Effects of Dairy Farm's Wastewater Irrigation on Wheat Production and Soil Health

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Abstract

An experiment was conducted at the experimental field of the Bangladesh Agricultural University (BAU) to investigate the effects of dairy farm's wastewater irrigation on wheat (*Triticum aestivum cv.* BARI "Shatabdi") production and soil health during 30 November 2013 through 22 March 2014. Three irrigation and three fertilizer treatments were involved in the experiment. The experiment was laid down in a split-plot design with three replications of the treatments. Various growth and yield data of the crop were recorded. For the effect of irrigation water quality, the highest and the lowest grain yield (2.88 t ha^{-1} and 2.71 t ha^{-1}) were obtained under I_3 and I_2, respectively. For the effect of fertilizer, the highest and the lowest grain yield (4.42 t $ha^{-1}$and 1.59 t ha^{-1}) were obtained under F_2 and F_0, respectively. The interaction effect between irrigation and fertilizer exerted a significant impact on the grain yield of wheat. Irrigation by wastewater did not significantly alter the quality parameters of the irrigated soils. The raw wastewater supplied more nutrients to the soil of the wheat field. Therefore, it may be used as a source of irrigation and fertilizer for wheat production without any hazard of the soil health.

Key words: Fertilizer, Irrigation, Soil, Wastewater, Wheat

Introduction

Water is an essential input to any crop for its survival, better development and bumper production. Crops may suffer due to insufficient availability of water. Water demand already exceeds supply in many parts of the world. Therefore, it is needed to seek alternative sources of irrigation water to ensure sustainability of the available resources. The global volume of wastewater is over 1500 km^3 per year. A large part of it is being used worldwide for irrigation in agriculture. According to ESCAP (2000), about 725 million m^3 of wastewater is produced annually from urban areas of Bangladesh of which 90% is untreated. Raw or partially treated wastewater is being applied to almost 20 million hectares of agricultural land in 50 countries of the world and is contributing to irrigate 20% area of world's agriculture. Among the various inputs, irrigation especially wastewater irrigation plays an important role in crop production. Properly treated wastewater can be used as a good source of irrigation due to its good nutritive value. So, wastewater is often seen as a resource. Virto *et al*. (2006) described the use of wastewater for irrigation as a prime solution in the optimization of water resources in semi-arid areas. Farmers prefer untreated wastewater because it is perceived as more dependable for irrigation because of its quick availability at low cost and its rich nutritive value. A properly planned use of wastewater not only takes advantages of the nutrients contained in it to grow crops but also removes surface water pollution problems and conserves the valuable water resources. Activities indirectly dependent on wastewater include the sale of seeds, pesticides and other inputs to wastewater farmers, renting of harvesting machinery or equipment, agricultural labor, services related to the transportation of products to markets, marketing of the products, animal husbandry with purchased wastewater-irrigated fodder and the provision of fish fry for aquaculture. Many resource poor farmers (with and without land) and very poor agricultural laborers can earn an income or gain food security through the use of this degraded resource (Buechler, 2004). Wheat is the most important cereal crop all over the world and about two third of the total population of the world live on it (Honsan *et al*., 1982). It provides more nourishment for the nations of the world than any other food crops. It supplies carbohydrate, protein, minerals and vitamins. Next to rice, wheat is the second most important food crop in Bangladesh (Razzaque and Hossain, 1990). According to BBS (2011), the annual production of wheat in Bangladesh is 0.90 million tons that is cultivated in 0.38 million hectares of land with an average yield of 2.39 t ha^{-1}. A large quantity of wastewater is produced from dairy farm in Bangladesh. So, there may be a good possibility to irrigate wheat with dairy farm's wastewater. A large amount of effluents (characterized by BOD, COD, sodium and other dissolved solids as well as micro-nutrients, and often heavy metals) is discharged on land or into water courses from dairy farms in Bangladesh. The disposal of the wastewater creates several environmental problems. But the use of this wastewater for irrigation can provide a potential solution to the problems. The impacts of wastewater widely vary with the source of water, soil type and types of crops to be grown. The potential impacts depend on the time of irrigation and long term irrigation with wastewater increases salts, organic matter, and plant nutrients in soil (Munir *et al*., 2006). But in our country, the impacts of dairy farm's wastewater on the growth and yield of potential crops, especially wheat, and on soil properties have not been studied thoroughly. While the additional nutrients can be a bonus as additional fertilizer, excess nutrients, particularly carbon and nitrogen, can have adverse effects through excessive microbial activity and growth. So, it is necessary to evaluate the impacts of wastewater irrigation in wheat cultivation and on soil properties in Bangladesh. This study may help decision makers and planners to take decision on dairy farm's wastewater use for irrigating wheat in Bangladesh.

