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Growth, yield and water use efficiency of wheat in silt loam-amended loamy sand

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Abstract

This study investigated the growth, yield and water use efficiency of wheat in five soil textures obtained by amendment. This was done by executing field experiments that consisted of five soil treatments with 3 replications. The treatments were: (i) T_1: loamy sand, (ii) T_2: sandy loam, (iii) T_3: loam 1, (iv) T_4: loam 2 and (v) T_5: silt loam (used as amendment). Wheat was cultivated with four irrigations and recommended dose of fertilizers. Increased porosity and pore size distribution in the finer-textured soils improved soil structure with a consequent improvement in soil physico-chemical properties. The saturated hydraulic conductivity decreased significantly, while field capacity and water retention increased considerably as the textured of the soil become finer. The improved water and organic matter contents in treatments T_2 – T_5 stimulated growth of wheat and caused significant (p = 0.05) increase in leaf area index, plant height, number of total and effective tillers per plant, spike length, number of spikelets per spike, number of grains per spike, grain yield, and biological yield compared to T_1. The roots grew and branched profusely in the soil of high moisture and organic matter content; the largest root biomass was in the upper 20 cm of soil depth in all the treatments. The enhanced vegetative growth in terms of plant height and number of tillers per plant helped increasing straw yield, which together with yield attributing characters, improved the biological yield in the finer textured soils. Treatments T_2 – T_4 produced 1.2 to 2.8 times higher grain and biological yields compared to T_1. The irrigation requirement and total water used in a treatment increased as the texture of a soil became coarser. Treatment T_2 saved 1 to 13.6% and T_3– T_5 saved 29.4 to 57.5% irrigation water compared to T_1. T_1 provided the lowest water use efficiency, which increased gradually as the texture became finer. All treatments except T_1 maintained improved water regime.

Keywords: Clay content, Soil water, Wheat cultivation, Growth and yield, Water use efficiency

Introduction

Soil texture controls the water and fertility status of a soil for crop production. It influences many properties of a soil such as hydraulic conductivity, water holding capacity, aeration, susceptibility to erosion, organic matter content, cation exchange capacity, pH buffering capacity, salinity, soil structure and soil tilth. The balance of air to water, particularly the amount of water available to plant, is an important factor in assessing soil fertility. Soil structure that is controlled by the size and distribution of pores has a great influence on the storage and supply of nutrients for growth and yield of plant. At present, a significant proportion of agricultural land is remaining unproductive because of the fertility problems of the soil caused by, mainly, inappropriate soil management practices. Proper management of poor soils can enhance further increase in agricultural production. Sandy soils characterized by less than 18% clay and more than 68% sand in the first 100 cm of the soil depth are the poor soils that occur in many parts of the world (van Wambeke, 1992). These soils hold little water as the large pore spaces allow water to drain freely from the soil. The productivity of these soils is limited by low water holding capacities, high infiltration rates, high evaporation, low fertility levels, very low organic matter content, and excessive deep percolation losses. The water use efficiency of the crops cultivated in these soils is low. Clay soils, on the other hand, although exhibit opposite magnitudes of these properties are also not suitable for most agricultural crops.

About two-thirds of the world's population lives on wheat (Honsan *et al.*, 1982), which ranks first both in acreage and production (UNDP and FAO, 1988). Irrigation plays a vital role for good growth and development of wheat (Razzaque *et al.*, 1992). Therefore, practices that increase water use efficiency and reduce excessive amount of water applied to the field are important in water management. It is thus important to identify the suitable soil texture for its cultivation. However, results in this regard are still inadequate and sparse implying that more studies to generate comprehensive set of information are needed. This study generated information about the effects of amended soil texture on water and fertility regimes and thereby on the production potentiality of wheat in such soils. This was done by: (i) evaluating the physico-chemical properties of five different textured soils, and (ii) investigating the growth, yield and water use efficiency of wheat in these soils.

