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Performance of Wheat in Five Soils of Different Textures under Freshwater and Wastewater Irrigation

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Abstract

This study investigated the effects of five soils of different textures on wheat cultivation under irrigation with freshwater (FW) and municipal wastewater (WW). The experimental design was a split-plot with irrigation water quality as main factor and soil texture as sub-factor in three replications. These factors respectively comprised 2 and 5 treatments. Soil texture significantly ($p \leq 0.05$) influenced plant height, leaf area index (LAI), spike length, number of grains per spike, above ground dry matter (ADM)**,** grain yield, straw yield and biomass yield of wheat in most cases both under FW and WW irrigation. The harvest index (HI) of wheat responded significantly under FW irrigation only. Under FW, treatment T_5 (silt loam) produced the highest grain yield (4.2 t ha^{-1}) followed by T_3 (loam-1) (3.1 t ha^{-1}); the lowest yield (2.0 t ha^{-1}) was in the control treatment, T_1 (loamy sand). Under WW, treatment T_2 (sandy loam) produced the highest grain yield (5.0 t ha^{-1}) followed by T_4 (loam-2) (4.5 t ha^{-1}) both of which are statistically similar; the lowest yield (3.4 t ha^{-1}) was in the control treatment. Treatments T_2 and T_4 provided the highest straw yield (5.6 t ha^{-1}) and treatment T_2 provided the highest biomass yield (10.6 t ha^{-1}), both under WW; both T_2 and T_4 produced invariant biomass yields. Compared to other treatments, T_2 and T_4 gave statistically similar but significantly higher water productivity with respect to straw and grain yields. The lowest water productivity was in treatment T_1 under both water qualities. The results of this study provided sound criteria in selecting suitable lands for wheat cultivation based on irrigation water quality, specifically in alluvial plains where soil texture is prone to high variations. Also, the observed facts of improved productivity of lower quality coarse-textured soils due to addition of easily available and inexpensive clay would provide guidance to bring unproductive sandy soils under production by clay amendments.

Keywords: soil texture, water quality, cereal crop, yield response, water uptake, water productivity

1. Introduction

Irrigation water is becoming scarce with continuous increase in its demand almost everywhere in the world, especially in areas with intensive agricultural practices. Therefore, effective ways of water conservation and management are of primary importance (Al-Rashed and Sherif, 2000; Rahman et al., 2020). Wastewater (e.g., urban wastewater, industrial wastewater) is an unconventional water source, the availability of which is increasing over time due to increasing use of water by the growing population (van Rooijen et al., 2005). Under water-scarce situations, use of wastewater in irrigation is increasingly getting attention because of its increasing supply together with relatively low cost and growing awareness of environmental quality (Mojid et al., 2010). In case of poor fertility soils, wastewater is an important source of nutrients for crop production (Kiziloglu et al., 2007; Mojid and Wyseure, 2013). However, wastewater irrigation may also be hazardous to environment since it contains pollutants, such as macro- and micro-organic and inorganic matters. These constituents of wastewater may harm environment, health, soil, aquifer and crops (Feigin et al., 1990; US Environmental Protection Agency, 1992). Disposal of urban/municipal wastewater is also a problem of increasing importance throughout the world. Consequently, both the necessity to conserve freshwater and to dispose of wastewater safely and economically makes wastewater use in agriculture a very feasible option (Wang et al., 2007). Irrigation with municipal wastewater may permit a more efficient use of water resources and considerably limit environmental pollution due to its direct disposal into surface water bodies. Wastewater irrigation may be a prime solution in the optimization of water resources in water-scarce areas (Virto et al., 2006). Peri-urban agriculture with municipal wastewater is an emerging agricultural practice in Bangladesh (Mojid et al., 2010) and several other countries in the world. Wastewater reuse can reduce fertilizer rates due to its fertilizer contribution in crop production (Tabriz et al., 2011; Biswas et al., 2017; Biswas and Mojid, 2018) and thus can provide a low-cost source of irrigation water (Mojid et al., 2012a).

In many countries, most of the suitable lands have already been brought under agriculture, and cultivation now needs spilling over to marginal lands like hilly lands, charlands and other inferior quality lands. For example, the agriculture in Bangladesh is now being expanded in the large charland areas (river shores) of the country where soils are mostly coarse-textured (e.g., sandy soil). But, soil texture is an important control of water regime and nutrient availability for crop production; it influences the physical, chemical and hydraulic properties of soils. Sandy soils, characterized by less than 18% clay and more than 68% sand in the top 100 cm of the soil profile, occur in every part of the world (van Wambeke, 1992). The productivity of such soils is limited due to their low water holding capacities, high infiltration rates, high evaporation, low fertility levels, very low organic matter content (Mojid, et al., 2012b), and excessive deep percolation losses. These unfavorable soil properties cause low water productivity of the crops cultivated in these soils. Consequently, these soils have not received adequate research attention yet although cultivating sandy soils may be a promising intervention to increase food production in many developing countries like Bangladesh. A significant proportion of such land has been remaining unproductive because of its low fertility. Management of these soils through proper reclamation measures to increase crop productivity adds a great deal to interest in a day wherein the available land area for cultivation is declining all the time in Bangladesh and many other countries in the world.

