wastewater of Rajshahi City Corporation flowing through a concrete drain in close proximity of the experimental field was used as irrigation water. Low lift pump (LLP) was used to supply the wastewater to the experimental field through polyethylene pipe. A light irrigation amounting 10 mm was applied just after sowing/planting to ensure proper germination of seeds. Thereafter, irrigation was applied based on pan evaporation while potato was irrigated as per treatments filling the soil moisture content up to field capacity. Source of irrigation water in Cumilla was also urban wastewater of Debidwar Pouroshabha. This wastewater was mainly domestic origin discharged into drainage canal flowing through the outskirts of the town from where nearby farmers are using wastewater for crop irrigation. The wastewater was supplied to the experimental field using low lift pump (LLP) and hose pipe.

The irrigation quantities were calculated using the following equation:

$$I = Kc \times Epan \times WR \dots\dots\dots (1)$$

where, I is the irrigation quantity (mm), Kc is the pan coefficient, Epan is the cumulative pan evaporation between the two irrigations (mm), and WR is the wetting ratio for flood irrigation, 0.7 for alternate furrow and broad bed furrow irrigation, and 0.55 for drip irrigation).

Water productivity was evaluated with irrigation water use efficiency (IWUE) which indicates the yield per unit irrigation (Howell, 2001). The IWUE was calculated using the following equation (2):

$$IWUE = Y/I \dots\dots\dots(2)$$

Where, IWUE is the irrigation water use efficiency (kg m⁻³), Y is the total marketable yield (kg decare⁻¹) and I is the amount of seasonal irrigation quantity (mm).



Fig. 4 Urban wastewater carrying canals of Rajshahi City and Debidwar Pourashava

10.4 Collection and analysis of water and soil samples

Wastewater samples were collected before each irrigation event to examine its suitability for irrigation over the season. The samples were collected from the drainage canal carrying sewage effluent of Rajshahi municipality and Debidwar pourashaba, Cumilla. The wastewater samples were collected in white plastic bottles filling up to the brim and immediately sealed to avoid exposure to air. Before taking samples, the bottles were rinsed several times with water to be sampled. Then the samples were labeled and brought to the laboratory in an ice bag for chemical and biological analysis. Chemical analysis was done in the laboratories of BRAC, Gazipur and Soil Science Division, BARI, Gazipur, while bacteriological analysis was done in the Environmental Microbiological Laboratory of ICCDR'B.

Soil samples were collected randomly from different experimental plots at a depth of 0-15, 15-30 cm before sowing to know the initial status of the soil. The samples were then kept in poly bag and sent to the Soil Science Lab, BARI and Soil Analytical Lab of BRAC, Gazipur.

10.6 Collection and analysis of plant samples

Fresh plant samples of spinach, Indian spinach, potato and tomato were collected at their maturity stages. About 1 kg of each samples were harvested from the fields and labeled keeping them in a transparent poly bag. Then it was brought to the laboratory in an ice box for maintaining cool chain for biological analysis. Some samples were oven dried at 65° C for 72 hours. Then the samples were finely ground and stored in a sealed polyethylene bag for chemical analysis in the laboratories of BRAC, Gazipur, Humbolt Soil Testing Laboratory of BAU, Mymensingh, and BARI, Gazipur, All

bacteriological tests were done in the Environmental Microbiological Laboratory of ICCDR'B and WAFFEN (Water – Food – Feed - Environment) research laboratory, Dhaka.



Fig.5 Plant samples in ice boxes and plant washed water in amber plastic bottles for biological analysis

10.6 Assessment of human health risk for consuming wastewater irrigated produce

To assess the human health risk daily intake of metals (DIM) and health risk index (HRI) for the selected heavy metals were determined according to the following equations:

Daily intake of metals (DIM)

The daily intake of metals will be calculated using the following equation:

$$DIM = \frac{C_{\text{metal}} \times CF \times D_{\text{intake}}}{B_{\text{weight}}}$$

where, C_{metal} is the heavy metal concentrations (mg/kg) in the food crops,

CF is the conversion factor (0.085) used for the conversion of fresh vegetables to dry weights

D_{intake} is the daily intake (345 g) of the food crops (g/person/d)

B_{weight} is the average body weight (60 kg) of the adult population (kg/person)

Health risk index (HRI)

The HRI refers to the ratio of the daily intake of metals in the food crops to the oral reference dose (Rf_D) (EPA, 2002) and was calculated using the following equation:

$$HRI = \frac{DIM}{Rf_D}$$

The oral reference dose is an estimate of a daily oral exposure for the human population, which does not cause deleterious effects during a lifetime (US-EPA, 2009). The values of oral reference doses suggested by FAO/WHO for heavy metals were used to calculate HRI. An $HRI > 1$ for any metal in food crops indicates that the consumer population faces a health risk.

10.7 Statistical analysis of data

The collected data were evaluated statistically by the analysis of variance (ANOVA) in MSTAT software. The parameter means were separated by Duncan's multiple range tests.

11. Results and discussion

11.1 Evaluation of wastewater for irrigation/agricultural use

Evaluation of wastewater quality is essential before use in agriculture. In Rajshahi, there is no regulation or monitoring for application of wastewater in agriculture. Therefore, the poor peri-urban farmers apply wastewater to their fields, as and when required without any restrictions. In the present study, wastewater quality was evaluated for agricultural uses.

11.1.1 Chemical quality of wastewater

Table 1 revealed the chemical quality of urban wastewater and degree of restriction for agricultural use set by WHO (2006), FAO (1999), and DoE (1997) guidelines.

Hydrogen-ion concentration (pH)

The acidity or alkalinity of wastewater affects both crops and soils. The normal range of pH for irrigation water is between 6.5 and 8.4 (Pescod, 1992); pH 7.0 is neutral. A lower pH indicates increasing acidity, while a high pH indicates increasing alkalinity. The wastewater used in irrigating the experimental crops was slightly alkaline with the average pH value of 7.26 in Rajshahi and 7.21 in Cumilla. A pH above 8.5 is often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations. A high carbonate concentration causes calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution (Bauder *et al.*, 2004). Alkaline

Table 1. Chemical parameters of urban wastewater of Rajshahi and Cumilla used for irrigation

Quality parameters	Location		Restriction for agricultural use (Ayres and Westcot, 1985; cited in WHO, 2006)		
	Rajshahi	Cumilla	No restriction	Moderate restriction	Severe restriction
p ^H	7.26	7.21	Normal range 6.5-8.0		
EC (dS/m)	1.26	1.29	<0.7	0.7-3.0	>3.0
TDS (mg/l)	546	627	<450	450-2000	>2000
Nitrate Nitrogen, NO ₃ -N (mg/l)	1.23	1.19	<5	5-10	>10
Total Nitrogen, N (mg/l)	20.39	18.37	<30	30-40	>40
Total Phosphorus, P (mg/l)	2.17	1.95	<10	10-16	>16*
Potassium, K (mg/l)	13.32	12.66	<30		>30
Sulphur, S (mg/l)	2.51	2.17	<1000		>1000***
Boron, B (mg/l)	0.64	0.42	<0.7	0.7-3.0	>3.0
Zinc, Zn (mg/l)	0.12	0.09	<10		>10**
Sodium, Na (mg/l)	50.76	52.87	<1000***		>1000
Calcium, Ca (mg/l)	5.86	6.20	-	-	-
Magnesium, Mg (mg/l)	28.46	25.79	-	-	-
Copper, Cu (mg/l)	0.05	0.04	<3		>3**
Iron, Fe (mg/l)	0.36	0.30	<5		>5

Manganese, Mn	(mg/l)	0.66	0.56	<5	>5**
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(*Pescod, 1992; ** GoB, 1997; ***DoE, 1997)

water could intensify sodic soil conditions, which is detrimental to agriculture. The wastewater used in our experiments with a pH 7.21-7.26 was not a problem for the experimental crops.

Electrical conductivity (EC) and total dissolved solids (TDS)

Salinity of irrigation water was determined by measuring electrical conductivity, EC, and total dissolved solids, TDS. The average values of electrical conductivity observed in the wastewater were found to be 1.26 dS/m in Rajshai and 1.29 dS/m in Debidwar, Cumilla (Table 1), respectively, which indicates slight to moderate restrictions for agricultural use to comply with FAO guideline. On the other hand, TDS was found to be ranged from 546 to 627 mg/l which was moderately suitable for irrigation. Usually, crop yield is independent of salt concentration when salinity is below some threshold level. FAO (1999) suggested that there is no restrictions on the use of irrigation water with an EC of 0.7 dS/m or a TDS concentration of less than 450 mg/l. Ayres and Westcot (1985; cited in WHO 2006) reported that water with low salinity content (<0.5 dS/m) leaches the soluble minerals and salts. If calcium is leached, soil structure can be destabilized and fine soil particles become dispersed and clog the pore spaces, leading to reduced water infiltration, soil crusting and crop emergence problems.

Nitrogen (N)

Total nitrogen concentration of the wastewater was observed in the range of 20.37 – 22.39 mg/l which showed no restriction for irrigation (Table 1). Ayres and Westcot (1985) reported that the concentration of nitrogen required varies according to the crop with more sensitive crops being affected by nitrogen concentrations above 5 mg/l, whilst most other crops are relatively unaffected until nitrogen exceeds 30 mg/l. The sensitivity of crops also varies with the growth stage. High nitrogen levels may be beneficial during early growth stages but may cause yield losses during the later flowering and fruiting stages. This means that water containing high nitrogen levels, including domestic wastewater, can be used as a fertilizer early in the season but should ideally be reduced or blended with other sources of water later in the growth cycle.

Phosphorous (P)

Total phosphorus values (1.95 – 2.17 mg/l) observed in the wastewater of two different sites showed no restriction for agricultural use (Table 1). Municipal wastewater may contain between 4 mg/l and 16 mg/l of phosphorus as P and a typical value for waste water treated in a conventional wastewater treatment plants is 10 mg/l (Metcalf and Eddy, 2003; Pescod 1992). The usual range for phosphorus in irrigation water is 0 – 10 mg/l (Ayres and Westcot, 1985).

Potassium (K)

The concentration of potassium in the wastewater was found from 12.66 -13.32 mg/l to 14.71 mg/l which indicated no restriction for agricultural use according to Ayres and Westcot (1985) (Table 2). The normal concentration of K in treated wastewaters is 30 mg/l and is 0-2 mg/l in irrigation water (Pescod, 1992; Ayres and Westcot 1985). Mikklesen and Camberato (1995; cited in WHO, 2006) reported that generally irrigation water contains low potassium concentration, insufficient to cover the plant's theoretical demand, and fertilizer application is almost always necessary. The use of wastewater in agriculture does not normally cause negative environmental impact associated with potassium.

Sulphur (S)

From Table 1, sulphur concentration of the wastewater was observed in the range of 2.17– 2.51 mg/l which did not exceed the restriction limit for irrigation. The usual range for sulphur in irrigation water is 0–1000 mg/l (DoE, 1997)). So, this water can be used for irrigating the experimental crops with no restriction.

Boron

Boron as a micro-nutrient helps plant growth and development but can be detrimental if threshold level is exceeded. The concentration of boron in wastewater ranged from 0.42 to 0.64 mg L⁻¹ in wastewater. Jayakody (2007) reported that Boron is an essential element for plant growth but in relatively small amounts. For example, for some plants 0.2 mg/l in irrigation water is essential but 1-2 mg/l may be toxic. These values of B are within the safe limit (0.3–1.0 mg L⁻¹) for irrigation even for highly boron sensitive crops.