Materials and Methods

Site description

The field experiments were done at the experimental farm (24.75^{o}N latitude, 90.50^{o}E longitude) of the Bangladesh Agricultural University at Mymensingh, Bangladesh during the wheat growing seasons (December – March) of 2007–2008 and 2008–2009. The sub-tropical climatic conditions of the study area are characterized by an average annual rainfall of 2420 mm and mean annual temperature of 25.4 °C. The rainfall is concentrated over the months of May to September. The summer (March – September) is hot and humid and the winter (November – February) is moderate with occasional rainfall. The maximum temperature during the warm months of April – May varies from 28.8 to 35.9 ^{o}C while January is the coldest month. The minimum temperature varies from 9.6 to 12.9 ^{o}C.

Experimental treatments

Five soils: (i) T_1: loamy sand, (ii) T_2: sandy loam, (iii) T_3: loam 1, (iv) T_4: loam 2 and (v) T_5: silt loam were selected as treatments. Treatments T_2, T_3 and T_4 were realized by mixing approximately 75, 50 and 25% (by volume) loamy sand to the natural field soil (silt loam, T_5). The treatments were replicated thrice and the experiments were set up in Randomized Complete Block Design (RCBD). Three blocks, each of size 15 m × 1 m, were selected within an area of 15 m × 9 m in the experimental field. Each block was subdivided into 5 unit plots; the size of the unit plot was 1 m^2. The distance both between the adjacent blocks and adjacent plots was 2 m. A pit of 1 m^2 area and 0.6 m deep was dug in each plot. The soil, dug out from the plots, was thoroughly mixed manually. Loamy sand collected from the river Brahmaputra was dried in the sun. Erecting polyethylene sheet on the sides to prevent seepage, 3 pits were filled with the loamy sand (T_1), 3 with silt loam / field soil (T_5), and other pits with the mixture of loamy sand and silt loam soil at different proportions to realize the 3 remaining treatments. The particle size distribution and textural classes of the soils of the treatments are given in Table 1.

Table 1. Percentage of sand, silt and clay of the soils of different treatments along with their textural classes

Treatment	% Sand	% Silt	% Clay	Textural Class
T_1	79.48	14.48	6.04	Loamy Sand
T_2	54.48	37.02	8.50	Sandy Loam
T_3	52.72	38.24	9.04	Loam
T_4	41.00	49.00	10.00	Loam
T_5	15.00	72.00	13.00	Silt Loam

Wheat cultivation

The plots were fertilized with a Nutricoat fertilizer containing urea, triple super phosphate, muriate of potash and gypsum @ 200, 160, 50 and 120 kg ha^{-1}, respectively as recommended by Hussain *et al.* (2006). Two-third of urea and the entire dose of the other fertilizers along with cow dung @ 8.5 t ha^{-1} were applied during land preparation. The remaining urea was applied as top dressing before first irrigation. A wheat variety called Shatabdi, developed by the Bangladesh Agricultural Research Institute in 2000 was grown in the experimental plots. Before sowing, the seeds were purified by treating with Vitavax–200 @ 3 g kg^{-1} of seed. Seeds were sown in rows 20 cm apart and in 2–3 cm deep furrows @ 20 kg ha^{-1} on 20 December 2007 for the first crop season and 6 December 2008 for the second crop season. Any gap caused by damaged plants/un-germinated seeds in the plots was filled up to maintain the required plant population. The weeds grown in the plots were uprooted by weeding when required. There was no infestation of pests and diseases in the fields.

The wheat was irrigated following a schedule based on crop water requirement and soil-water content. Field capacity of the plots was determined in situ by saturating a small area of each plot and then measuring water content after 3 days. Four irrigations were applied to the crop both in the first and second year experiments. Soil-water content was measured in all plots with a Trime FM moisture meter before each irrigation. The quantity of water required to bring soil water to field capacity was calculated for each plot. The first irrigation was applied at 23 and 19 days after sowing (DAS) in the first and second year experiment, respectively. The second, third, and fourth irrigations were applied at 53, 61, and 72 DAS, respectively in the first year and at 45, 62 and 77 DAS, respectively in the second year. An equal amount of water was applied to the three replications of each treatment in each particular irrigation.