Addition of fine natural deposits, such as clay and bentonite, can increase productivity of sandy soils by eliminating or minimizing constraints associated with these soils. This proposition is specifically suitable in areas where these amendment materials are available naturally in abundance and inexpensive (Al-Omran et al., 2004). Until now, information on the effects of using clay as an amendment for sandy soils on crop yields, specifically wheat yield, under wastewater irrigation are not available. However, soil texture is an important factor to be considered in wastewater irrigation because soil fertility or soil contamination will depend mainly on soil texture. Therefore, a suitable soil texture for irrigated crops is a concern in wastewater irrigation. If wastewater irrigation could be used for keeping soil productivity sustainable, it would reduce water deficit, increase the overall crop production and thereby provide food security in resource-scarce regions, such as Bangladesh. A comprehensive knowledge of the effects of municipal wastewater on the growth and yield of crops in soils of different textures is necessary before recommending irrigation with wastewater. This study was planned to investigate the impact of five soils of different textures on wheat cultivation under irrigation with municipal wastewater in terms of growth and yield attributes of wheat as well as the yield, and to identify suitable soil texture(s) for wheat cultivation under freshwater and wastewater irrigation.

2. Material and Methods

2.1 Experimental Site

The experiment was done in the central farm of Bangladesh Agricultural University in Mymensingh, Bangladesh (24.75°N latitude, 90.50°E longitude and 18 m a.m.s.l.). The average maximum and minimum air temperatures ranged from 22.2ºC to 30.0ºC and from 10.7ºC to 20.0ºC, respectively, over the experimental period (November through March) in three consecutive cropping seasons (2008–09, 2009–10 and 2010–11). The mean relative humidity, pan evaporation and sunshine varied from 74% to 86%, 1.9 mm to 3.9 mm and 4.3 h to 8.4 h, respectively. An amount of 53-mm rainfall (i.e., 41 mm and 12 mm in December and February, respectively) was recorded over the 2010–11 cropping season with 50.2 mm of effective rainfall. No rainfall occurred over crop cycle in the two previous years.

2.2 Field Plot Preparation

An area of 14 m × 10 m was divided into 3 strips each of them being split in 2 blocks. The distance between the adjacent strips was 2 m and that between the adjacent blocks was 1 m. Each block was split in 5 unit plots of 1 m^2 each. Two adjacent unit plots within a block was 1 m separated. The experimental layout was a split-plot with 10 irrigation water quality and soil texture treatments in 3 replications that gives a total number of 30 plots. In each unit plot, a pit of 60 cm depth and 1 m square area was dug manually with a spade. A polyethylene sheet was placed on the four vertical sides of each pit to prevent lateral seepage of water. All the pits were filled with a mixture of loamy sand collected from river shore and field soils at different ratio to obtain the five different soil textures required in each block (Table 1); this table also contained the average bulk density, saturated hydraulic conductivity, organic matter, electrical conductivity (EC) and pH of the soils. More details on plot preparation are available in the literature (Mojid et al., 2009; Mojid et al., 2012b).

2.3 Experimental Design and Set-Up

Three-year historical data involving irrigation experiments were analyzed with the aim to evaluate the interaction effects of soil texture and irrigation water quality on wheat cultivation. The experimental design was a split-plot with irrigation water quality as the main factor of two levels and soil texture as sub-factor of 5 levels, which gives 10 treatments in 3 replications (Fig. 1). The water quality was composed of freshwater (FW) obtained from a deep borehole well (I_1) and wastewater (WW) from municipal sewage of Mymensingh town (I_2). The soil texture involved loamy sand (control T_1), sandy loam (T_2), loam-1 (T_3), loam-2 (T_4) and silt loam (T_5).