Metals and metalloids

Some metals and metalloids of specific concentrations are essential for adequate plant growth, but are toxic at elevated concentrations. The metallic constituents present in the wastewater of Rajshahi and Cumilla were Zn, Na, Ca, Mg, Cu, Fe, Zn and Mn and their concentrations were below the threshold level for agricultural use set by WHO (Ayres and Westcot 1985; cited in WHO 2006). On the other hand, B concentration ranged from 0.20 mg/l to 0.42 mg/l was in the slight restriction range (0.7-3.0 mg/l), as compared to FAO guideline (Table 1). Jayakody (2007) reported that Boron is an essential element for plant growth but in relatively small amounts. For example, for some plants 0.2 mg/l in irrigation water is essential but 1-2 mg/l may be toxic. Excessive iron (> 5 mg/l) can reduce the phosphorous component in water by precipitating the dissolved phosphate. Therefore, phosphorous might not be readily available for plant uptake in the presence of excessive iron.

11.1.2 Microbiological quality of wastewater

Maintaining microbial standard is needed in the safety of water used to irrigate crops that are eaten raw, such as salad crops. The average total coliform, TC, and faecal coliform, FC, counts in the

wastewater were ranged from 7.1×10^6 - 11.2×10^6 and 6.4×10^6 - 10.8×10^6 CFU per 100 ml, respectively (Table 2). The guidelines for the reuse of wastewater in crops, eaten either cooked or raw, recommend that total coliforms in the effluent should be below 100 colonies per 100 ml in 80 percent of the samples when no faecal coliform should be in 100 ml samples (WHO, 1980). But, the WHO guidelines of 1989 for wastewater used in agriculture suggested maximum FC of less than 1000 thermotolerant coli per 100 ml for root crops likely to be eaten uncooked, and 10,000 thermotolerant coli per 100 ml for leaf crops likely to be eaten uncooked, but no standard for irrigation of cereal crops (WHO, 2006). The effluent for reuse must comply with reuse standards to

Table 2. Microbiological quality of wastewater used for irrigation

Parameters	Rajshahi	Comilla	WHO standard
TC (CFU/100ml)	7.1×10^6	11.2×10^6	1000
FC (CFU/100ml)	6.4×10^6	10.8×10^6	1000
Total aerobic bacterial count (CFU/ml)	7.0×10^4	9.0×10^4	-
Faecal streptococci (CFU/100ml)	2.0×10^3	3.0×10^3	-
Thermotolerant E. Coli (CFU/100ml)	3.7×10^6	4.2×10^6	410

minimize environmental and health risks (WHO, 1989). With regard to health, the reuse criteria refer mainly to faecal coliform content, which according to WHO (1989), should be less than 10^3 per 100 mL. Wastewater of Debidwar, Cumilla and Rajshahi municipality was also contaminated by the total aerobic bacterial count in the range of 7.0×10^4 to 9.0×10^4 , by the faecal streptococci in the range of 2.0×10^3 - 3.0×10^3 and in the the range of 3.7×10^6 - 4.2×10^6 by the E. coli. The presence of pathogenic microorganisms in wastewater can pose a significant problem for agricultural use. Hence, wastewater treatment and the selection of less risky production systems, which avoid contact between the edible part of the plant and irrigation water, may be an alternative option in reducing microbial risks to leafy vegetables.

11.2 Effect of wastewater irrigation on spinach

11.2.1 Growth and yield of spinach

Wastewater and fertilizer significantly influenced plant height and leaf number per plant. Irrespective of irrigation system, plant height and leaf number increased with increasing the fertilizer dose from 60% RFD to 100% RFD. In respect of plant height and leaf number, the difference between two irrigation systems was trivial. Plant height ranged from 28.2 cm to 25.6 cm under flood irrigation system, while it ranged from 27.8 cm to 25.4 cm under broad bed furrow (BBF) irrigation system. As leaves per plant was positively correlated with the plant height, it follow

the same trend as that of plant height with the highest number in longer plant and the lowest number in the shortest plant. Leaves number was maximum in 100% RFD and minimum in 60% RFD ranging from 7.3 to 6.1 and 7.2 to 6.4, respectively under flood and broad bed furrow irrigation. Both plant height and leaves number under freshwater irrigation with 100% RFD were comparable to those obtained under wastewater irrigation with 80% RFD.

Table 3. Growth and yield of spinach as affected by fertilizer dose and water quality

Irrigation system	Fertilizer dose	Plant population (no./m ²)	Plant height (cm)	Leaves/plant (no)	Yield (t/ha)
Floodww (I ₁)	F ₁ =100%	120	27.6	7.3	45.50
	F ₂ =80%	112	27.2	6.4	42.00
	F ₃ =60%	108	26.8	6.1	40.30
BBFww (I ₂)	F ₁ =100%	116	27.8	7.2	45.00
	F ₂ =80%	116	26.8	6.9	42.75
	F ₃ =60%	112	26.4	6.4	40.50
Floodfw	F=100%	152	25.8	6.6	42.45
CV (%)		9.12	6.76	3.45	7.56
LSD _{0.05}		ns	1.42	ns	2.18

Like vegetative growth, fresh yield of spinach showed a significant variation with the combined effect of wastewater and fertilizer. Fresh yield of spinach was recorded the highest under wastewater irrigation with 100% RFD followed by the 80% RFD and the lowest was recorded under wastewater with 60% RFD. However, the trends in yields under two irrigation systems were likely be the plant height and leaves number per plant. Here too, yield ranged from 45.50 to 40.30 t/ha under flood irrigation, and from 45.0 to 40.50 t/ha under broad bed furrow irrigation system with the maximum values in 100% RFD and minimum values in 60% RFD. The decrease in fresh yield of spinach under lower dose of fertilizer was primarily due to reduction in plant height and leaves number per plant. Yield under freshwater irrigated 100% RFD control treatment was well comparable to that under wastewater irrigated with 60% RFD treatment. This higher yield even under 60% RFD with wastewater could be attributed to the increase in the absorption of macro and micro nutrients from the wastewater. Several researchers endorsed the increase in crop production to the increase in the nutrient availability (Mandi and Abissy, 2000; Noor et al., 2014; Munir and Mohammad, 2004; Lopez et al., 2006; Adhikari et al., 2011).

11.2.2 Availability of nutrients for spinach through wastewater irrigation

The amount of some macro- nutrients added through the wastewater irrigation to the spinach field are given in Table 4. On the average, the raw wastewater applied through irrigation supplied 33.22, 4.95, 23.42 and 4.84 kg ha⁻¹ of N, P, K, and S, respectively. The quantity of these nutrients was equivalent to 24.77 % N, 15.41% P, 80.48% K and 68.27% S of the recommended fertilizers needed for spinach production. If these amounts are considered for spinach cultivation with wastewater, farmers may get the benefit from fertilizer saving. However, in our study, the yield with wastewater

Table 4. Nutrient supplied (kg/ha) through wastewater irrigation to spinach field

Nutrient	Contribution by raw wastewater	Crop requirement	% of crop requirement added by wastewater
N	33.22	92.00	24.77
P	4.95	20.00	15.41
K	23.42	20.00	80.48
S	4.84	5.00	68.27

irrigation and 80% of the recommended fertilizer was identical with the yield under freshwater irrigation and 100% of the recommended fertilizer. The yield of spinach with wastewater and 80% fertilizer was even higher than that of the standard practice with freshwater and 100% fertilizer (Table 3). Though the effect of nutrients from applied fertilizer and that coming from wastewater are different, it is obvious that about 20% of the recommended fertilizer could be saved when spinach is cultivated under irrigation with wastewater.

11.2.3 Effect of wastewater irrigation on soil of spinach field

Soil chemical properties affected due to irrigation with wastewater in two irrigation systems are shown in Fig. 6. Soil pH increased in wastewater irrigated plots compared to fresh water irrigated plot. Between the two irrigation systems, soil pH was slightly higher in flood irrigation (FLI) than broad bed furrow irrigation (BBFI). Slightly higher pH in wastewater irrigated soil was probably as a result of high pH value of the wastewater used for irrigation. The amount of wastewater needed for irrigation in flood irrigation was higher in comparison with BBFI and hence the soil pH was also higher in FLI than BBFI. For the same reason soil EC was found higher in wastewater irrigated soil under BBFI than under FLI system. However, the EC values that measured on 1:5 soil extract was significantly higher in wastewater irrigated plots under both irrigation systems than fresh water irrigated plot. The OM and total-N level of the WW-irrigated soils were higher than that of fresh water irrigated treatments. Soil organic content (OM) significantly increased with wastewater application and with increasing the amount of irrigation in BBFI system (Fig. 6), which is attributed directly to the contents of the nutrients and organic compounds in the wastewater applied. This result supports the findings of Angin et al., 2005 who reported that wastewater application increased OM and N contents of soils. The differences between K concentrations in soils irrigated with wastewater and fresh water were related to K concentration of the applied water and to a smaller extent for fertilizer application. K concentration in wastewater irrigated soil was slightly higher than that of fresh water irrigated soil, but was lower than that in initial soil (not shown). However, regardless of water quality, the soil P concentration increased in all treatments, which is due to application of phosphate fertilizer and the wastewater effect. As expected, P values were greater in 100% RFD with wastewater irrigation than that of fresh water irrigated treatment. The S

content of soil showed the same trend as of P. The P and S level of the wastewater-irrigated soil increased in the range of 0.24-