Data recording and analyses

Crop: In order to determine leaf area index (LAI), leaves of ten representative plants were collected from each plot at the flowering stage and their total area was measured by using a leaf area meter. Total area covered by the ten plants was calculated from the density of plant population. The LAI was calculated by the ratio of leaf area to the ground area.

The crop was harvested on 3 April 2008 after 104 days of sowing in the first year and on 25 March 2009 after 110 days of sowing in the second year when the spikes were completely ripened. At the time of harvesting, ten plants from each plot were selected randomly and kept in separate bundles. The crop of the whole plot was also harvested, bundled separately and tagged. Data on plant height, length of spike, spikelets per spike and number of grains per spike were recorded on the ten sampled plants. The total, effective and non-bearing tillers of each plot were recorded from the harvested crop. The plant materials of each plot were then threshed after sun drying and cleaned to separate the grains and straw. The grains of each plot and that of the ten sample plants were dried in the sun to 14% moisture content to determine grain yield and yield contributing parameters. Similarly, straw yield was determined. The biological yield, defined by the sum of the grain and straw yields, was determined for each plot. Following Gardner *et al*. (1985), the harvest index was calculated from the ratio of the grain yield to biological yield. The above-ground biomass of the crop was determined after drying them at 70 ºC for 72 hours.

The development of roots in different treatments was quantified in both the crop seasons. Just after harvesting, the roots of 0–20, 20–40 and 40–60 cm depths were collected separately by sampling soil columns with a representative area for one wheat row. The roots were separated by washing the soils carefully. The masses of the roots over the sampling depths for the treatments were determined by drying the roots first in air and then in oven at 80 ºC for 48 hours. The ratio of root to shoot was calculated to evaluate the effect of roots on yield and yield parameters. The analysis of variance (ANOVA) of the crop data was done for the Randomized Complete Block Design (RCBD, 1 factor) with MSTAT-C program.

Water: Soil-water content at 0 – 20 cm soil profile of the plots was measured at sowing, before irrigation, immediately after irrigation, 48 hours after irrigation or rainfall and at harvesting during the two crop seasons with a Trime FM soil moisture meter. The effective rainfall defined as the fraction of rainfall available in the root zone that helps germinating plants or maintaining their growth was determined following the USDA Soil Conservation Method (Smith, 1992). Total 13.13 cm rainfall occurred in two events during the growing period of wheat in the first year provided an effective rainfall of 10.37 cm. There was no rainfall during the growing period of wheat in the second year. The water requirement for wheat was computed by (Michael, 1985, p.538) adding the applied irrigation water, effective rainfall during the growing season and contribution of soil water. The field water use efficiency (FWUE) of wheat was calculated for different treatments by the ratio of crop yield to the total amount of water used in the field during the entire growing period of the crop.

Soil: Three soil samples were collected from each plot at 20 cm increments to a depth of 60 cm by using hand auger after harvesting the crop. The collected samples were dried in air, crushed and sieved with a 2-mm mesh sieve. Composite samples were prepared by thoroughly mixing the samples of the same depth from the three replications for each treatment. Also, undisturbed soil samples were collected in 5 cm × 5 cm cylindrical cores in triplicate from the surface of each plot for determining some of the soil properties.

By determining the fractions of sand, silt and clay of the soils by hydrometer method their textural classes were found from the Marshall's triangle. The saturated hydraulic conductivity of the undisturbed soils in the cores was measured by constant head method. The saturated soils were weighed and then dried in oven at 105^{o}C for 24 hours. The porosity of the samples was taken equal to the water content at saturation. The bulk density was determined from the oven dry soils and their volumes. For measuring pH, 20 g air dry soil from a composite sample was taken in plastic bottle and 50 ml distilled water was added to it. The suspensions were shaken on an electrical shaker for 20 minutes and then kept undisturbed for five hours. The pH of the partly settled soil suspensions was measured by a glass electrode pH meter.