Table 1. Percentage of sand, silt and clay, and textural classes, average bulk density (γ), saturated hydraulic conductivity (K_{sat}), organic matter content (OM), electrical conductivity (EC) and pH of the experimental soils

Treatments	% Sand	% Silt	% Clay	Textural class	γ (g cm^{-3})	K_{sat} (cm h^{-1})	OM (%)	EC (S cm^{-1})	pH
T_1	79.48	14.48	6.04	Loamy sand	1.41	27.36	0.39	11.4	5.99
T_2	54.48	37.02	8.50	Sandy loam	1.37	1.34	0.99	14.9	5.88
T_3	52.72	38.24	9.04	Loam-1	1.38	1.27	0.86	13.3	5.13
T_4	41.00	49.00	10.00	Loam-2	1.36	0.67	1.34	34.1	4.88
T_5	15.00	72.00	13.00	Silt loam	1.28	0.41	1.47	29.8	6.05

Table 2 lists the pertinent chemical constituents of freshwater and wastewater used for irrigating the experimental wheat plots. It is noted that the concentrations of boron, iron, potassium, nitrate nitrogen, phosphate phosphorus, sodium, lead, copper, zinc and cadmium in wastewater were below their threshold values set by Food and Agriculture Organization (FAO) (1992) for safe use in agriculture, except for manganese. Details of the quality parameters of Mymensingh sewage are found in Mojid et al. (2010). Recommended fertilizer doses for wheat – 120 kg N, 32 kg P, 62 kg K, 20 kg S, 3 kg Zn and 1 kg B per hectare in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and borax, respectively – were used. Two-thirds of urea and the entire doses of the other fertilizers were applied as basal dose. The remaining urea was top dressed before applying the first irrigation. Wheat seeds (cv. *Shatabdi*, @ 120 kg ha^{-1}) were sown at 2–3 cm depth in 20-cm apart rows on 6 December 2008, 6 December 2009 and 24 November 2010. In order to control insect pests, Bavistine (0.9 kg ha^{-1}) and Ridomil Gold (1 kg ha^{-1}) were sprayed before first irrigation.

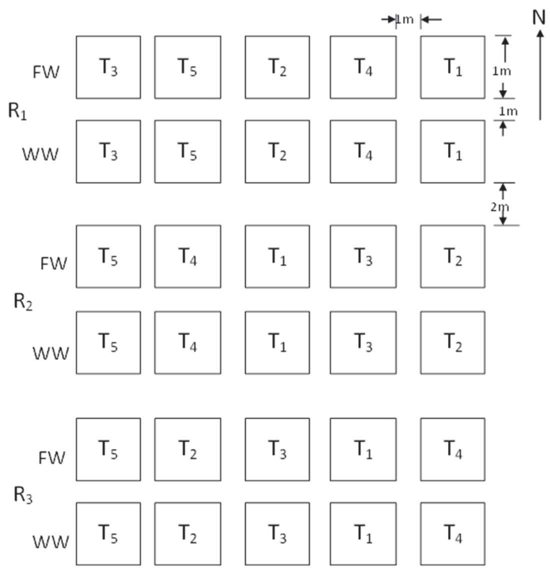

Figure 1. Field layout of the irrigation water quality vs. soil texture experiment executed on the central farm of Bangladesh Agricultural University in Mymensingh, Bangladesh

Table 2. Chemical constituents of freshwater (FW) and wastewater (WW) used for irrigation of experimental plots of wheat at Bangladesh Agricultural University farm, Mymensingh

Water type	Chemical constituents (mg L^{-1}, dS m^{-1} for EC)				
	TN	P	K	EC	pH
FW	1.52 ± 0.03	0.039 ± 0.005	2.35 ± 0.04	0.385 ± 0.017	7.08 ± 0.03
WW	18.39 ± 2.4	4.28 ± 0.64	13.59 ± 1.25	1.049 ± 0.078	7.33 ± 0.12

2.4 Data Recording

Irrigation was scheduled based on crop-water requirement and observation of soil moisture condition. Because of lighter texture, total four irrigations were applied to treatments T_1 (loamy sand), T_2 (sandy loam) and T_3 (loam-1) compared to treatments T_4 (loam-2) and T_5 (silt loam) in which total three irrigations were applied. Soil moisture was measured in the plots with a digital soil-moisture meter (DSMM, General Tools and Instruments) before applying irrigation. Leaf area index (LAI) was determined at 75 days after sowing (DAS) on five representative plants collected from each plot with an LI-3100 AREA METER (LI-Cor. Inc. Lincoln. Nebraska, USA). Total area covered by all five plants was calculated from the planting density. By definition, the LAI was calculated as the ratio of leaf area to the covering ground area. The above ground dry matter (ADM) of the crop was also determined at 75 DAS by collecting five representative plants from each plot. The plants were oven-dried at 60^oC in 72 h and weighed to determine the ADM. The crop was harvested when the spikes were completely ripened. The harvested crop of each plot was bundled separately and tagged. In order to assess the change in soil moisture status during the growing season, the soil-moisture content of each plot was measured immediately after harvesting. Soil-moisture content data, recorded over time, were used to estimate water used by the crop during the growing season. After harvest, different crop attributes, such as the number of total tillers, effective and non-bearing tillers, plant height, spike length, spikelets per spike and grains per spike for each plot were counted. Plant materials were then air-dried. Threshing, cleaning and drying of grains and straws of each plot were done carefully, grain and straw yields being recorded separately. The harvest index (HI) of wheat was determined by the ratio of grain yield to total biomass yield (grain plus straw yield). The water productivity of wheat, defined as the ratio of yield to total amount of water used, was determined both for grain and biomass yields. Root development of wheat in different treatments was measured at the end of the growing season. Just after harvest, roots over three different soil depths (0–15, 15–30 and 30–45 cm) were collected separately by sampling soil columns with a representative area of the soil surface. Roots were obtained after careful soil-washing through a plastic net. They were successively air-dried and oven-dried at 60^oC in 72 h to obtain their mass. The root-density was calculated by dividing the root dry weight by the covering area. The analysis of variance of data obtained was done by using Statistix 10 software package of Analytical Software (2019). Comparison of means of the plant attributes among the factors and treatments was done using Tukey's HSD test at 5% level of significance ($p \leq 0.05$).