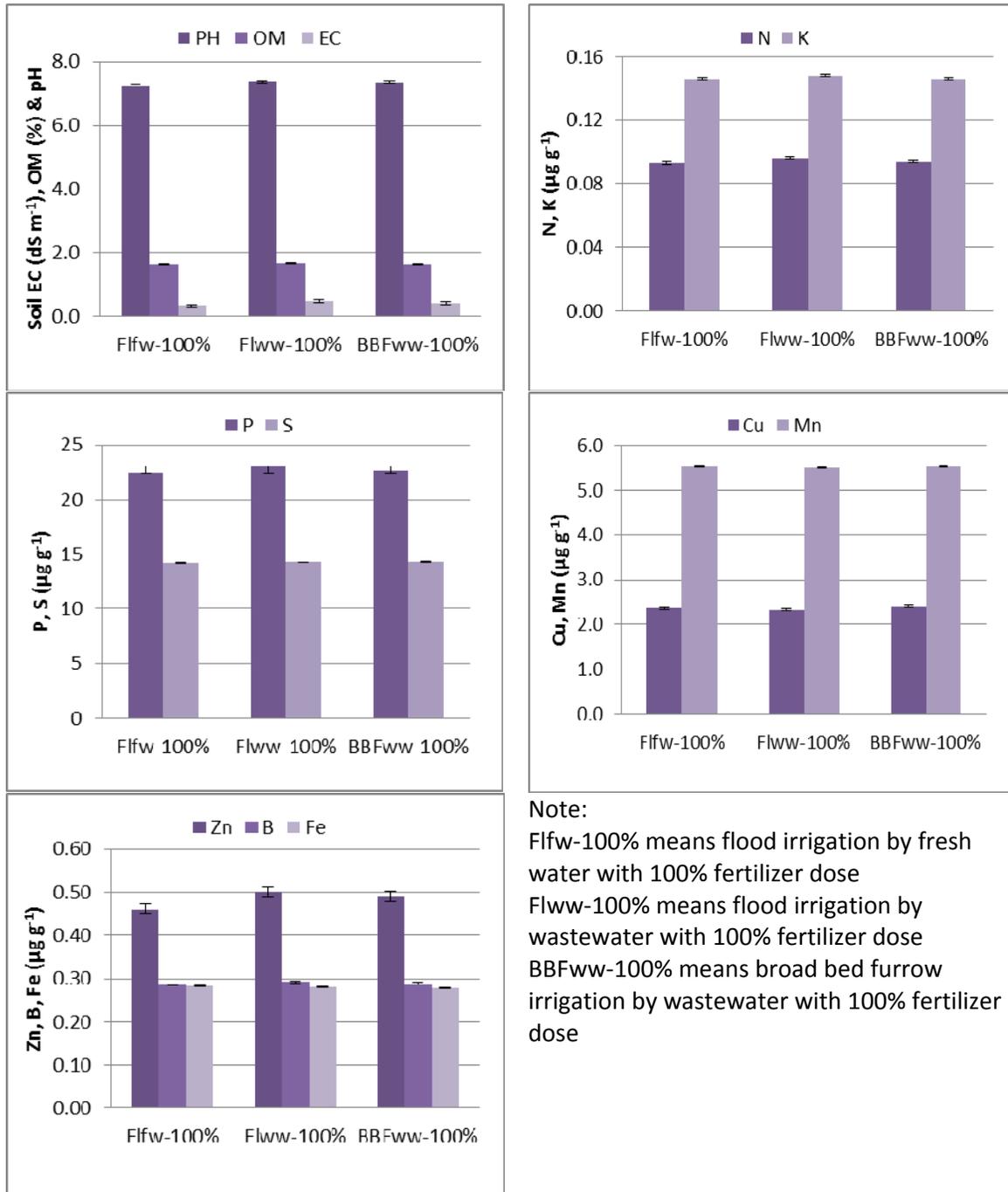


Fig. 6. Changes in soil chemical properties of spinach field irrigated with wastewater in flood and broad bed furrow irrigation system and fresh water in flood irrigation system as control.

0.71 μg g⁻¹ and 0.06-0.08 μg g⁻¹, respectively. These changes in soil can be due to considerable amount of P and S content in wastewater. The micronutrients Zn and B content increased in the soil of wastewater-irrigated plots because of their presence in the wastewater with slightly higher

values in FLI than BBFI system. On the other hand, the response of soil micronutrients like Cu, Fe and Mn showed no consistent changes in the wastewater-irrigated soil, probably due to low concentration of heavy metals (Table 1) in the wastewater, since the wastewater used for this study was almost exclusively of domestic origin, with little industrial contribution. There is inconsistency on research findings on the impact of wastewater irrigation on soil micronutrients. Mohammad and Mazahreh (2003) reported an increase in soil Fe and Mn with wastewater irrigation and no response with regard to the soil Cu and Zn. On the other hand, Mancino and Pepper (1992) found no effect on soil micronutrients. Soil Cu and Zn had accumulated significantly in the upper soil with wastewater irrigation (Lawes, 1993). Increases in a number of soil parameters like OM, N, P, K, S, Zn and B were found due to the enrichment of soil by these nutrients with wastewater irrigations. Similar agreements were also reported by Pomares (1984) and Siebe (1996), and they suggested that application of wastewater to cropland and forest lands is an attractive option for disposal because it can improve the chemical properties and nutrient contents of soils.

11.2.4 Macro- and micro-nutrients content of spinach

The effect of wastewater on macronutrient (N, P, K and S) and micronutrient (Zn and B) contents of spinach grown under two irrigation systems and three fertilizer doses are shown Fig. 3. Not all the nutrients increased with increasing the application of fertilizer doses But in general, plant essential nutrient (total N, P, and K) were found higher in plants grown in flood irrigation system with 100% fertilizer dose. On average over fertilizer dose, nitrogen content increased by 1.31%, P by 1.73% and K by 4.01% in FLI (flood irrigation) system compared to BBFI system. Increase in S content was remarkably higher (about 8.23%) in flood irrigated spinach. Enhancement of these plant nutrients with wastewater application indicates that irrigation with wastewater provided the soil with these nutrients which enhanced the requirement for plant growth and soil fertility. In addition, application of more water in FLI system added more nutrients through wastewater resulted in higher nutrient content in plants. Nitrogen concentration in plant was reported to be higher when grown with wastewater (Day et al, 1979), who found that N recovery in plants with wastewater was higher than the N recovery in plant material grown with well water. These results were attributed to significant

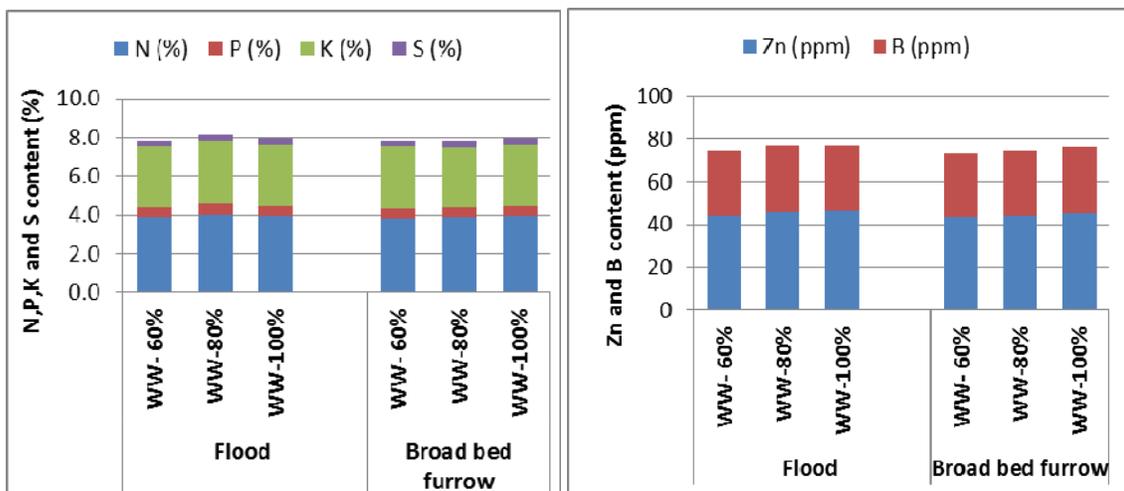


Fig. 7. Macro-and micro-nutrient contents of spinach grown under flood and broad bed furrow irrigation systems with different fertilizer doses

increase in soil nitrogen with wastewater irrigation compared with the control. Mohammad and Mazahreh (2003) and Papadopoulos and Stylianou (1988) have reported an increase in P and K uptake by the plants irrigated with treated wastewater. Micronutrients are essential for plant nutrition although they are required by the plants in relatively much smaller amounts compared to macronutrients. Micronutrient contents (Zn and B) of the plants were affected by wastewater application as much of the requirement of these nutrients was fulfilled by wastewater application. On average, Zn content increased by 2.06% and B increased by 2.43% in flood irrigated plants over broad bed furrow irrigation. These results are in agreement with the findings of Brar et al., (2002) and Mohammad and Mazahreh (2003) who reported an increase in micronutrients uptake by the plant increased in leaves of plants irrigated with sewage water than that irrigated with ground water. It is seen from the Figure that the uptake of macro- and micronutrients was slightly higher in 80% fertilizer dose than other doses under flood irrigation system while under broad bed furrow irrigation system; the higher values are recorded at 100% fertilizer dose.

11.2.5 Microbiological quality of spinach

Figure represents all investigated bacterial categories, associated with the spinach stems and leaves (shoot system) under the two irrigation systems. It was expected that all bacterial contamination were not affected by fertilizer doses for a given irrigation system. However, there is a clear impact of irrigation system on all categories except the total aerobic bacterial count. Apparently, there was a considerable drop in the counts of all bacterial counts under the broad bed furrow (BBF) irrigation system compared to flood irrigation system. This was expected simply because of the plant exposure to irrigation water was higher in flood irrigation system than BBF irrigation system. Moreover, the reduction in bacterial count under freshwater irrigated spinach (not shown) was significant compared to wastewater spinach under flood irrigation system, but non-significant compared to BBF irrigation system. This reduction may be justified by the water quality as well as irrigation system. As the plant is grown in the broad bed and the wastewater flow through the furrow so it is expected that bacterial contaminations are less in BBFI comparison with flood irrigation where the wastewater comes to direct contact with the plants. Figure shows that all bacterial count (TC, FC and *E. coli*) except TABC were reduced by about one log cycle because of less contact between spinach and wastewater

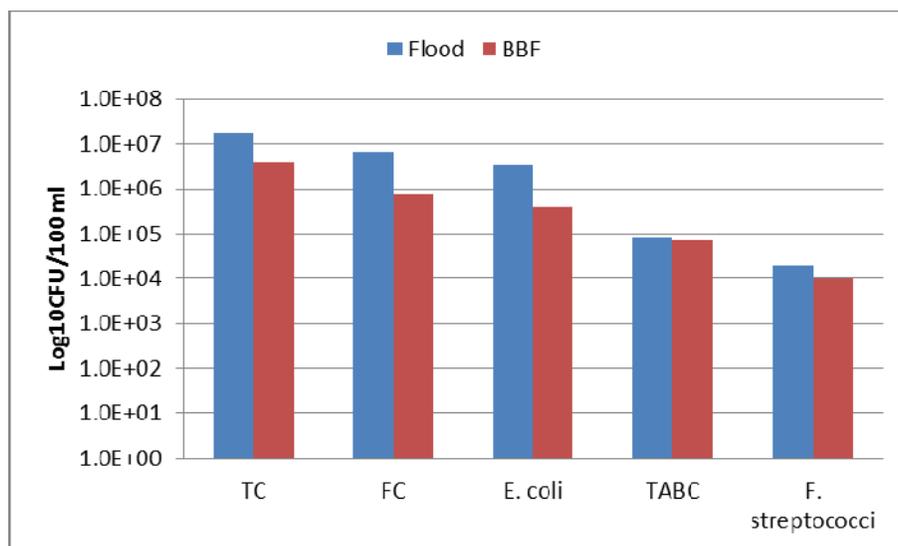


Fig. 8. Bacterial contamination of spinach grown with wastewater irrigation under flood and broad bed furrow irrigation systems

under BBF irrigation system. Total coliform (TC) reduced from 1.80×10^7 to 3.8×10^6 , FC from 6.6×10^6 to 7.5×10^5 , and E. coli from 3.5×10^6 to 4.0×10^4 CFU/100 ml. But rate of reduction was minimal in case of TABC and F. streptococci. The results are partially substantiated the unrestricted wastewater reuse and suggest the need for treatment to improve product quality and to protect consumer health.