Results and Discussion

Soil properties

Sand and silt fractions, the two inert parts, constitute only the skeletal portion of a soil, but clay fraction performs an additional role in soil–solute reactions. Consequently, most soil properties, especially the hydro-chemical and electrical properties, are described by the clay fraction of a soil. The bulk density, porosity and field capacity of the soils under the five treatments are listed in Table 2. The bulk density decreased, but the porosity and field capacity increased as the texture of the soil became finer in the treatments. The field capacity increased by 78, 80, 91 and 135% in treatment T_2, T_3, T_4 and T_5, respectively compared to that in T_1 implying that soil-water regime improved in the finer textured soils. The pH was the highest in treatment T_5 that was close to the pH of the treatments T_1 and T_2. The lowest pH was in T_4. These results of soil pH agreed well with that of Imsamut and Boonsompoppan (1999) who reported the acidic nature of sandy soils. The organic matter content increased as the clay content of the treatments increased.

Table 2. Bulk density, porosity, field capacity, pH and organic matter of the soils under different treatments

Treatment	Bulk density g cm^{-3}	Porosity %	Field capacity %	pH	Organic matter %
T_1	1.41	43	14.0	5.99	0.39
T_2	1.37	47	24.9	5.88	0.99
T_3	1.38	45	25.2	5.13	0.86
T_4	1.36	50	26.8	4.88	1.34
T_5	1.28	52	32.9	6.05	1.47

Water regimes

Figs. 1a and 1b delineate soil-water distribution at 20 cm depth in the wheat plots during the growing season of 2007–2008 and 2008–2009, respectively. The highest soil-water content was in treatment T_5 that was followed by treatments T_4, T_3, T_2 and T_1 due to their gradual decrease of clay content. It is noted that a small increase in silt loam (amendment) in T_2 remarkably improved soil-water distribution; the rate of this improvement, however, decreased with further increase in silt loam. As illustrated in Fig. 2, soil-water content varied widely in different treatments after application of irrigation. Treatments T_2, T_3, T_4 and T_5 retained considerably more water compared to T_1. Thus, addition of silt loam to loamy sand remarkably increased soil-water availability to crops. Similar, impact of clay on water regime was also described by Afifi (1986) and Reuter (1994). The saturated hydraulic conductivity of T_1, T_2, T_3, T_4 and T_5 was 27.36, 1.34, 1.27, 0.67, 0.41 cm h^{-1}, respectively. The silt loam, especially the clay, in the treatments reduced the macro pores in loamy sand with an eventual significant ($p = 0.05$) reduction in the saturated hydraulic conductivity of the treatments. Our results are thus in agreement with that of Al-Darby (1996) who reported that clay in sandy soils reduced the hydraulic properties by limiting percolation losses while maintaining adequate infiltration rate and water retention.

Growth characters

As delineated in Fig. 3, the leaf area index, LAI, of wheat for the 2008 – 2009 crop season varied widely among the treatments; it was the lowest in T_1 and increased with the increasing quantity of silt loam in the treatments. The plant height in the treatments increased significantly compared to T_1 in both the growing seasons except in T_2 during 2007 – 2008 crop period (Table 3). An average of 0.9, 8.5 and 8.8% increase in plant height occurred in T_3, T_4 and T_5, respectively compared to T_1 during the first year crop period and 5, 9, 17 and 10% increase occurred in T_2, T_3, T_4 and T_5, respectively during the second year crop period. In both the growing seasons, the number of total tillers per plot significantly increased in the finer textured treatments as compared in Table 3. An increase in the number of total tillers per plot of 97, 123, 108 and