3. Results and Discussion

3.1 Growth Attributes of Wheat

Quality of irrigation water affected the plant height, leaf area index, above-ground dry matter and root-density at different depths significantly ($p < 0.05$) except root density at 30–45 cm soil layer (Table 3). WW (I_2) produced significantly taller plants and greater LAI and ADM than FW (I_1), which produced greater root-density than WW. Texture of the soils did not influence plant height and LAI significantly ($p \leq 0.05$) except treatment T_1 (Loamy sand, Table 1), which produced significantly shorter plant and smaller LAI than the other treatments (Table 3). Treatment T_3 (Loam-1, Table 1) produced the tallest plants (84.6 cm) and T_4 (Loam-2) produced the shortest plants (82.9 cm). Treatment T_5 (Silt loam) produced the highest LAI and T_1 produced the least LAI; in general, LAI increased with the increase in clay content of the soils. Lower saturated hydraulic conductivity of the amended soils (T_2–T_5) than the control treatment (T_1) (Table 1) reduced percolation losses of water in the amended treatments. The reduced percolation loss augmented soil-water and nutrient retention with a consequent increase in soil fertility, which enhanced the growth of wheat leaves and, consequently, caused increase in LAI. ADM of wheat increased significantly as texture of the soils became finer except treatment T_5, which produced significantly higher ADM than treatment T_1 but lower ADM than the other treatments.

Soil texture significantly influenced root-growth at the top 0–15 cm soil layer; the coarser the texture the higher was the root-density. Most of the roots were obtained in the top 0–15 cm soil layer; only small fractions of roots were in the lower layers. Soil texture exerted only minimal influence on root-growth at the lower soil layers. The topsoil retained most of the nutrients both from the applied fertilizers and WW and promoted more extensive growth of roots in the upper soil profile compared to the lower one (Table 3). Increased root growth with increasing fertilizer was also reported by Li et al. (2004). The three coarser-textured soils (T_1, T_2 and T_3) provided significantly higher root-density compared to the two finer-textured soils (T_4 and T_5) (Table 3). Lesser amount of irrigation water could be applied in coarser-textured soils with a quicker water loss through percolation and evaporation compared to the finer-textured soils. Consequently, plants in coarse-textured soil (e.g., T_1) generally suffered from water stress for a while before each irrigation application. Although irrigation was scheduled based on soil-water status, the allowable soil-water deficit was higher in coarse-textured soils compared to that in fine-textured soils. The extensive root system helped the plants to take up more water and nutrients from the soil than did the narrow root system. The plants thus compensated, to some extent, water deficit by increasing water-uptake through additional rooting in coarse-textured soils.