Materials and Methods

An experiment was carried out at the central farm of the Bangladesh Agricultural University (BAU), Mymensingh (24.75° N latitude and 90.50° E longitude), during the period from November 2013 through March 2014 to investigate the effects of irrigation by dairy wastewater on wheat (*Triticum aestivum cv.* BARI "Shatabdi") production and soil health under different fertilizer doses. The soil of the experimental field is silt loam underlain by sandy loam, and it belongs to the Old Brahmaputra Floodplain (BARC, 2005) with bulk density, electrical conductivity, initial pH, organic matter, average field capacity and permanent wilting point of 1.33 g cm^{-3}, 0.23 dS m^{-1}, 7.73, 0.48%, 38.19% (v/v) and 18.37 % (v/v), respectively. During the growing season of wheat, there was only 27.70 mm rainfall. Two factors (irrigation as the main factor and fertilizer as the sub factor) were evaluated in the experiment. The irrigation treatments - I_1: Irrigation with fresh water, I_2: Irrigation with mixed water (fresh water: wastewater = 1:1) and I3: Irrigation with raw wastewater. The fertilizer treatments were- F_0: no application of fertilizer, F_1: half dose fertilizer and F_2: full dose fertilizer. The experiment was laid out in a split-plot design with three replications of the treatments. Two different doses of fertilizers were applied to the experimental plots; one half and full dose of recommend fertilizer. Two-thirds of urea (104.16 g $plot^{-1}$) and full doses of the other fertilizers-Triple Super Phosphate (96 g $plot^{-1}$), Muriate of Potash (66 g $plot^{-1}$), Gypsum (65 g $plot^{-1}$), Zinc sulphate (4.8 g $plot^{-1}$) and Borax (3 g $plot^{-1}$) were applied to the selected nine plots (size: 3m x 2m) as basal dose during last ploughing. At the same time two-thirds of urea (52.08 g $plot^{-1}$) and half doses of the other fertilizers-Triple Super Phosphate (48 g $plot^{-1}$), Muriate of Potash (33 g $plot^{-1}$), Gypsum (32.5 g $plot^{-1}$), Zinc sulphate (2.4 g $plot^{-1}$) and Borax (1.5 g $plot^{-1}$) were applied to the other nine plots. The rest of urea for full dose (52.08 g $plot^{-1}$) and half dose (26.04 g $plot^{-1}$) was top dressed after 24 DAS. No fertilizer was applied to the other remaining nine plots. The wheat seeds (120 kg ha^{-1}) were sown in furrows with a spacing of 20 cm during *'Joe'* condition on 30 November 2013. Weeds were controlled by uprooting before application of irrigation. First weeding was done after 38 DAS and second weeding was done after 61 DAS. Adequate soil moisture content was available in the field at CRI stage. Three irrigations, the first (1.17 cm) at 40 DAS, second (1.70 cm) at 63 DAS and third (5 cm) at 85 DAS were applied to each plot. The quality parameters of the dairy farm's wastewater used for irrigation pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), phosphorus (P), phosphate (PO_4), phosphorus pentoxide (P_2O_5), boron (B), zinc (Zn) and potassium (K) were measured very carefully to determine the quality of the wastewater. The volumetric soil moisture content was measured at sowing (0.35) and harvesting (0.23) with a digital soil moisture meter. The quality parameters of the irrigated soil electrical conductivity (EC), pH, organic carbon (OC), total nitrogen, phosphorus (P), potassium (K) and calcium (Ca) were recorded very carefully. A harvest area of 1 m × 1 m was selected in the middle portion of each plot and then the matured crop was harvested by cutting the plants at ground level. The harvested crop of each plot was bundled separately and tagged. The data on plant population (plants per square meter), plant height at harvest, number of tillers per plant and weight of 1000 grains (dried at 12% moisture content) were recorded. Grain yield, straw yield, biological yield, harvest index and field water use efficiency (FWUE) for different treatments were calculated. The FWUE was calculated by