11.3 Effect of wastewater irrigation on Indian spinach

11.3.1 Growth and yield of Indian spinach

The growth parameters and yield of Indian spinach as obtained under different treatment combinations are summarized in Table 5. Wastewater with different fertilizer doses had significant impact on stem length, leaves per plant, leaf size, and yield of Indian spinach. Irrespective of irrigation system, application of 80% and 100% RFD along with irrigation by wastewater produced the most optimistic but statistically identical growth attributes of Indian spinach. Similarly, application of 60% RFD, in combination with irrigation by wastewater, and application of 100% RFD, in combination with irrigation by fresh water (T_1), also exhibited identical growth and yield attributes. These results demonstrate clear positive effects of wastewater on Indian spinach production. The tallest stem (80.6 cm) recorded in the plot treated with 100% RFD and irrigated by wastewater was only 6.3% taller than that receiving 60% fertilizer. This treatment also produced the highest breadth (12.53cm) of leaves. But the stem thickness was found maximum in treatment either I_1F_2 or I_2F_2 , rather than treatment I_1F_1 and I_2F_1 . A correlation between stem thickness and stem length was observed. The longer stem had lower thickness and conversely short stem had higher thickness. Though the stem length was found to be the highest in 100% RFD but the number of leaves per plant was found slightly higher in 80% RFD treatment. Number of leaves per plant under treatment 80 and 100% RFD was comparable. The maximum leaf length found in 100% RFD was identical to that obtained under 80% RFD and the minimum was in 60% RFD with wastewater irrigation. While treatment 80% RFD with wastewater irrigation produced the highest leaf breadth and the 60% RFD with irrigation by wastewater demonstrated the lowest leaf breadth. A 20% reduced RFD along with wastewater irrigation produced the leaf breadth that was very close to treatment with full fertilizer dose. Like growth attributes, significant differences occurred in differential fertilized treatments for fresh yield of Indian spinach compared to 60% RFD treatment. Wastewater irrigation with 80% RFD gave the yield that was identical with the yields under wastewater irrigation with 100% RFD.

Table 5. Growth and yield of Indian spinach as affected by fertilizer dose and water quality

*Treatment	Plant population (no./m ²)	Plant height (cm)	Leaves/plant (no.)	Leaf length (cm)	Leaf breadth (cm)	Yield (t/ha)
I_1F_1	30.18	77.2	26.4	15.56	12.53	47.64
I_1F_2	32.76	76.4	26.8	15.64	12.51	46.29
I_1F_3	30.91	74.2	24.2	14.88	12.09	44.39
I_2F_1	26.33	80.6	27.2	15.66	12.56	48.60

I ₂ F ₂	27.44	79.8	25.2	15.64	12.49	47.21
I ₂ F ₃	27.26	72.4	23.7	14.67	12.14	43.44
LSD _{0.05}	ns	5.34	3.05	ns	ns	2.02
CV (%)	3.86	6.59	4.32	7.16	6.78	5.74

*I₁: Flood irrigation and I₂: BBF irrigation; F₁, F₂ and F₃ denote 100, 80 and 60% of RFD, respectively

With the application of fertilizer, the increase in yield was not so much. Compared to 60% RFD treatment, yield increased by 7.32% in flood irrigation system and 11.87% in BBFI system at 100% RFD; whereas at 80% RFD, the increment was about 4.28% and 8.67% in FLI (flood irrigation) and BBFI system, respectively. That is, the increase in yield became smaller with further application of fertilizer and there was almost no difference in yield between the treatments receiving 80% RFD and 100% RFD with wastewater irrigation. The fresh yield of Indian spinach under 60% RFD with irrigation by wastewater was significantly lower than that obtained under both 80% and 100% RFD with irrigation by wastewater. These results clearly demonstrate that fertilizer enormously influenced the growth and yield of spinach, and irrigation by wastewater exerted further positive impacts on all crop attributes except in I₁F₁ where application of 100% RFD along with irrigation by wastewater caused over fertilization without any significant increase of growth and yield. These results are intuitively supported by those of Pradhan *et al.*, (2001) who stated that both wastewater and nitrogen positively affect crop yields, and replacing some wastewater with freshwater and nitrogen fertilizer increases production.

11.3.2 Contribution of wastewater to nutrient requirement of Indian spinach

The amount of macro- nutrients added through wastewater to the field of Indian spinach during the growing season is given in Table 6. On average, about 38.21 kg N, 6.00 kg P, 31.06 kg K, and 6.52 kg S/ha were added to soil through irrigation with wastewater that corresponded, respectively, to 38.21, 30.04, 62.12, and 36.25% of RFD for Indian spinach production (Table 3). If these amounts are not considered for cultivation of Indian spinach with wastewater, then the benefit from wastewater nutrients will not be realized. Moreover, yields were not increased proportionately with fertilizer application, as occurred under application of 100% RFD along with wastewater irrigation. Compared to 60% RFD, yield increased by 5.8% under 80% RFD, and about 10.3% under 100% RFD by wastewater irrigation. Janssen *et al.*, (2005) however stated that evaluation of wastewater as a source of nutrients is not realistic by simple comparison of nutrients in wastewater and fertilizers since their effects are different. On average, the fresh yield of Indian spinach under 60% RFD with irrigation by wastewater and under 100% RFD with irrigation by fresh water was very close. These results indicate that wastewater complemented about 20% fertilizer deficit, and the nutrients supplemented by wastewater were more effective than those supplied by fertilizers.

Table 6. Nutrient supplied (kg/ha) through wastewater irrigation to the soil of Indian spinach field

Nutrient	Nutrient contribution by wastewater	Nutrient requirement for Indian spinach	% of crop requirement added through wastewater
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N	43.94	115.00	38.21
P	6.00	20.00	30.04
K	31.06	50.00	62.12
S	6.52	18.00	36.25

11.3.3 Chemical quality of wastewater -irrigated Indian spinach

The macro- and micro-nutrient contents in Indian spinach grown under two irrigation systems with wastewater and three fertilizer doses are presented in Fig 4. In general, macro nutrient (total N, P, and K) were found slightly higher in plants grown in flood irrigation system with higher fertilizer dose. On average over fertilizer dose, N content increased by 1.57%, P by 5.31% and K by 1.83% in flood irrigation system compared to broad bed furrow irrigation system. Increase in S content was not significant; only 0.48% increase was recorded in flood irrigated spinach. Enrichment of these plant nutrients with wastewater application indicates that irrigation with wastewater provided the soil with these nutrients which enhanced the uptake by plants. Moreover, application of more water in flood irrigation system added more nutrients through wastewater resulted in higher nutrient content in plants. Nitrogen concentration in plant shoots was reported to be higher when grown with wastewater (Day et al, 1979), who found that N recovery in plants with wastewater was higher than the N recovery in plant material grown with well water. Mohammad and Mazahreh (2003) and Papadopoulos and Stylianou (1988) have reported an increase in P and K uptake by the plants irrigated with treated wastewater. Micronutrients are essential for plant nutrition although they are required by the plants in relatively much smaller amounts compared to macronutrients. Micronutrient contents (Zn and B) of the plants were affected by wastewater application as much of the requirement of these nutrients was fulfilled by wastewater application. On average, Zn content increased by 3.10% and B increased by 3.58% in flood irrigated plants over broad bed furrow irrigation. This result corroborate the findings of Brar et al., (2002) and Mohammad and Mazahreh (2003) who reported an increase in micronutrients uptake by the plant increased in leaves of plants irrigated with sewage water than that irrigated with ground water.

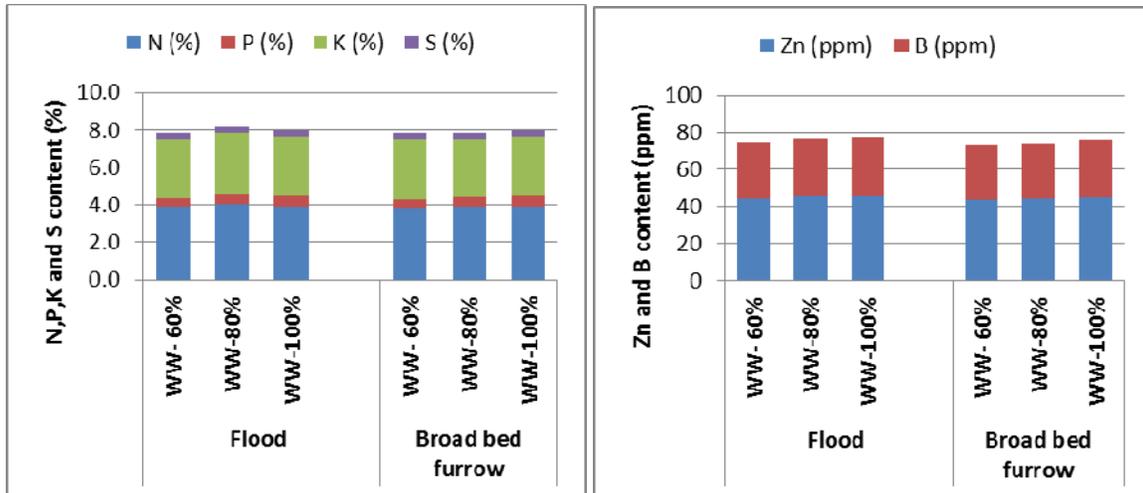


Fig. 9. Macro- (N,P,K,S) and micro-nutrient (Zn and B) contents in Indian spinach grown under flood and broad bed furrow irrigation systems with different fertilizer doses

11.3.4 Microbiological quality of Indian spinach

The bacterial contamination of Indian spinach by irrigation with wastewater was compared between two irrigation systems: flood irrigation and broad bed furrow (BBF) irrigation system is illustrated in Fig. 10. The total coliform, TC, fecal coliform, FC, total aerobic bacterial count (TABC) and *Escherichia coli* (*E. coli*) were detected in fresh Indian spinach. In general, the microbial population content was higher in Indian spinach grown with wastewater in flood irrigation system than that grown with wastewater in broad bed furrow irrigation system. *Salmonella* and *vibrio coli* were not detected in any treatments. The presence of pathogenic microorganisms in wastewater can pose a significant problem for agricultural use. Since the fecal coliform level in Indian spinach was more than 1000 per 100 g, hence it can be classified as undesirable for consumption according to the International Commission on Microbiological Specifications for Food (ICMSF, 1974) guidelines. Therefore, care must be taken to avoid wastewater contact with the crops that are consumed uncooked and leads to hygienic problems. Controlling fecal coliform content is important because these organisms live in a broad range of environmental conditions, mainly due to their ability to grow and survive under adverse conditions, and can often be found in soil, food, water and a wide variety of animals (Kayser, 2003). In this study, a slight difference in bacterial contamination of wastewater-irrigated vegetable under flood and BBF irrigation systems were observed. Indian spinach was contaminated by the total coliforms in the range of 1.30×10^7 to 1.6×10^7 CFU/100 mL, by the fecal coliform in the range of 4.3×10^6 to 5.4×10^6 CFU/100 mL, by *E. coli* in the range of 1.8×10^6 to 2.4×10^6 with the higher values in flood irrigation system and lower values in BBF irrigation system. Contamination by Total aerobic bacterial count and Fecal *streptococci* were found minimum compared to other bacterial contamination.