134% during 2007–2008 and of 108, 105, 72 and 99% during 2008–2009 was observed in treatments T_2 T_3, T_3 and T_5, respectively relative to T_1. The number of effective tillers per plot also increased significantly in treatments T_2, T_3, T_4 and T_5 compared to T_1. These results thus signified the tremendous impact of soil texture on wheat cultivation. Increased water and organic matter contents in finer textured soils enhanced spike length of wheat (Table 3); the more the fine particles, the large was the spike length. Soil amendment by silt loam enhanced the number of spikelets per spike by stimulating the growth of spike length in both the crop seasons. As a consequence, the number of spikelet per spike in T_2, T_3, T_4 and T_5 increased by 3.5, 9.0, 9.5 and 13.4%, respectively in 2007–2008 and by 21.4, 15.0, 22.0 and 18.6%, respectively in 2008–2009 crop period over T_1. The largest root biomass was in the upper 20 cm of soil depth in all the treatments. About 50–60% of the roots grew within the top 0–20 cm layer during 2007–2008 and 70–92% roots grew in the same layer during 2008–2009 crop period. In this layer, the highest amount of roots was recorded in treatment T_2 during 2007–2008 and in T_3 during 2008–2009. Both at 20–40 cm and 40–60 cm depths, T_4 provided the maximum and T_1 provided the minimum quantity of roots in the two crop periods.

Table 3. Growth parameters of wheat under five soil treatments during 2007 – 2008 and 2008 – 2009 crop periods

Treatment	Plant height cm		No. of tillers plot^{-1}		No. of effective tillers plot^{-1}		Spike length cm		No. of spikelets spike^{-1}	
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
T_1	80.6^B	81.3^D	149^B	74^D	139^B	72^D	6.9^{AB}	15.1^B	13.4^B	15.9^C
T_2	79.1^B	85.3^C	249^A	154^C	274^A	150^C	6.8^B	15.5^{AB}	13.9^{AB}	19.3^A
T_3	81.3^B	88.8^B	319^A	234^B	310^A	230^B	7.3^{AB}	16.1^{AB}	14.6^{AB}	18.3^B
T_4	87.4^A	95.3^A	311^A	242^B	289^A	237^B	7.8^{AB}	16.3^A	14.7^{AB}	19.4^A
T_5	87.7^A	89.3^B	338^A	309^A	325^A	306^A	8.0^A	15.3^{AB}	15.2^A	18.9^{AB}
CV (%)	2.82	1.9	17.78	8.27	18.97	8.24	8.3	3.61	5.08	2.05
LSD $_{(0.05)}$	4.42	3.17	91.48	31.58	92.95	30.89	1.15	1.06	1.37	0.71

Common letter(s) within the same column do not differ significantly at 5% level of significance.

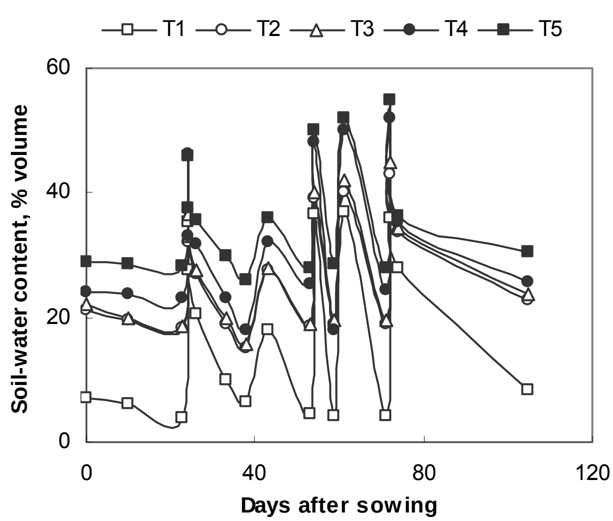

Fig. 1a. Soil-water distribution at 20 cm depth in the experimental plots during the growing season of 2007–2008