$$\text{FWUE} = \frac{Y}{WU}$$

where WU is seasonal crop-water use in the field (cm) and Y is grain yield (kg ha^{-1}). The crop-water use was calculated by

$$WU = IR + ER + \sum_{i=1}^{n} \frac{(M_s - M_h)}{100} D_i$$

where IR is total irrigation water applied (cm), ER is seasonal effective rainfall (cm), M_s is soil moisture content (% volume) at sowing, M_h is soil moisture content (% volume) at harvest and D_i is depth of root zone layer (average 60 cm for wheat). The effective rainfall was calculated by

$$ER = \frac{P_{total}\ (125 - 0.2P_{total})}{125} \text{ [for } P_{total} < 250 \text{ mm]}$$

and

$$ER = 125 + 0.1\ P_{total} \text{ [for } P_{total} > 250 \text{ mm]}$$

where P_{total} is the total rainfall (mm) during the wheat growing period.

The growth and yield attributes of wheat and the quality parameters of the irrigated soil were tabulated in proper forms for statistical analyses. The analysis of variance (ANOVA) was done following the methods described by Gomez and Gomez (1984). MSTAT-C computer package (Russel and Eisensmith, 1983) was used to carry out the statistical analysis.

Table 1. Some important quality parameters of wastewater of BAU dairy farm along with the FAO and Bangladesh standard for irrigation

Parameters	Dairy wastewater	FAO standard	Bangladesh Standard
pH	7.31	6.5-8.0	6.0-9.0
EC (dS m^{-1})	0.624	0.7	1.2
BOD (mg l^{-1})	126	-	10
COD (mg l^{-1})	407	-	<400
NH_3-N (mg l^{-1})	50.0	-	-
NO_3-N (mg l^{-1})	ND	10	-
NO_2-N (mg l^{-1})	0.008	-	-
PO_4 (mg l^{-1})	32.3	10	
P_2O_5 (mg l^{-1})	24.1	-	-
P (mg l^{-1})	10.5	-	15
Zn (mg l^{-1})	ND	2.0	10
K (mg l^{-1})	60.9	30	
B (mg l^{-1})	ND	2.0	2.0

*ND-Not Detectable

Results and Discussion

Quality parameters of dairy wastewater

Some important quality parameters of wastewater of BAU dairy farm are summarized in Table 1 along with the FAO standard and Bangladesh standard of water for irrigation. The EC of the wastewater was 0.624 dS m^{-1}. The FAO recommended standard value of EC for irrigation is 0.70 dS m^{-1} and in Bangladesh standard, it is 1.2 dS m^{-1} shown in Table 1. Wilcox (1955) classified irrigation water as excellent, good, permissible, doubtful and unsuitable depending on EC values as <0.25, 0.25-0.75, 0.75-2.0, 2.0-3.0 and >3.0 dS m^{-1}, respectively. So, comparing with the standard values of EC for irrigation, the dairy farm's wastewater was suitable for irrigation. The pH of the wastewater was 7.31. The FAO standard for acceptable range of pH for irrigation water is 6.5-8.0 and in respect to Bangladesh standard, it is 6.0-9.0 (Table 1). The concentrations of NH_3-N, PO_4, P_2O_5, P and K of wastewater were higher than the limits set by FAO. The concentration of NO_2-N was very low in the wastewater. The concentrations of NO_3-N, Zn and B were not detected in the wastewater.