The interaction effects of irrigation water quality and soil texture were significant on the growth attributes in most cases except for the root-density at two lower soil layers, 15–3 cm and 30–45 cm (Table 3). The plant height ranged from 75.7 cm (I_1T_1) to 89.7 cm (I_2T_2) among different (10) combinations of irrigation water quality and soil texture. Only a few treatment combinations exerted significant effect on LAI. The highest LAI was obtained in T_2 under FW irrigation (3.6) and in T_5 under WW irrigation (2.7) and the overall lowest LAI in T_1 under WW irrigation (1.2). These observations in LAI are in agreement with the findings of Mojid et al. (2012c) who obtained leveling-effects of irrigation water quality when it contained more than 75% WW; the influence of WW on LAI reached a plateau when irrigation was applied entirely with WW (Fig.5 in Mojid et al., 2012c). The leveling-off of irrigation on LAI occurred due to over-fertilization of wheat with recommended fertilizer doses in combination with fertilizer contribution of WW in their experiments. This effect also occurred in our study in the plots irrigated with WW; with recommended fertilizer doses and fertilizer contribution from WW the plots provide smaller LAI than those under FW irrigation. Most treatment combinations exerted significant effect on ADM. The smallest ADM was in I_1T_1 and largest ADM in I_2T_4. Table 3 demonstrates that WW contributed more in increasing plant height and ADM than FW in all five soil textures. The textural effects on plant height and ADM were more systematic under FW than under WW; in general, the coarser the soil the smaller were these plant attributes. The trend of root-growth in the top soil layer in relation to irrigation water quality was opposite to that of plant height and ADM. FW in combination with the soil textures produced more roots compared to the combination of WW and soil textures. The interaction of irrigation water quality and soil texture did not reveal any systematic textural effect on root density. Since the root density in the entire root zone was dominated by that in the top layer, the interaction effect of irrigation water quality and soil texture was also similar to that in the top soil layer.

Table 3. Quantity of applied irrigation, average plant height, leaf area index (LAI), above-ground dry matter (ADM) and root density of wheat as influenced by irrigation water quality, soil texture and their interaction over three cropping seasons in Mymensingh, Bangladesh

Treatment	Irrigation (cm)	Plant height (cm)	LAI at 75 DAS	ADM at 75 DAS	Root density (kg m^{-2}) at depth			
					0–15 (cm)	15–30 (cm)	30–45 (cm)	0–45 (cm)
Irrigation								
I_1 (FW)	–	80.5a	1.84a	3.3a	0.44a	0.11a	0.04a	0.58a
I_2 (WW)	–	85.0b	2.92b	6.0b	0.31b	0.07b	0.04a	0.42b
Soil texture								
T_1	22.7	79.1a	1.72a	3.6d	0.41a	0.10a	0.04a	0.55a
T_2	20.7	84.2b	2.46b	4.6bc	0.39ab	0.11a	0.05a	0.54a
T_3	18.2	84.6b	2.37b	5.2ab	0.39ab	0.09a	0.04a	0.52ab
T_4	15.0	82.9b	2.61b	5.5a	0.35bc	0.08ab	0.04a	0.48b
T_5	13.8	82.9b	2.74b	4.3cd	0.31c	0.06b	0.04a	0.41c
Irrigation × Soil texture								
I_1T_1	22.7	75.7e	2.3bc	1.9f	0.46ab	0.13a	0.04a	0.63bc
I_1T_2	20.7	78.7de	3.6c	2.5ef	0.52a	0.13a	0.04a	0.69c
I_1T_3	18.2	82.2bcd	2.6bc	4.3cd	0.45bc	0.1ab	0.04a	0.58ab
I_1T_4	15.0	80.7cd	3.4c	3.6de	0.43bc	0.1ab	0.04a	0.58ab
I_1T_5	13.8	85.1abc	2.8c	3.9d	0.31de	0.06b	0.04a	0.42a
I_2T_1	22.7	82.6bcd	1.2a	5.2cd	0.35bcd	0.08ab	0.05a	0.48ab

I_2T_2	20.7	89.7a	1.3a	6.8ab	0.26e	0.08ab	0.06a	0.39a
I_2T_3	18.2	86.9ab	2.2bc	6.0bc	0.32bcde	0.09ab	0.05a	0.46ab
I_2T_4	15.0	85bc	1.9ab	7.3a	0.27e	0.07b	0.04a	0.38a
I_2T_5	13.8	80.7cde	2.7c	4.8cd	0.32cde	0.06b	0.03a	0.41a

Common letter(s) within the same column do not differ significantly at 5% level of significance. D.f. regarding the split-plot design: Erro1 = 2; Interaction Factor 1 x Factor 2: 4; Error 2: 16. Total 53-mm rainfall (41 mm in December and 12 mm in February) occurred in 2010–11 cropping season; no rainfall occurred over crop cycles in the two previous years.

Addition of even a small quantity of amendment (as in T_2) remarkably improved soil-water retention; the rate of this improvement, however, decreased with further increase in amendment. Reduced evaporation rate due to higher water-holding capacity of clay than sand also helped increasing soil-water content in the amended treatments. The water content at field capacity increased with increasing clay content of the treatments following a strong linear relation ($r^2 = 0.93$). The amendment helped increasing the field capacity by 78%, 80% and 91% in treatment T_2, T_3 and T_4, respectively compared to T_1 (Mojid et al., 2012b). The WW contained N, P and K at concentration of 17.5 mg L^{-1}, 3.7 mg L^{-1} and 10.3 mg L^{-1}, respectively and added these nutrients to the irrigated soils and elevated their fertility. Increased nutrients (e.g., N, P, K) in WW compared to FW improved fertility of the soils under irrigation with WW and enhanced vegetative growth of wheat with the consequent increase in plant height, LAI and ADM of the crop (Table 3). However, the elevated quantity of available water associated with more nutrient retention in finer-textured soils generally enhanced crop growth attributes more compared to that of the coarse-textured soils.