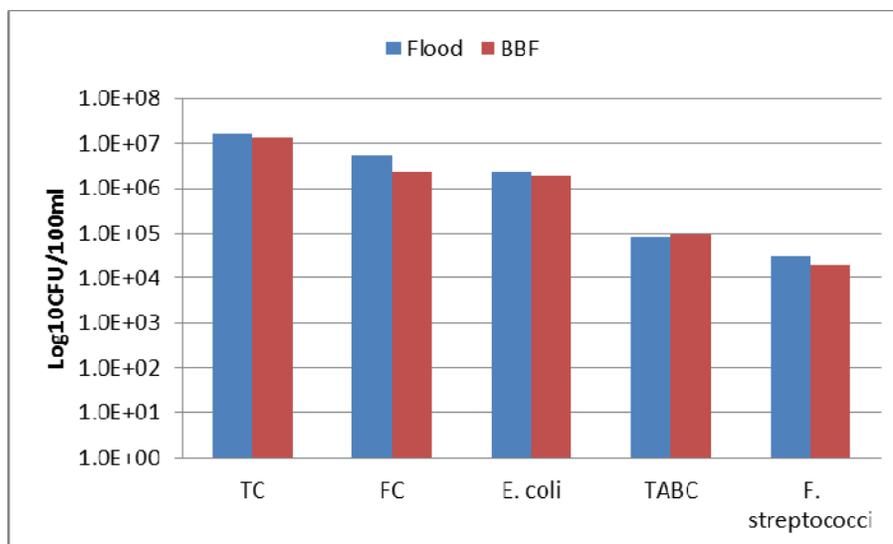


Fig. 10. Bacterial contamination of Indian spinach grown with wastewater irrigation under flood and broad bed furrow (BBF) irrigation systems

11.4 Effect of wastewater irrigation on tomato

11.4.1 Yield variables and fruit yield of tomato

The yield contributing characters and yield of tomato under four different improved irrigation methods were compared with the flood irrigation method (Table 7). Almost all yield contributing parameters like number and weight of fruit per plant were varied significantly when compared with flood irrigation system. But these parameters did not vary so much when compared among improved methods such as furrow irrigation (FI), alternate furrow (AFI), broad bed furrow (BBFI) and drip irrigation (DI) system. Among these four methods, almost no variations were observed between TFI and flood irrigation in respect of yield contributing parameters and fruit yield as well. The highest number and weight of fruit per plant were obtained from drip irrigation very closely followed by broad bed furrow, alternate and traditional irrigation in Cumilla. But in Rajshahi, fruit yield under drip irrigation was significantly higher than other irrigation systems. It may be because of delay in setting of drip system in Cumilla and thereby the delay in starting of drip irrigation. The unit fruit weight did not respond significantly with the irrigation methods; but it was however, slightly higher fruit weight in drip irrigation system.

Table 7. Yield and yield components of tomato as influenced by wastewater irrigation with different methods

Treatment	Plant height (cm)	No. of fruit/plant	Wt of fruit/plant (kg)	Unit fruit wt (g)	Fruit yield (t/ha)
Cumilla					
T ₁ (TFI)	115.6	36.33	2.68	83.77	85.42
T ₂ (AFI)	113.9	37.00	2.62	80.81	85.24
T ₃ (BBFI)	115.2	37.00	2.77	84.86	87.01
T ₄ (Drip)	117.4	36.80	2.83	86.90	88.80

T ₅ (Flood)	109.5	23.0	1.51	71.65	53.32
LSD _{0.05}	ns	0.328	0.527	6.91	2.52
CV (%)	6.33	3.14	3.28	4.42	7.52
Rajshahi					
T ₁ (TFI)	116.9	40.08	2.03	60.65	70.86
T ₂ (AFI)	117.8	42.24	2.59	71.32	73.67
T ₃ (BBFI)	116.6	41.98	2.64	72.89	72.58
T ₄ (Drip)	120.3	46.02	2.74	69.54	80.76
T ₅ (Flood)	101.7	27.40	1.23	54.89	50.42
LSD _{0.05}	10.84	4.95	0.650	7.18	4.62
CV (%)	9.34	7.41	5.22	5.08	9.10

The yield of tomato was significantly influenced by the different irrigation methods. Like the fruit yield per plant, in Cumilla, yield per hectare (88.8 t/ha) under drip irrigation was significantly higher than the yield under TFI (83.42 t/ha). But it was identical with the yields obtained in AFI and BBFI systems. In Rajshahi, a significantly higher tomato yield (80.76 t/ha) was achieved by drip irrigation than achieved by furrow (70.86 t/ha), alternate furrow (73.67 t/ha) and broad bed furrow irrigation (72.58 t/ha) systems. This may be due to the frequent application of small quantities of water in drip irrigation applied at 3 days interval favored the plant growth as well as yield. No significant difference was found among yields in TFI, AFI and BBFI irrigation systems. Unlike Cumilla, yield under TFI and AFI was almost same with slightly lower yield in TFI system. On average over locations, about 30% of water was saved in AFI system compared to TFI system. That is, TFI received the highest amount of irrigation water (362 mm) in 10 events and gave the identical yield of 83.42 t/ha, while AFI only 249 mm of water to produce almost same yield of 77.95 t/ha. Performance of BBFI system was same as AFI in terms of water use and yield. In both the locations, drip irrigation not only produced the highest yield, but also offered a greater saving of water (45%) and fertilizer (40% of NK). However, significantly lowest yield (51.87 t/ha) were obtained in flood irrigation system with the highest amount of water use (388 mm).

11.4.2 Water use and water productivity of tomato

The effect of irrigation systems on water use and water productivity were also evaluated and demonstrated in Fig 11. WP was calculated from the mean yields of tomato and depth of water applied for all the irrigation systems. Total water use ranged from 226 to 391 mm in Cumilla and from 234 to 385 mm in Rajshahi with minimum in DI system and maximum in flood irrigation system. Among the different furrow irrigation systems, water use was found higher in TFI system than that of AFI and BBFI systems. Over the locations, water use for TFI was ranging from 365 to 359 mm significantly followed by AFI (246 to 252 mm) and BBFI (242 to 260 mm). These

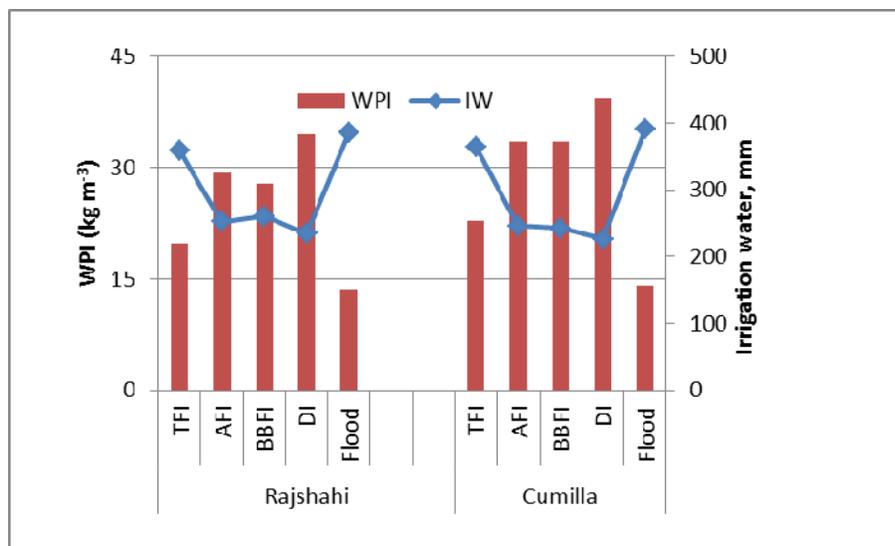


Fig. 11. Irrigation water applied and water productivity of tomato grown under different irrigation systems

happened to realize higher water productivity (31.33 kg/m^3) in AFI than that of in TFI (21.29 kg/m^3). However, the highest water productivity of 36.90 kg/m^3 was obtained from the treatment that received a total of 17 irrigations at 3 days interval through drip system and the lowest (13.36 kg/m^3) from flood irrigation system. Though drip irrigated treatment had the highest water productivity, it was comparable to WP of AFI and BBFI systems. So, all of these water saving methods can be advised to adopt by the farmers for cultivation of tomato.

11.4.3 Microbiological quality of tomato

Microbiological contamination of tomato crop grown under different irrigation systems with wastewater is illustrated in Fig 12. The total coliform, TC, fecal coliform, FC, and *Escherichia coli* (*E. coli*) were detected in fresh tomatoes. Among the irrigation systems, drip irrigation considerably reduced the total coliform compared to other irrigation systems. The reduction of total coliform under BBF was comparable to drip system. In general, the microbial population content in tomatoes was found higher in flood irrigation system followed by furrow (FI) and alternate furrow irrigation (AFI) while the population was the lowest in drip irrigation system. This is because the contamination of wastewater irrigated crops mainly depends on its contact opportunity with wastewater. In the case of drip irrigation system, irrigation application being localized, the possibility of contact was truncated. This fact is also reflected in flood irrigation system where direct contact between crop and wastewater happened to intensifying the contamination. However, the pathogenic bacteria *Salmonella* and *vibrio coli* were not detected in any treatments. The presence of pathogenic microorganisms in wastewater can pose a significant problem for agricultural use. Tomato being a salad crop, usually it is consumed in raw form and uncooked. Therefore, care must be taken to avoid the contact of wastewater with the crops to mitigate the hygienic problems. In a similar study with lettuce and radish (Bastos and Mara, 1995) reported that contamination of wastewater irrigated produce was less under drip than furrow technique.

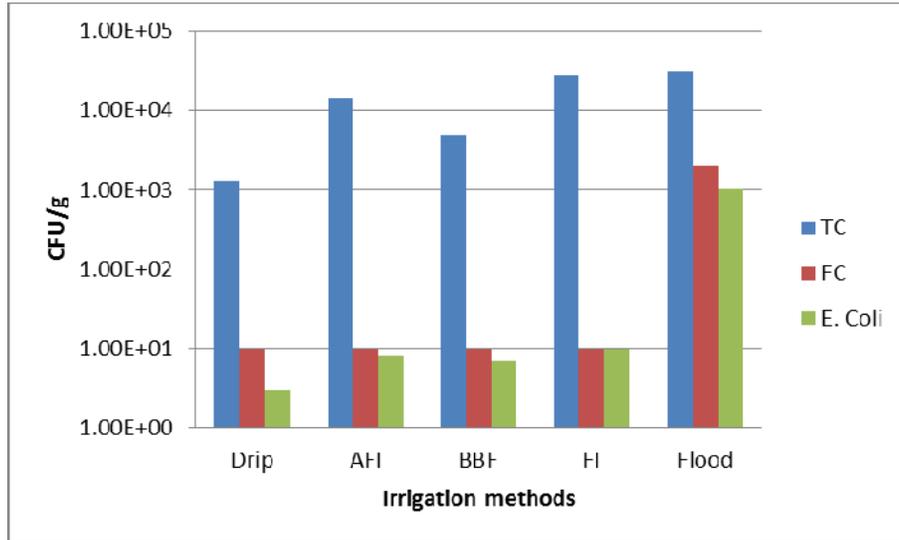


Fig. 12. Bacterial contamination of tomato grown with wastewater irrigation in different irrigation methods

11.5 Effect of wastewater irrigation on potato

11.5.1 Growth, yield variables and yield of potato

The growth, yield variables and yield of potato tuber as obtained under different combination of fertilizer and wastewater are presented in Table 8. The wastewater irrigation combined with different fertilizer doses had significant positive impact on plant height and unit weight of tuber. There existed an increasing trend of these parameters with the increasing fertilizer dose. That is, the maximum values of these two variables were obtained in treatment that received wastewater with full (100%) fertilizer dose. The minimum values of these parameters were obtained by treatment that received 60% of the recommended fertilizer. No significant difference, in respect of stem per hill and tuber per plant was observed among the fertilizer doses. However, 80% fertilizer with wastewater and 100% fertilizer with fresh water provided the identical results for all variables.