Effect of irrigation on growth and yield

The irrigation treatments exerted different degrees of influence on various crop attributes, maximum attributes differed insignificantly while others differed significantly. The crop attributes and yields under different irrigation treatments are listed in Table 2. The highest number of fertile plants was obtained under irrigation by fresh water (I_1) and the lowest number of fertile plants was under mixed water (I_2). The tallest plant (66.14 cm) was obtained with wastewater irrigation (I_3). The mean plant height increased by 1.79 and 1.17% in treatment I_3 and I_2, respectively compared to the control treatment, I_1. The highest LAI (2.19) was found in treatment I_3 and the lowest LAI (2.05) was found in treatment I_2. The highest number of spikes (3182.0) and spikelet (8411.0) per square meter area was both found in treatment I_2. The highest 1000-grain weight of 49.97 g was obtained with treatment I_3 and the 1000-grain weight increased by 4.76 and 1.36% in I_3 and I_2, respectively compared to the treatment I_1. Treatment I_3 produced the highest grain yield of 2.88 t ha-1and the grain yield increased by 3.24 and 6.01% in I_1 and I_3, respectively compared to the treatment I_2. The highest straw yield (1.18 t ha^{-1}) and biological yield (4.05 t ha^{-1}) was both obtained under I_3. These results indicate that raw wastewater supplied some nutrients to the wheat crop and increased the grain yield.

Table 2. Number of plant m^{-2}, plant height and leaf area index (LAI), spike m^{-2}, spike length, spikelet m^{-2} and weight of 1000 grains, grain, straw and biological yields of wheat under three irrigation and three fertilizer treatments, and their interaction

Treatment	No. of plant m^{-2}	Plant height (cm)	LAI	Spike m^{-2}	Spikelet m^{-2}	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
I_1	226.0^{A}	64.98^{A}	2.06^{B}	3054.0^{A}	7805.0^{A}	47.70^{B}	2.80^{A}	1.03^{B}	3.83^{A}
I_2	216.0^{A}	65.74^{A}	2.05^{B}	3182.0^{A}	8411.0^{A}	48.35^{B}	2.71^{A}	0.72^{C}	3.44^{B}
I_3	220.8^{A}	66.14^{A}	2.19^{A}	3106.0^{A}	8399.0^{A}	49.97^{A}	2.88^{A}	1.18^{A}	4.05^{A}
CV (%)	5.45	5.11	5.06	4.09	8.52	1.67	8.34	10.52	6.84
$LSD_{0.05}$	12.03	3.34	0.10	127.20	698.90	0.81	0.23	0.10	0.26
F_0	190.6^{B}	52.73^{C}	1.09^{C}	2196.0^{C}	5363.0^{C}	45.56^{C}	1.59^{C}	0.68^{C}	2.28^{C}
F_1	202.3^{B}	66.14^{B}	1.72^{B}	2882.0^{B}	7206.0^{B}	49.39^{B}	2.38^{B}	1.19^{A}	3.57^{B}
F_2	269.9^{A}	77.99^{A}	3.49^{A}	4265.0^{A}	12050.0^{A}	51.08^{A}	4.42^{A}	1.06^{B}	5.47^{A}
CV (%)	5.45	5.11	5.06	4.09	8.52	1.67	8.34	10.52	6.84
$LSD_{0.05}$	12.03	3.34	0.10	127.20	698.90	0.81	0.23	0.10	0.26
I_1F_0	190.3^{C}	52.48^{C}	1.06^{E}	1877.0^{E}	4640.0^{D}	45.77^{D}	1.44^{D}	0.77^{D}	2.21^{E}
I_1F_1	220.7^{B}	63.49^{B}	1.90^{C}	3115.0^{C}	7729.0^{C}	47.63^{C}	2.35^{B}	1.28^{A}	3.63^{BC}
I_1F_2	267.0^{A}	78.98^{A}	3.21^{B}	4170.0^{B}	11050.0^{B}	49.71^{B}	4.62^{A}	1.04^{BC}	5.66^{A}
I_2F_0	181.3^{C}	51.15^{C}	1.09^{E}	2043.0^{E}	4867.0^{D}	44.94^{D}	1.51^{D}	0.23^{E}	1.73^{F}
I_2F_1	195.7^{C}	66.95^{B}	1.52^{D}	2905.0^{C}	7130.0^{C}	48.36^{BC}	2.21^{BC}	1.06^{BC}	3.27^{CD}
I_2F_2	271.0^{A}	79.11^{A}	3.55^{A}	4599.0^{A}	13240.0^{A}	51.75^{A}	4.43^{A}	0.88^{CD}	5.31^{A}
I_3F_0	200.0^{BC}	54.57^{C}	1.12^{E}	2667.0^{D}	6582.0^{C}	45.96^{D}	1.84^{CD}	1.05^{BC}	2.89^{D}
I_3F_1	190.7^{C}	67.99^{B}	1.74^{C}	2626.0^{D}	6758.0^{C}	52.18^{A}	2.59^{B}	1.22^{AB}	3.81^{B}
I_3F_2	271.7^{A}	75.86^{A}	3.71^{A}	4025.0^{B}	11860.0^{B}	51.78^{A}	4.20^{A}	1.25^{A}	5.45^{A}
CV (%)	5.45	5.11	5.06	4.09	8.52	1.67	8.34	10.52	6.84
$LSD_{0.05}$	20.84	5.80	0.18	220.40	1210.00	1.40	0.40	0.18	0.45