3.2 Yield Attributes of Wheat

Irrigation water quality influenced significantly the yield attributes of wheat, such as spike density, spike length, spikelets per spike and grains per spike, with WW producing more spikes per unit area, longer spike, more spikelets per spike and more grains per spike (Table 4). The weight of 1000 grains of wheat remained unaffected by irrigation water quality. Soil texture exerted significant influence on spikes per square meter and spike length for most treatments and on spikelets per spike and 1000-grain weight for a few treatments; grains per spike remained unaffected by the soil textures. Table 4 demonstrates that all the yield attributes improved as texture of the soils became finer. Poor nutrient availability and water-retention capacity of loamy sand (T_1) and sandy loam (T_2) compared to the other soil textures suppressed the yield attributes in these treatments.

Table 4. Quantity of applied irrigation, average number of spikes per square meter, spike length, spikelets per spike, grains per spike and 1000-grain weight of wheat as influenced by irrigation water quality, soil texture and their interaction over three cropping seasons in Mymensingh, Bangladesh

Treatment	Irrigation (cm)	Spikes (m^{-2})	Spike length (cm)	Spikelets ($spike^{-1}$)	Grains ($spike^{-1}$)	1000-grain weight (g)
	Irrigation					
I_1 (FW)	–	208.5a	12.9a	15.7a	36.8a	47.9a
I_2 (WW)	–	267.3b	13.5b	16.8b	39.2b	47.4a
			Soil texture			
T_1	22.7	199.2c	12.7b	15.1b	36.3a	46.6b
T_2	20.7	243.2ab	13.2ab	16.0ab	37.1a	46.2b
T_3	18.2	235.8b	13.5a	16.7a	38.9a	49.8a
T_4	15.0	248.6ab	13.2ab	16.6a	39.1a	47.5b
T_5	13.8	262.6a	13.5a	16.8a	38.7a	47.9ab
			Irrigation × Soil texture			
I_1T_1	22.7	177.0a	12.3ab	14.6c	33.6de	44.5a
I_1T_2	20.7	195.9ab	12.5ab	14.2c	33.1e	46.5abc
I_1T_3	18.2	221.7bcd	13.3bc	17.3ab	39.4abc	49.4bc
I_1T_4	15.0	199.2ab	12.8ab	15.4bc	36.4bcde	49.1bc
I_1T_5	13.8	248.6cde	13.8c	17.3ab	41.5ab	47.3abc
I_2T_1	22.7	221.3abc	13.0abc	15.6bc	39.0abc	48.7abc

I_2T_2	20.7	290.6e	13.9c	17.9a	41.1abc	46.0ab
I_2T_3	18.2	249.9cde	13.7bc	16.2abc	38.4abcd	50.3c
I_2T_4	15.0	298.0e	13.6bc	17.9a	41.9a	45.9ab
I_2T_5	13.8	276.6de	13.1abc	16.4abc	35.9cde	48.6abc

Common letter(s) within the same column do not differ significantly at 5% level of significance. D.f. regarding the split-plot design: Erro1 = 2; Interaction Factor 1 x Factor 2: 4; Error 2: 16.

The interaction effects of irrigation water quality and soil texture on the yield attributes of wheat were significant for most treatment combinations (Table 4). FW in combination with loamy sand (I_1T_1) and sandy loam (I_1T_2) produced the poorest yield attributes, while WW in combination with loam-2 (I_2T_4) produced the most improved spikes per square meter, spikelets per spike and grains per spike. The longest spike was obtained in I_2T_2 treatment combination, which produced statistically similar spike length to I_2T_3, I_2T_4 and I_2T_5 treatment combinations. The 1000-grain weight was the highest in I_2T_3. WW in combination with the five soil textural treatments provided more improved yield attributes of wheat compared to FW in combination with the soil treatment, further implying that WW contributed more in improving the yield attributes compared to FW. Table 4 also demonstrates that the yield attributes generally continued increasing as the texture of the soil became finer under irrigation with FW; however, such trend was not evident under irrigation with WW. These results revealed that under FW irrigation and recommended fertilizer doses the overall fertility levels of the soil textural treatments did not reach their possible maximum limits in all treatments for fertilizing wheat. Although irrigation with WW contributed increasingly on the growth attributes of wheat as soil texture became finer, it did not contributed in the same way on the yield attributes.