Application of fertilizer at an increasing rate along with wastewater gradually improved the yield of potato. But no significant improvement was observed in tuber yield of potato between the two successive fertilizer treatments either in furrow irrigation or in alternate furrow irrigation system. That is, difference in yield between 60% RFD and 80% RFD was insignificant, but a significant increment in yield was observed when fertilizer application was increased from 60% to 100% RFD. However, there was a great variation in yield between the two locations with significantly higher yield in Rajshahi. The significantly lower yield was recorded in Cumilla site because of heavy rainfall in the proper planting time happened to differ the sowing date of potato by at least 25 days. In Rajshahi, yield ranged from 38.03 to 42 t/ha under FI and from 37 to 41.5 t/ha under AFI system

with the lowest values at 60% RFD and the highest values at 100% RFD. The trend in yield was found same in Cumilla but with lower magnitude than that of Rajshahi.

Table 8. Yield and yield contributing parameters of tomato as affected by different fertilizer doses and water qualities

Treatment	Plant height (cm)	Stem/hill (no.)	Tuber/plant (no)	Weight of tuber/plant (g)	Tuber yield (t/ha)
Rajshahi					
T ₁	69.80	3.27	7.00	595	39.35
T ₂	64.47	3.00	8.87	793	42.23
T ₃	62.93	3.40	7.93	661	41.50
T ₄	72.93	2.73	7.93	665	38.03
T ₅	68.87	3.07	6.80	583	41.69
T ₆	63.87	2.67	6.93	641	39.93
T ₇	57.80	2.93	7.13	543	37.18
LSD _{0.05}	ns	ns	ns	43.44	3.63
CV (%)	6.96	3.43	3.87	7.28	6.78
Cumilla					
T ₁	47.2	2.5	4.9	288	15.11
T ₂	44.5	2.7	4.1	271.5	17.86
T ₃	44.3	2.5	4.5	270	15.63
T ₄	44.3	2.7	4.2	267	13.28
T ₅	43.3	2.7	4.9	279	16.51
T ₆	43.5	2.8	4.3	273	15.05
T ₇	44.5	3	4.5	270	12.81
LSD _{0.05}	ns	ns	ns	37.86	2.34
CV(%)	5.22	4.75	5.28	6.17	5.15

In Cumilla, the yield varied only from 12 to 16 t/ha under AFI and 13 to 17 under furrow irrigation system. The wastewater with 60% fertilizer produced the yield that was significantly different from that produced by wastewater with 100% fertilizer doses. The yield produced by 80% fertilizer dose was at par compared either with 60% RFD or with 100% RFD. That is, the increase in yield with the successive increase in fertilizer application was not significant. The enhanced plant growth and stem per hill containing greater number of tubers with elevated unit weight contributed to the higher yields at Rajshahi. These enhanced parameters also contributed to obtain higher yields under wastewater irrigation with 100% fertilizer dose at both the locations. Between the two different water qualities with full fertilizer dose, wastewater performed better than freshwater in terms of yield variables and yield. However, yield under 100% RFD with fresh water irrigation was identical with that obtained under 80% RFD with wastewater. Actually, wastewater contained considerable amounts of nutrients that contributed increasing growth variables by accumulation of more photosynthates in sink eventually contributed to increased tuber yield. This finding was in agreement with Kattimani *et al.* (1989) and Chakrabarti (1995) who reported that nutrients from

wastewater accumulated in soil, and after mineralization, became available to plants and resulted in higher growth and yield.

11.5.2 Availability of nutrients through wastewater irrigation

The amount of nutrients added through wastewater to potato field during the growing season is given in Table 9. On average, about 33.22, 4.95, 23.42 and 4.84 kg ha⁻¹ of N, P, K and S respectively was supplied to the potato field through wastewater irrigation. The quantity of these nutrients N, P and K

Table 9. Nutrient supplied through wastewater irrigation to potato field

Nutrient	Contribution by raw wastewater (kg/ha)	Crop requirement (kg/ha)	% of crop requirement added through wastewater
N	33.22	138.00	24.07
P	4.95	30.00	16.52
K	23.42	90.00	26.02
S	4.84	12.00	40.36
Zn	0.2316	1.00	23.16
B	1.0422	1.00	104.22

was equivalent to 24.07, 16.52, 26.02 and 40.36%, respectively of the recommended fertilizers needed for potato production. If these amounts are not considered for potato cultivation with wastewater, over-stimulation and excessive growth of the plants would cause yield loss. Janssen *et al.* (2005) however stated that evaluation of wastewater as a source of nutrients was not possible by simple comparison of nutrients in wastewater with fertilizers since the effects of wastewater's nutrients were different. Though Zn and B are micro nutrients, it plays a major role for potato production. In our study, it is evident that the full requirement of B can completely be met by wastewater irrigation. Even about 23% requirement of Zn, another essential micro nutrient for potato cultivation, can be fulfilled by wastewater irrigation. This should be taken into account for potato cultivation under wastewater irrigation to have the best result with a saving on fertilizer cost.

11.5.3 Nutrient aspects of wastewater irrigated potato

The effect of fertilizer and wastewater irrigation on macro- and micro elements contents of potato in two irrigation system are illustrated in Fig.13. Figure showed the highest macro elements (N, P, K and S) content in potato were obtained from treatment of irrigation by wastewater with higher fertilizer doses under TFI system. The increase of macro elements content in potato could be related to the amount of these nutritious elements in wastewater. The highest N content in potato was observed in full fertilized plots irrigated with wastewater. Fresh water irrigation with full fertilizer dose had the lower N content in potato even than that irrigated by wastewater with 80% fertilizer dose. The P, K and S content in potato was hardly affected by the different fertilizer dose;

but wastewater irrigation slightly raises these nutrient contents in potato. Mostly the nutrient contents were higher in the crop that received higher dose of fertilizer with wastewater than that received fresh water. This indicates greater recovery of N, P, K and S in presence of wastewater. However, the highest P, K and S content in potato was recorded in wastewater irrigated plots under TFI than AFI system because of nutrients added through wastewater was higher in TFI system. The nutrients added through fertilizer and wastewater made the NPKS elements available for plant and consequently causes the increase of their absorption by plant. Parhamfar (2006) in a research also presented the same results on this matter. The Zn and B contents of tubers were also affected by the wastewater and fresh water irrigated treatments. In this case too, wastewater irrigated treatments under TFI system had the higher Zn and B in potato tubers Macro- and micro-elements contents of plants increased with wastewater irrigation was reported by Kiziloglu *et al.*, (2007). The increase in Zn uptake by tubers is so minute that it does not pose any hazard to consumers. This suggest that the presence of these elements in wastewater below their recommended levels is not harmful for potato in terms of yield and quality, as their uptake by tubers, the main edible part, was not significant.

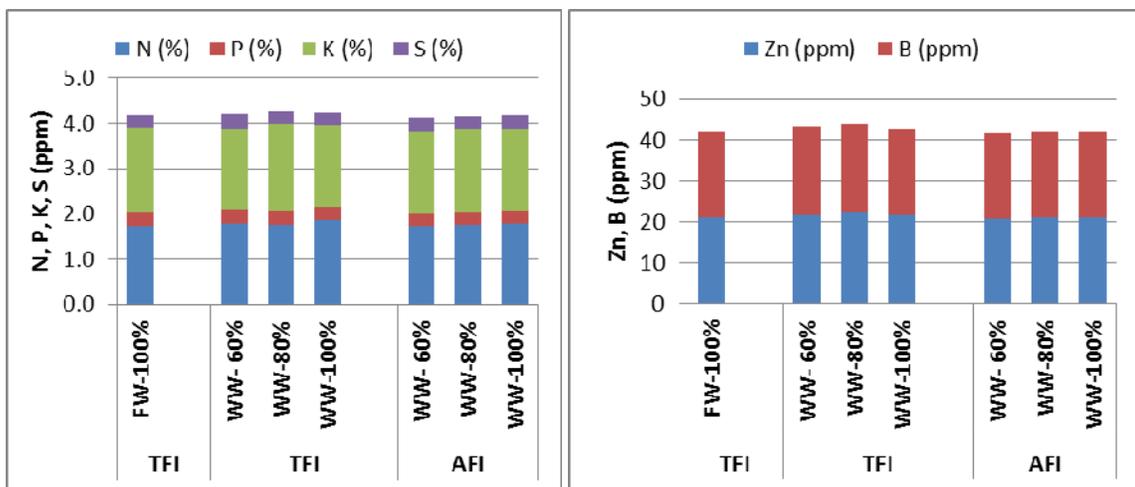


Fig. 13. Macro- and micro-nutrient contents of potato grown in traditional furrow irrigation (TFI) and alternate furrow irrigation (AFI) system with different fertilizer doses

11.5.4 Microbiological aspects of wastewater irrigated potato

Figure 14 shows bacterial counts in wastewater irrigated potato under the effects of water quality and irrigation systems: furrow irrigation and alternate furrow irrigation systems. Results indicated that the effect of irrigation systems was not significant in all investigated categories except fecal coliform count where AFI system considerably reduced the fecal coliform. The total bacterial count was also affected by water quality with higher contamination by wastewater and lower under fresh water. As the interaction between irrigation systems and water qualities is concerned, a positive effect was obtained on total bacteria count, total coliform and E. coli while other categories such as TABC and F. streptococci were not affected. Because of the large number of bacteria in wastewater (Table 2), TC and FC counts were greater in potatoes grown under irrigation by wastewater than

those grown under irrigation by fresh water. The count of TC varied from 1.8E+06 to 1.6E+06 cfu, FC from 9.0E+05 to 6.0E+05 cfu and that of *E. coli* varied from 5.0E+05 to 4.0E+05 cfu/100 ml with the minimum count in AFI and the maximum in furrow irrigation system by wastewater, while the lowest count of all categories of bacteria was recorded in fresh water irrigated potatoes (not shown in figure). But the difference in contamination between fresh water- and wastewater- irrigated potatoes under AFI system was insignificant. All studied bacterial counts were considerably lower in potatoes than in wastewater because of their reduction during percolation of wastewater through the soil and also because of their death caused by sunlight. Cleaning the potato skins just after harvest might also be an additional reason for lower TC, FC and *E. coli* counts on potato skins than in wastewater used for irrigation. The results thus reveal that the coliforms could not persist in the soil for a long time. If the potatoes were left in sunlight for a few hours or days, the coliform count would have decreased considerably. According to WHO (1980), the reuse of wastewater in irrigating crops requires that the TC in wastewater must be below 100 colonies per 100 mL in 80% of the samples and no FC should be in 100 ml samples. The reuse criteria refer to FC content which according to Mara & Cairncross (1989) should be $<10^3$ cfu/100 ml. The municipal wastewater used in this study did not meet these criteria. Interestingly, though fresh well water was free from coliform, potatoes grown with this fresh water had both total coliform and fecal coliform. This might be due to their presence in soil.