Effect of fertilizer on growth and yield

The crop attributes and yields under different fertilizer treatments are listed in Table 2. The highest number of plants (269.9) was obtained under full dose fertilizer application (F_2) and the lowest number of plants (190.6) was under no application of fertilizer (F_0). The tallest plant of 77.99 cm was obtained with full dose fertilizer (F_2) and the average plant height increased by 25.43 and 47.90% under treatment F_1 and F_2, respectively compared to the treatment F_0. The highest LAI (3.49) was found under the treatment F_2 and the lowest LAI (1.09) was found under the treatment F_0. The highest number of spikes (4265.0) and spikelet (12050.0) per square meter area was both found in treatment F_2. The highest 1000-grain weight of 51.08 g was obtained with treatment F_2 and the 1000-grain weight increased by 8.41 and 12.12% in F_1 and F_2, respectively compared to the treatment F_0. Treatment F_2 produced the highest grain yield of 4.42 t ha^{-1} and the grain yield increased by 49.44 and 177.10% in F_1 and F_2, respectively compared to the treatment F_0. The highest straw yield (1.19 t ha^{-1}) and the biological yield (5.47 t ha^{-1}) were obtained under the treatment F_1 and F_2, respectively. At 5% level of significance, the crop attributes and yields under treatments F_0, F_1 and F_2 were statistically dissimilar.

Interaction effects of irrigation and fertilizer on growth and yield

The interaction effect of irrigation and fertilizer on the crop attributes and yields was significant under most treatment combinations (Table 2). The highest number of plants (271.7) was obtained under the treatment combinations I_3F_2 and the lowest number of plants (181.3) was obtained under the treatment combinations I_2F_0. The tallest plant of 79.11 cm was obtained under I_2F_2 and the plant heights increased by 60.02% and 24.72% in I_2F_2 compared to that in I_1F_0 and I_3F_2, respectively. The highest LAI (3.71) was found under the treatment combination I_3F_2 and the lowest LAI (1.06) was found under the treatment combination I_1F_0. The highest number of spikes (4599.0) and spikelet (13240.0) per square meter area was both found in the treatment combination I_2F_2. The highest 1000-grain weight of 52.18 g was obtained with the treatment combination I_3F_1 and the 1000 grain weight increased by 16.11% in the treatment combination I_3F_1 compared to the treatment combination I_2F_0. The treatment combination I_1F_2 produced the highest grain yield of 4.62 t $ha^{-1}$and the grain yield increased by 220.83% and 10.00% under I_1F_2 compared to that under I_1F_0 and I_3F_2. The highest straw yield (1.28 t ha^{-1}) and the biological yield (5.66 t ha^{-1}) were obtained under the treatment combination $I_1F_1$and I_1F_2, respectively. The biological yield increased by 226.60% under the combination I_1F_2 compared to that under I_2F_0.

Effect of irrigation on harvest index and water use efficiency

The irrigation treatments employed significant influence on the harvest index (HI), water use efficiency for grain production (WUEg) and biomass production (WUEb) of wheat (Table 3). The harvest index (HI) increased by 1.67 and 14.22% in I_1 and I_2, respectively compared to the treatment I_3. As compared in Table 3, wastewater irrigation significantly reduced the harvest index (HI) of wheat. The observed HI implies that mixed water contributed more in producing straw yield than in producing grain yield. The highest WUEg (194.20 $kg^{-1}ha^{-1}cm^{-1}$) and WUEb (264.80 $kg^{-1}ha^{-1}cm^{-1}$) was both obtained under treatment I_3. The water use efficiency for biomass production, WUEb, increased by 10.90 and 19.46% in I_1 and I_3, respectively compared to the treatment I_2. Raw wastewater supplied nutrients to the plants, which contributed increasing grain yield in treatment I_3. Consequently, the water use efficiency was higher under the treatment I_3 than the treatments I_1 and I_2.