3.3 Yield and Harvest Index of Wheat

As given in Table 5, irrigation water quality influenced significantly wheat traits like grain yield, straw yield and biomass yield; harvest index remained unaffected. Irrigation with WW improved these wheat traits irrespective of soil textural differences. The effect of soil texture was statistically similar on these traits of the crop except treatment T_1 (loamy sand, Table 1), which produced significantly lower grain, straw and biomass yields compared to the other treatments (T_2–T_5). However, these three yield measures of wheat increased with the increase of clay content in the treatments. The field soil (T_5) contained four times higher organic carbon (0.85%) than the control (T_1). Consequently, the amendment considerably elevated organic carbon (hence organic matter) in treatments T_2, T_3 and T_4 compared to T_1. Poor yields in T_1 could be explained by lower organic matter, other nutrients (N, P and K) and water contents in this treatment. Reduced wheat yield under lower soil-water content was also reported by Simsek et al. (2005).

Table 5. Quantity of applied irrigation, average grain, straw and biomass yields, harvest index (HI), and water productivity resulting from grain (WP_g) and biomass yields (WP_b) as influenced by irrigation water quality, soil texture and their interaction over three cropping seasons in Mymensingh, Bangladesh

Treatment	Irrigation (cm)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biomass yield (t ha^{-1})	HI (-)	WP_g (kg m^{-3})	WP_b (kg m^{-3})
Irrigation							
I_1 (FW)	–	2.88a	3.61a	6.48a	0.44a	1.25a	2.84a
I_2 (WW)	–	4.12b	4.83b	8.95b	0.46a	2.28b	4.99b
Soil texture							
T_1	22.7	2.70a	3.31a	6.02a	0.44a	1.20c	2.75a
T_2	20.7	3.66b	4.44b	8.10b	0.44a	1.84ab	4.05b
T_3	18.2	3.47b	4.16b	7.62b	0.45a	1.68b	3.78b
T_4	15.0	3.72b	4.54b	8.26b	0.46a	1.99ab	4.45b
T_5	13.8	3.94b	4.64b	8.59b	0.46a	2.11a	4.55b
Irrigation × Soil texture							
I_1T_1	22.7	2.0f	2.8f	4.7e	0.42ab	0.8f	1.94f
I_1T_2	20.7	2.3ef	3.3ef	5.6de	0.41b	0.9ef	2.28f
I_1T_3	18.2	3.1de	4.0cde	7.0cd	0.44ab	1.3de	3.04def
I_1T_4	15.0	2.9def	3.4def	6.3de	0.46ab	1.2ef	2.79ef

I_1T_5	13.8	4.2abc	4.6bcd	8.7bc	0.47a	2.0cd	4.16bcd
I_2T_1	22.7	3.4cde	3.9cde	7.3cd	0.47ab	1.6de	3.55cde
I_2T_2	20.7	5.0a	5.6ab	10.6a	0.47ab	2.8a	5.82a
I_2T_3	18.2	3.8bcd	4.4cd	8.2c	0.47ab	2.0cd	4.51bc
I_2T_4	15.0	4.5ab	4.7abc	10.2ab	0.45ab	2.7ab	6.12a
I_2T_5	13.8	3.7bcd	5.6a	8.4bc	0.45ab	2.2bc	4.94ab

Common letter(s) within the same column do not differ significantly at 5% level of significance. D.f. regarding the split-plot design: Erro1 = 2; Interaction Factor 1 x Factor 2: 4; Error 2: 16.

The interaction effect of irrigation and soil texture under recommended fertilizer dose was more favorable for wheat yields (grain, straw and biomass yields) when irrigation was done with WW compared to irrigation with FW. Irrigation with WW produced greater grain, straw and biomass yields in the corresponding soil treatments when compared with irrigation with FW (Table 5). Harvest index, HI, remained mostly unaffected by the interaction effect of irrigation water quality and soil texture. Like yield attributes, FW in combination with loamy sand (I_1T_1) produced the lowest yields of wheat that were similar to the yields under the combination of FW and sandy loam (I_1T_2) but significantly lower than the yields of other treatment combinations. Treatments T_3, T_4 and T_5 produced statistically similar grain and straw yields under FW irrigation. Inadequate soil water along with reduced nutrient in T_1 retarded physiological processes in the plants and consequently reduced the crop yields. Under FW irrigation, the grain, straw and biomass yields increased as the texture of the soil became finer except the treatment combination I_1T_4, which produced lower yields than the treatment combination I_1T_3. The enhanced vegetative growth in terms of plant height and number of tillers per plant in the amended treatments increased straw yield that, in turn, together with yield attributes, improved the biomass yield. The amendment, however, did not systematically influence the harvest index of wheat. Irrigation with FW in combination with recommended fertilizer dose produced the most improved yield of wheat in silt loam (T_5), thus revealing that this soil texture is the most suitable for wheat cultivation under recommended fertilizer doze and irrigation with FW. The interaction effect of irrigation with WW and soil texture on the yields of wheat had no systematic trend with the texture of the soils except that the treatment combination I_2T_1 produced the lowest yields, which were significantly lower than the yields of other treatment combinations. The highest grain yield was obtained in treatment combination I_2T_2, straw yield in I_2T_2 and I_2T_5, and biomass yield in I_2T_4. The enhanced vegetative growth due to increased soil-water content augmented straw yield, which, together with yield attributing characters, improved the biomass yield. Under WW irrigation, soil texture minimally influenced the HI of wheat. These results again revealed that, under FW irrigation and recommended fertilizer doses, the overall fertility levels of the soil textural treatments did not reach their maximum limits in all treatments for wheat growth, while the fertility levels under irrigation with WW might reach or even exceeded the maximum limits except in the most light-textured soil (T_1). These results are in agreement with the findings of Mojid et al. (2012c) who obtained suppressed grain yield of wheat when the applied irrigation comprised over 75% WW and recommended fertilizer dose was applied.