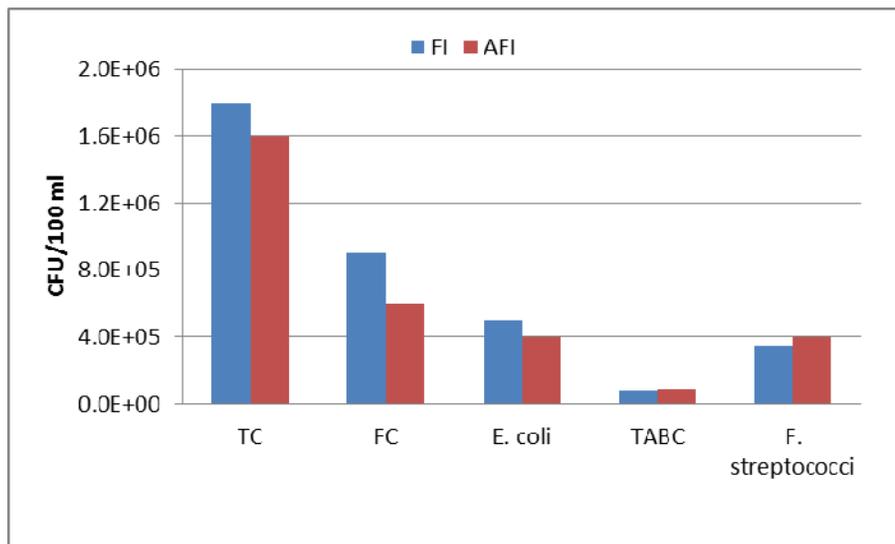
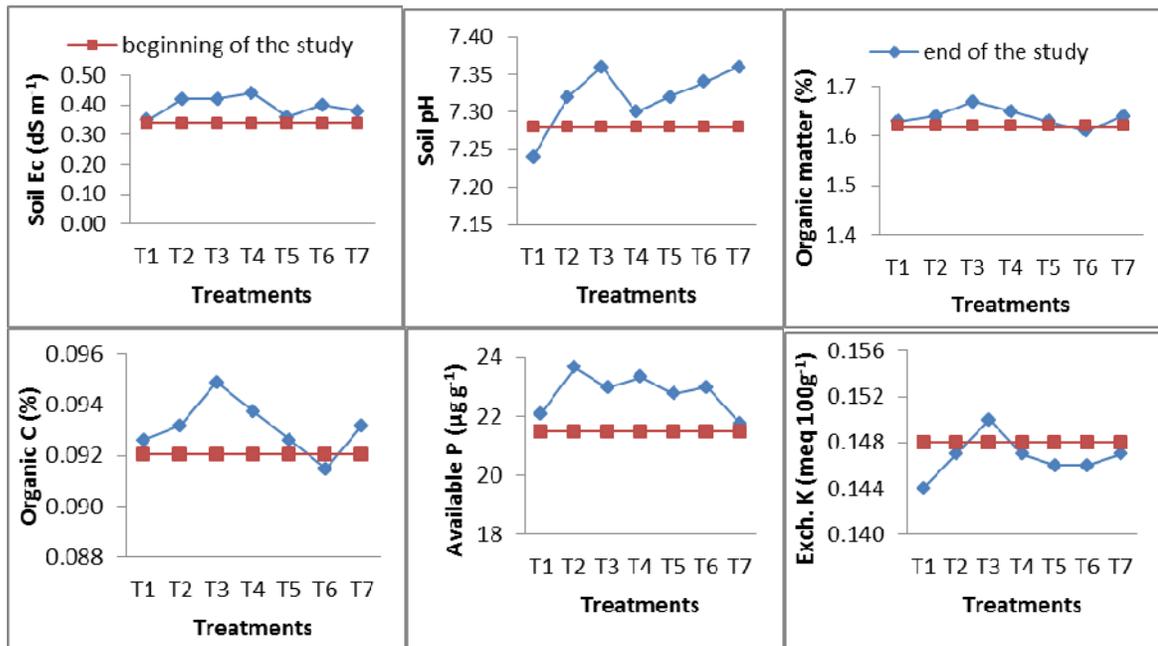


Fig. 14. Bacterial contamination of potato grown with wastewater irrigation under furrow (FI) and alternate furrow irrigation (AFI) system

11.5.5 Effect of wastewater irrigation on soil properties

Figure 15 illustrated the changes in soil properties of potato field due to the combined effect of fertilizer and wastewater under furrow and alternate furrow irrigation system. Results showed that most of the parameters, except K concentration, were found in increasing trend with slightly higher in furrow irrigation than in alternate furrow irrigation (AFI) system. This is because the AFI system received less wastewater than furrow irrigation system and thereby nutrients added through

wastewater irrigation were less. A slight increase in pH of wastewater irrigated soil compared to fresh water irrigated soil was observed due to higher pH of wastewater than that of fresh water. Soil EC was negatively affected by irrigation with wastewater as compared to soil irrigated with fresh groundwater. In general, soil EC increased by irrigation with wastewater. An average increase (0.10 dS m⁻¹) of EC in wastewater-irrigated soil was, probably a result of comparatively high electrical conductivity ranged from 1.12 dS m⁻¹ to 1.26 dS m⁻¹ in the wastewater. There was a slight difference in the N content of wastewater and groundwater irrigated soils. The N content of wastewater irrigated soil at the end of the study was greater than that at the beginning while irrigation with fresh water slightly reduced N content of the soil.



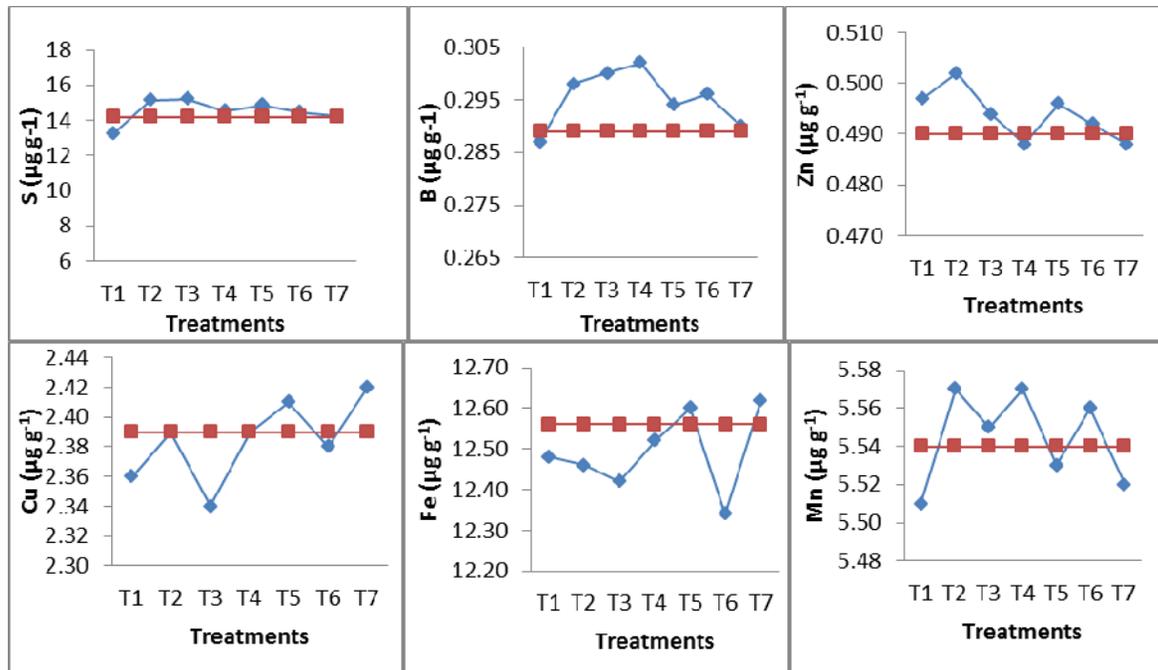


Fig. 15 Changes in soil chemical properties due to irrigation with urban wastewater (T₁: FW irrigation with 100% RFD, T₂, T₃ & T₄: WW irrigation in TFI and T₅, T₆ & T₇ in AFI system with 100, 80 and 60% of RFD, respectively)

The organic matter content of the soil showed similarities with the N content. A slight increase in soil organic matter (OM) was observed due to wastewater irrigation compared to fresh water. The increase in organic matter ranged from 0.008% to 0.035% in the wastewater-irrigated soil. Angin (2005) also reported that wastewater application increased organic matter and N contents of soils. Irrespective of water quality, the soil P concentration increased in all treatments, which is due to application of NPK fertilizer and the wastewater effect. As expected, P values were greater in 100% RFD with wastewater irrigation than that of fresh water irrigated treatment. The S content of soil exhibited the same trend as of P. The P and S level of the wastewater-irrigated soil increased in the range of 0.02- 0.15 $\mu\text{g g}^{-1}$ and 0.02-0.32 $\mu\text{g g}^{-1}$, respectively. These changes in soil can be due to considerable amount of P and S content in wastewater. The differences between K concentrations in soils irrigated with wastewater and fresh water were related to K concentration of the applied water and to a smaller extent for fertilizer application. K concentration in wastewater irrigated soil was slightly higher than that of fresh water irrigated soil, but the trend was negative. The average increase of exchangeable K ranged from 0.03 to 0.36 meq 100g⁻¹ in wastewater-irrigated treatments. The reduction in K content in the groundwater irrigated soil may be due to plant uptake and no addition of K through fresh irrigation water which is the case for irrigation with wastewater. While boron content increased as much as 12% in the full fertilized wastewater-irrigated treatment. This is because of high amount of exchangeable K and boron present in the wastewater. On the other hand, heavy metals like Fe, Mn, Zn and Cu in the soils did not show any consistent changes in the wastewater-irrigated soil, probably due to low concentration of heavy metals (Table 1) in the wastewater, since the wastewater used was almost exclusively of domestic origin, with little industrial contribution. Increases in a number of soil parameters like OM, N, P, K, S

and B were found due to the enrichment of soil by these nutrients with wastewater irrigations. Similar agreements were also reported by Pomares (1984) and Siebe (1996), and they suggested that application of wastewater to cropland and forest lands is an attractive option for disposal because it can improve the chemical properties and nutrient contents of soils.