Table 3. Harvest index (HI), water use efficiency for grain production (WUEg) and biomass production (WUEb) of wheat under three irrigation and three fertilizer treatments, and their interactions

Treatment	Harvest index (%)	WUE_g ($kg^{-1}ha^{-1}cm^{-1}$)	WUE_b ($kg^{-1}ha^{-1}cm^{-1}$)
I_1	70.69^B	171.3^B	245.1^B
I_2	79.42^A	175.3^B	221.0^C
I_3	69.53^B	194.2^A	264.8^A
CV (%)	8.63	2.73	3.49
$LSD_{0.05}$	6.31	4.87	8.41
F_0	71.98^B	102.9^C	146.6^C
F_1	66.92^B	154.6^B	229.2^B
F_2	80.74^A	283.3^A	355.1^A
CV (%)	8.63	2.73	3.49
$LSD_{0.05}$	6.31	4.87	8.41
I_1F_0	65.38^{BC}	92.60^G	141.3^F
I_1F_1	65.01^{BC}	151.2^E	232.4^C
I_1F_2	81.68^A	270.2^C	361.5^A
I_2F_0	87.05^A	97.20^G	112.3^G
I_2F_1	67.60^{BC}	144.3^E	210.4^D
I_2F_2	83.62^A	284.5^B	340.2^B
I_3F_0	63.50^C	119.0^F	186.1^E
I_3F_1	68.15^{BC}	168.3^D	244.8^C
I_3F_2	76.93^{AB}	295.2^A	363.5^A
CV (%)	8.63	2.73	3.49
$LSD_{0.05}$	10.93	8.44	14.56

Common letter(s) within the same column do not differ significantly at 5% level of significance analyzed by Duncan's Multiple Range Test

Effect of fertilizer on harvest index and water use efficiency

As compared in Table 3, the application of fertilizer exerted significant influence on the harvest index (HI), water use efficiency for grain production (WUEg) and biomass production (WUEb) of wheat. Treatment F_2 provided the highest HI of 80.74% and F_1 provided the lowest HI of 66.92%. The harvest index increased by 20.65 and 7.56% in the treatments F_0 and F_2, respectively compared to the treatment F_1. The water use efficiency that demonstrates the productivity of water in producing crop yields significantly differed among the three fertilizer treatments both for grain and biomass production. The highest water use efficiency for grain production, WUEg (283.3 $kg^{-1}ha^{-1}cm^{-1}$), was obtained under full dose fertilizer application (F_2) and the water use efficiency for grain production increased by 50.24 and 175.32% under F_1 and F_2, respectively compared to F_0. The highest water use efficiency for biomass production, WUEb (355.1 $kg^{-1}ha^{-1}cm^{-1}$), was obtained under F_2 and the water use efficiency increased by 56.34 and 142.22% under the treatments F_1 and F_2, respectively compared to that under the treatment F_0. Both water use efficiencies increased significantly with the increasing quantity of fertilizer application.

Table 4. Some important quality parameters of irrigated soil under three irrigation and three fertilizer treatments, and their interactions for wheat production