3.4 Water Productivity of Wheat

Irrigation water quality influenced significantly water productivity of wheat related to grain and biomass yields, with WW providing significantly greater water productivity compared to FW (Table 5). Both water productivity data increased as soil texture became finer since the treatments with high clay content consumed small amount of water. Similar findings were reported by Ismail and Ozawa (2007). Particularly, treatments T_2 to T_5 saved 30% to 60% irrigation water compared to treatment T_1. Irrespective of water quality, loamy sand (T_1) provided the least water productivities of wheat and silt loam (T_5) provided the greatest values. Both water productivities were significantly lower in T_1 treatment than in the other soil treatments. In terms of water productivity related to grain yield, treatment T_5 performed best; this performance was however statistically similar to that of T_4. In terms of water productivity related to biomass yield, the best-performing treatment was also T_5, whose performance was similar to that of treatments T_2, T_3 and T_4.

Soil texture exerted varying degrees of influence on the two water productivity data in different combinations of irrigation water quality and soil texture. WW in combination with soil textures provided higher water productivities related to both grain and biomass yields compared to the corresponding treatment combinations of FW and soil textures. Loamy sand (T_1) in combination with irrigation with FW (I_1T_1) produced the least water productivities, while silt loam (T_5) with FW irrigation (I_1T_5) produced the greatest water productivities. Under FW irrigation, both water productivity data increased as the texture of the soil became finer except treatment T_4, which provided statistically similar but lower water productivities compared to treatment T_3. The highest water productivity for grain production in T_5 revealed that wheat, cultivated under irrigation with FW in combination with the recommended fertilizer doses, most effectively utilized water in grain production. Thus, clay helped conserving soil water and nutrients by improving soil structure that contributed increasing growth and water productivity of wheat. The control treatment always provided the lowest water productivity since irrigation requirement and, hence, total water used in a plot increased with the decreasing clay content of the plot. Under WW irrigation, the treatment combination I_2T_1 provided the least water productivities, which were significantly lower than that under the other treatment combinations. The treatment combination I_2T_2 provided the most improved water productivity related to grain yield and I_2T_4 provided such water productivity related to biomass yield. The interaction effects of irrigation with WW and soil texture did not reveal any systematic trend in relation to textural variations except the loamy sand (T_1), which provided the least water productivity data.

4. Conclusions

Addition of small quantities of clay (2.4–4.0%) through silt loam transformed loamy sand to sandy loam and loam. This amendment improved soil structure, reduced saturated hydraulic conductivity (by reducing the macro pores) of the soil, and increased soil-water and nutrient contents. Consequently, irrigation water quality contributed to wheat cultivation differently following soil texture. Soil-water and organic-matter contents of fine-textured soils were much higher than that of loamy sand. In terms of grain, straw and biomass yields, sandy loam and loam-2 performed the best with high water productivity followed by silt loam irrespective of irrigation water quality; loamy sand performed the least. The least water productivity was obtained in loamy sand while the amended soils could save 30% to 60% of irrigation water. Among the five soil textures, sandy loam and loam appeared the most suitable soil textures for wheat cultivation since they produced more grain and biomass yields compared to loamy sand. The results of this study thus provide information in selecting lands with suitable soil texture for wheat cultivation, specifically in alluvial plains where soil texture varies widely. However, the essence of this study is that amendment of lower quality coarse-textured soils by adding naturally available and inexpensive clay could improve crop productivity through better water regimes and higher nutrient content.

Conflict of interest

The authors declare that there is no conflict of interest.

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