11.6 Human health risk

Health risk index (HRI) calculated on the basis of the oral reference dose and are presented in Fig. 16. FAO/WHO 2013 suggested oral reference doses (R_fDo) for heavy metals were used to calculate HRI. From the result, it is seen that the HRI values for Indian spinach were much below the one (1.0)

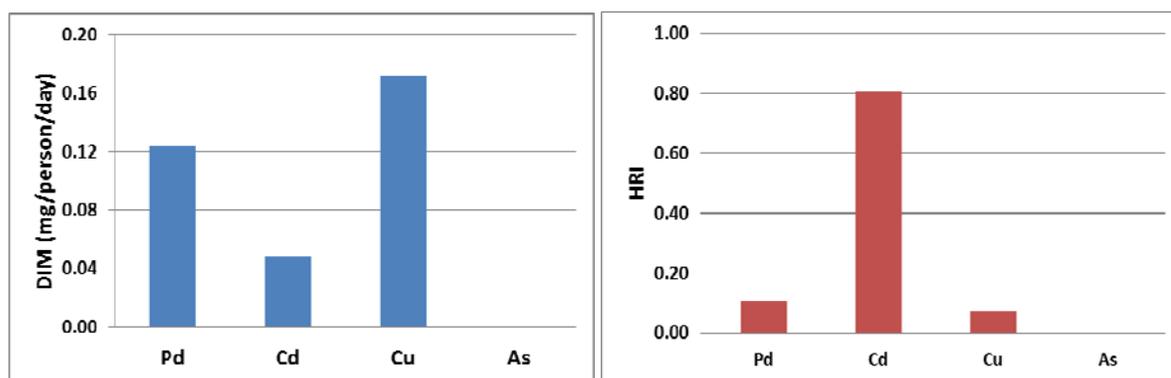


Fig. 16 Daily intake of heavy metals (DIM) and health risk index (HRI) of individual heavy metals through consumption of Indian spinach

for all heavy metals. For Pb and Cu, the HRI values were even less than 0.1 and As was nil, but a comparatively higher value of HRI (0.8) was found for Cd. When HRI exceeds one (1.0), there is concern for health effect (Huang *et al.*, 2008). This low HRI for heavy metals (Pb, Cu, As) observed in Indian spinach has little potential to pose health risk to the consumer. It can be said that consumers of wastewater-irrigated Indian spinach are almost free of risk. Comparatively higher value of HRI for Cd, though less than 1.0, might probably have exposed to some potential health risk through the intake of Cd via consuming locally grown Indian spinach. Even though there was no apparent risk when each metal was analyzed individually, the potential risk could be multiplied when considering all heavy metals. The finding of this study regarding DIM and HRI showed that the consumption of vegetables grown in wastewater irrigated soils was nearly free of risks. Consumption of vegetables with elevated levels of heavy metals may lead to high level of body accumulation causing related health disorders. But the situation could however change in the future depending on the dietary pattern of the community and the volume of contaminants added to the ecosystems. Therefore regular monitoring of heavy metal contamination in the vegetables grown at wastewater irrigated area is necessary.

12. Research highlights/findings

Wastewater irrigation affected not only the growth and yield of crops, but also the chemical properties of the soil. It also affected the quality of crops either by the enrichment in mineral

content or by degrading with biological or chemical contamination. However, the major findings of this research project are as follows:

- The yields of leafy vegetables like spinach and Indian spinach were found significantly higher under wastewater irrigation compared to freshwater irrigation. The yield obtained under 80% of recommended fertilizer dose (RFD) in both flood (FLI) and broad bed furrow irrigation (BBFI) systems were comparable to the yield under 100% RFD fresh water irrigated crops. The yield of potato under wastewater with 80% RFD was identical with that obtained under fresh water with 100% fertilizer dose. The difference in yield between 80% and 100% RFD with wastewater irrigation, and the nutrient added by wastewater reveals that about 20-25% of RFD could be reduced for cultivation of these crops with wastewater. No significant difference in potato yield was observed between traditional furrow (TFI) and alternate furrow irrigation (AFI) system. Among the irrigation methods, drip irrigation (DI) gave the highest yield with about 44% water saving than TFI, followed by AFI and BBFI with about 36% saving of water.
- Application of wastewater increased the soil fertility with enrichment in organic matter, macro-(NPKS) and micro-nutrients (Zn, B). But no consistency changes were observed in case of heavy metals accumulation as the wastewater used for irrigation was almost from domestic origin. Wastewater not only increased the yield of crops, it also increased the N, P, K, S, B, and Zn content of the crops. In this study, the crops those were irrigated with wastewater exhibit an increase in the concentrations of macro and micro elements in both the soil and the crops.
- A high bacterial contamination with fecal coliforms (FC), total coliforms (TC), total bacterial aerobic counts (TABAC), fecal streptococci and *Escherichia coli* (*E. coli*) was observed in fresh spinach and Indian spinach irrigated with urban wastewater and the irrigation methods had significant role in minimizing the contamination. The bacterial contamination was found lower in BBFI than FLI system for spinach and Indian spinach. Similarly, lower count of these categories of bacteria was recorded in AFI than TFI for potato. For tomato, drip irrigation had the lowest bacterial contamination compared to other irrigation techniques. Though crop cultivation with wastewater using proper irrigation techniques could minimize the contamination of crops, the degree of contamination was still higher for its safe use. However, this information is only a first indication of a possible health risk. To quantify the risk, it is important to assess human exposure.
- Wastewater irrigation positively affected the growth and yield of all studied crops, while methods of irrigation had little effect on it.
- The difference in yield between 80% and 100% RFD with wastewater irrigation, and the nutrient added by wastewater reveals that about 20-25% of RFD could be reduced for cultivation of these crops (Spinach, Indian spinach and potato) with wastewater.

- Crops irrigated with wastewater exhibited an increase in the concentrations of macro (NPKS) and micro elements (Zn, B) in both the crops and the soils. But no consistence changes were observed in case of heavy metals accumulation in soil.
- Though crop cultivation with wastewater using proper irrigation techniques (BBFI for leafy vegetables, AFI for potato, and drip irrigation for tomato) could minimize the bacterial (FC, TC, TABC, *F. streptococci* and *E. coli*) contamination of crops, the degree of contamination was still higher for its safe use. However, this information is only a first indication of a possible health risk. To quantify the risk, it is important to assess human exposure.

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B. Implementation Position

1. Procurement:

Description of equipment and capital items	PP Target		Achievement		Remarks
	Phy (#)	Fin (Tk)	Phy (#)	Fin (Tk)	
(a) Office equipment					
Laptop	01	60000.00	01	60000.00	
Camera	01	25000.00	01	25000.00	
Secretariat table	01	20000.00	01	20000.00	
Revolving chair	01	10000.00	01	10000.00	
Guest chair	04	16000.00	04	16000.00	
Almirah	01	24000.00	01	24000.00	
(b) Lab & field equipment					
Colorimeter	01	250000.00	01	244500.00	
Digital pH meter	01	15000.00	01	15000.00	
Amber plastic bottle	50	6000.00	50	6000.00	
Ice box	02	12000.00	02	12000.00	
Soil auger	02	8000.00	02	8000.00	
Aluminum pot	50	5000.00	50	5000.00	
Centrifugal pump with accessories	02	60000.00	02	60000.00	
	06	150000.00	06	150000.00	
Plastic tank with drip irrigation accessories	100 kg	30000.00	100 kg	30000.00	
Canvas hose pipe					
(c) Other capital items					

2. Establishment/renovation facilities:

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	

3. Training/study tour/ seminar/workshop/conference organized:

Description	Number of participant			Duration (Days/weeks/ months)	Remarks
	Male	Female	Total		
(a) Training	39	11	50	1+1=2	Farmers training in each site
(b) Workshop					Inception and Annual Workshop arranged by PIU



Fig. Pictorial view of farmers' training in Rajshahi and Cumilla

C. Financial and physical progress Fig in Tk

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
A. Contractual staff salary	551500	492087	492087	0	89.22	Delay in recruitment
B. Field research/lab expenses and supplies	770000	958414	1017593	-59179	100	
C. Operating expenses	360000	197548	158906	38642	54.87	Some utilities not used
D. Vehicle hire and fuel, oil & maintenance	220000	203000	185840	17160	84.87	Maintenance not required
E. Training/workshop/seminar etc.	150000	150000	150000	0	100	
F. Publications and printing	150000	0	0	0		
G. Miscellaneous	40000	18563	38286	-19723	95.71	
H. Capital expenses	699000		694500	4500	100	

D. Achievement of Sub-project by objectives: (Tangible form)

Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output(i.e. product obtained, visible, measurable)	Outcome(short term effect of the research)
(i) To evaluate the effect of urban wastewater irrigation on the yield and contamination of vegetable crops and soil	Experiments were conducted in farmers' field of Rajshahi and Cumilla with tomato, potato, spinach and Indian spinach. Data on yield and yield parameters of different crops were collected at harvest. Bacteriological and chemical test of some crops and soil has already been done and some crops and soil samples are still in lab for chemical analysis.	Leaflet	Farmers will be aware about the positive and negative impact of using wastewater for crop irrigation
(ii) To determine health risk to the consumers of wastewater irrigated produce, and contribution of wastewater to nutrient requirement for the crops, and	Health risk index (HRI), target hazard quotient (THQ), accumulation factor (AF), etc have been determined partially to assess the human health risk. Complete assessment will be done after chemical analysis to determine uptake of heavy metals is completed. Characterization of wastewater has been done and its contribution to nutrient requirements of crops under wastewater irrigation has been determined.		Farmers will be benefited through proper fertilizer management for wastewater irrigation by which farmers will be able to save money on fertilizer cost. On the other hand, consumer will be aware about the health risk from wastewater irrigated produce.
(iii) To develop an effective management practice for the use of wastewater for growing vegetable	Irrigation management techniques like bed and furrow irrigation, alternate furrow irrigation and drip irrigation have been adopted. Very small stabilization pond and low		Adoption of proper irrigation management techniques will reduce the contamination of vegetable and salad crops.

crops to minimize the microbial and other contaminations.	cost filter have been designed to reduce the pollutant load of wastewater to be used for irrigation.		
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E. Materials Development/Publication made under the Sub-project:

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Technology bulletin/ booklet/leaflet/flyer etc.	01		
Journal publication	01		
Information development			
Other publications, if any			

F. Technology/Knowledge generation/Policy Support (as applied):

i. Generation of technology (Commodity & Non-commodity)

Use of urban wastewater for leafy vegetable and salad crops.

ii. Generation of new knowledge that help in developing more technology in future

Microbial contamination of wastewater-irrigated crops can be reduced by adopting proper irrigation technics. Treatment aspects can also be considered for future.

iii. Technology transferred that help increased agricultural productivity and farmers' income

Use of nutrient-rich urban wastewater for irrigation will help increase crop productivity and thereby farmers' income. Ultimately livelihood of farmers will improve.

iv. Policy Support

Policies, strategies, laws and guidelines support needs to use of wastewater in agriculture. This initiative can reduce pressure on groundwater as well as energy consumption.

G. Information regarding Desk and Field Monitoring

i) Desk Monitoring [description & output of consultation meeting, monitoring workshops/seminars etc.):

- Sources and constituents of wastewater are to be ensured.
- Some technologies are to be adopted by which wastewater could be used safely as well as it is not harmful for human health.
- Study should be continued to have a good conclusion.

ii) Field Monitoring (time& No. of visit, Team visit and output):

Throughout the crop growing season, more than 15 numbers of field visit and monitoring was done by the project personnel, scientists of Irrigation and Water Management, Regional Wheat Research Centre and On Farm Research Division.

I. Lesson learned/Challenges (if any)

- i) Proper irrigation methods and management can be adopted as non-treatment options to reduce the contamination of wastewater irrigated produce;
- ii) Farmers can save money on fertilizer use if they take into account the nutrient value of wastewater;
- iii) Farmers are not aware of the health hazard from the consumption of wastewater irrigated produce;
- iv) Involving farmers and other stakeholders in wastewater quality monitoring can increase trust in wastewater quality and acceptance of reuse for agricultural irrigation.

J. Challenges (if any)

- i) Treatment of wastewater to reduce pollutant load
- ii) Adoption of code of good agricultural practices by the farmers

Signature of the Principal Investigator

Date

Seal

Counter signature of the Head of the organization/authorized representative

Date

Seal