Treatment	EC (dS m^{-1})	pH	OC (%)	Total N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
I_1	0.191^A	8.21^A	0.31^A	0.045^A	7.10^A	45.3^A	313.8^A	101.6^A
I_2	0.193^A	8.09^B	0.38^A	0.040^A	6.26^B	42.0^A	330.9^A	76.6^A
I_3	0.227^A	8.11^B	0.38^A	0.045^A	8.32^C	44.0^A	309.0^A	111.3^A
$LSD_{0.05}$	0.07	0.08	0.21	0.04	1.82	22.3	162.2	67.6
F_0	0.195^A	8.01^B	0.31^A	0.032^A	6.96^B	42.1^A	305.2^A	80.2^A
F_1	0.207^A	8.12^A	0.33^A	0.036^A	7.09^A	44.4^A	327.5^A	103.5^A
F_2	0.203^A	8.14^A	0.38^A	0.050^A	7.37^A	43.1^A	308.3^A	89.0^A
$LSD_{0.05}$	0.06	0.06	0.17	0.03	1.48	18.2	132.5	55.3
I_1F_0	0.179^A	8.01^B	0.24^A	0.029^A	6.41^B	45.09^A	310.1^A	98.9^A
I_1F_1	0.203^A	8.19^A	0.25^A	0.031^A	6.62^A	46.7^A	313.1^A	103.8^A
I_1F_2	0.183^A	8.20^A	0.37^A	0.059^A	7.58^A	44.0^A	314.6^A	97.9^A
I_2F_0	0.177^A	8.01^B	0.35^A	0.036^A	6.01^B	38.5^A	374.9^A	74.1^A
I_2F_1	0.183^A	8.06^B	0.37^A	0.037^A	6.37^A	38.7^A	371.2^A	96.7^A
I_2F_2	0.206^A	8.11^A	0.38^A	0.043^A	6.16^A	45.3^A	290.6^A	56.6^A
I_3F_0	0.250^A	8.09^B	0.37^A	0.044^A	8.07^B	43.1^A	296.8^A	108.6^A
I_3F_1	0.234^A	8.11^A	0.38^A	0.041^A	8.26^A	48.0^A	298.3^A	110.0^A
I_3F_2	0.225^A	8.12^A	0.38^A	0.048^A	8.37^A	40.0^A	319.6^A	112.6^A
$LSD_{0.05}$	0.10	0.11	0.30	0.05	2.57	31.5	229.4	94.9

Interaction effects of irrigation and fertilizer on harvest index and water use efficiency

The interaction effects of irrigation and fertilizer exerted significant influence on the harvest index (HI), water use efficiency for grain production (WUEg) and biomass production (WUEb) of wheat in most treatment combinations (Table 3). Treatment combination I_2F_0 provided the highest HI of 87.05% and I_3F_0 provided the lowest HI of 63.50%. The treatment combinations, I_1F_2, I_2F_0, I_2F_2, and I_3F_2 are identical in providing harvest index. The highest water use efficiency for grain production, WUEg (295.2 $kg^{-1}ha^{-1}cm^{-1}$), was obtained under the treatment combination I_3F_2 and the lowest WUEg (92.60 $kg^{-1}ha^{-1}cm^{-1}$) was obtained under the treatment combination I_1F_0. The water use efficiency for grain production increased by 218.8% under I_3F_2 compared to that under I_1F_0. The treatment combination I_3F_2 provided significantly higher WUEg than other treatment combinations. The highest water use efficiency for biomass production, WUEb (363.50 $kg^{-1}ha^{-1}cm^{-1}$), was obtained under I_3F_2 and the lowest WUEb (112.30 $kg^{-1}ha^{-1}cm^{-1}$) was obtained under I_2F_0. The water use efficiency for biomass production increased by 223.69% under I_3F_2 compared to that under I_2F_0.

Effect of irrigation and fertilizer on soil quality

The quality parameters of the soils under various irrigation and fertilizer treatments are given in Table 4. For the effect of irrigation treatments, the raw wastewater irrigation produced the highest values of EC (0.227 dS m^{-1}), OC (0.38 %), P (8.32 ppm) and Mg (111.30 ppm). The mixed water irrigation produced the lowest values of pH (8.09), total N (0.040 %), P (6.26 ppm), K (42.0 ppm) and Mg (76.60 ppm) and the fresh water irrigation produced the lowest values of EC (0.191 dS m^{-1}) and OC (0.31 %). For the effect of fertilizer treatments, the highest values of pH (8.14), OC (0.38 %), total N (0.050 %) and P (7.37 ppm) were recorded under full dose fertilizer application and the highest values of EC (0.207 dS m^{-1}), K (44.4 ppm), Ca (327.5 ppm) and Mg (103.50 ppm) were recorded under half dose fertilizer application. The lowest values of EC (0.195 dS m^{-1}), pH (8.01), OC (0.31 %), total N (0.032 %), P (6.96 ppm), K (42.1 ppm), Ca (305.2 ppm) and Mg (80.20 ppm) were recorded under no fertilizer application. For the interaction effects between irrigation and fertilizer, the highest values of EC (0.250 dS m^{-1}), pH (8.20), OC (0.38 %), total N (0.059 %), P (8.37 ppm), K (48.0 ppm), Ca (374.9 ppm) and Mg (112.60 ppm) were recorded under the treatment combinations I_3F_0, I_1F_2, I_3F_2, I_1F_2, I_3F_2, I_3F_1, I_2F_0 and I_3F_2, respectively. The lowest values of EC (0.177 dS m^{-1}), pH (8.01), OC (0.24 %), total N (0.029 %), P (6.01 ppm), K (38.5 ppm), Ca (290.60 ppm) and Mg (56.60 ppm) were recorded under the treatment combinations I_2F_0, I_1F_0, I_1F_0, I_1F_0, I_2F_0, I_2F_0, I_2F_2 and I_2F_2, respectively. Both the irrigation and fertilizer treatments and their combinations did not cause any significant change in the quality parameters of the soils, except soil pH and phosphorus (P) content of the soils. Irrigation by dairy wastewater significantly reduced soil pH, the mixed water and raw wastewater however employed identical effect on soil pH. Wastewater irrigation also caused significant difference in soil P content, raw wastewater added more phosphorus (P) in the irrigated soils. These results indicate that raw wastewater supplied more nutrients to the soil and the soil was moderately alkaline. So, irrigation by wastewater did not significantly alter the quality parameters of the irrigated soil.

Conclusions

Wastewater contained different nutrients and organic matter, which optimistically contributed to the growth and yield attributes of wheat. The raw wastewater irrigation produced the highest grain, straw and biological yields. The 1000 grain weight and water use efficiencies for grain and biomass production were also obtained maximum under raw wastewater irrigation. For the interaction effects between irrigation and fertilizer, the maximum grain yield, 1000 grain weight and water use efficiency for grain production were obtained under fresh water irrigation with full dose fertilizer application, wastewater irrigation with half dose fertilizer application and wastewater irrigation with full dose fertilizer application, respectively. On the other hand, the lowest grain yield and water use efficiency for grain production were obtained under fresh water irrigation with no application of fertilizer. Irrigation by the raw wastewater did not significantly alter the quality parameters of the irrigated soil. So, it is concluded that the dairy farm's wastewater has good potential to be used as a source of irrigation and fertilizer in the wheat field without any hazard of the soil health.

References

BARC (Bangladesh Agricultural Research Council). 2005. Soil fertility status of different agroecological zones, *BARC Soils Publication,* 45: 15-32.

BBS (Bangladesh Bureau of Statistics). 2011. Year Book of Agricultural Statistics of Bangladesh.Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

Buechler, S. 2004. A Sustainable Livelihoods Approach for Action Research on Wastewater Use in Agriculture, In: C. Scott. N. Faruqui and L. Rachid-Sally (Eds.), Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities, Wallingford. IJK: CAB International in Association with International Water Management Institute and International Development Research Center, pp. 25-40.

ESCAP (Economic and Social Commission for Asia and the Pacific). 2000. Human Resources Development Section, Social Development Division, Bangkok 10200, Thailand.

Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research, Wiley, New York, USA, 680 p.

Honsan, H.; Bolang, N. E. and Anderson, R. G. 1982. Wheat: the third world food, West View Press Inc. Boulder, Colorado, USA, 13 p.

Munir, J.; Rusan, M.; Hinnawi, S. and Rousan, L. 2006. Long-term effect of wastewater irrigation of foragecrops on soil and plant quality parameters, International Conference on Sustainable WaterManagement, Rational Water Use, Wastewater Treatment and Reuse, Marrakech, Morocco.

Razzaque, M. A. and Hossain, A. B. S. 1990. The wheat development programme in Bangladesh: Wheat for the nontraditional warm areas, *A Proceeding of International Conference CIMMYT,* Mexico, pp. 44-54.

Russell, D. F. and Eisensmith, S. P. 1983. MSTAT-C. Crop Soil Science Department, Michigan State Univ., USA.

Virto, I.; Bescansa, P.; Imaz, M. J. and Enrique, A. 2006. Soil quality under food processing wastewater irrigation in semi-arid land, northern Spain: aggregation and organic matter fractions, *J. Soil and Water Con.* Ankeny, 61(6): 398-407.

Wilcox, L. V. 1955. Classification and Use of Irrigation Water, United States Department of Agriculture, Circular No. 969, Washington D. C., 19 p.