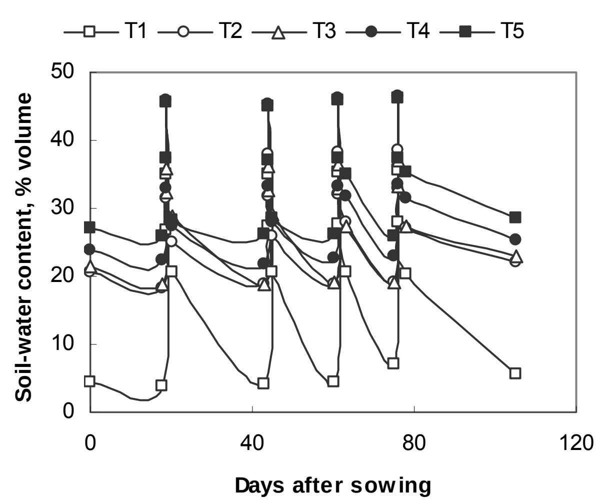

Fig. 1b. Soil-water distribution at 20 cm depth in the experimental plots during the growing season of 2008–2009

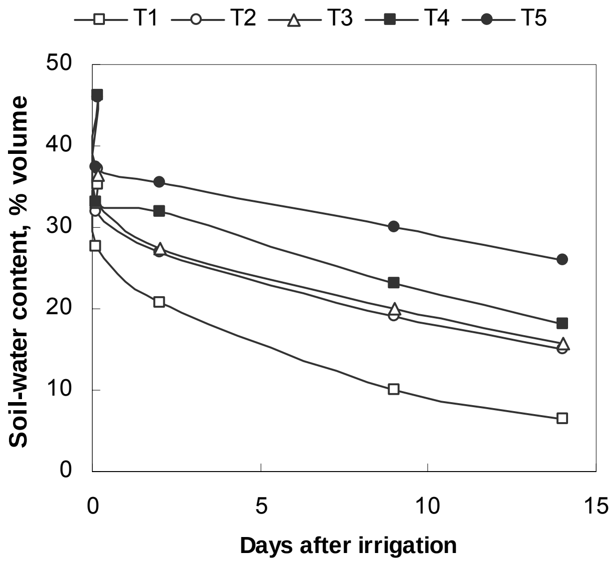

Fig. 2. Soil-water content of different treatments over time after irrigation

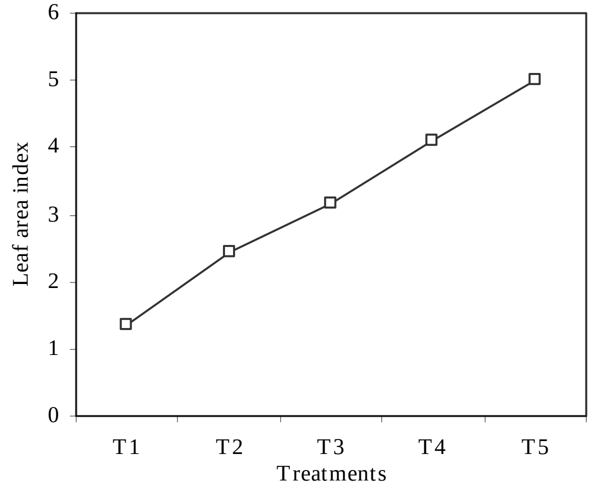

Fig. 3. Variation of leaf area index of wheat in five soil treatments

Yield characters and yield

Addition of silt loam to loamy sand caused significant increase in the number of grain per spike in the treatments as compared in Table 4. The number of grain per spike in treatments T_2, T_3, T_4 and T_5 increased by 6.7, 9.7, 11.0 and 12.0%, respectively over T_1 during 2007–2008 crop period and 13.5, 19.9, 16.9 and 20.3%, respectively during 2008–2009 crop period. The first small increment of silt loam thus imparted tremendous effect in increasing the number of grain in the spikes. In both the crop periods, the grain yield increased with the increase of silt loam in the treatments. There were significant differences in yield between T_1 and other treatments. Inadequate soil water along with reduced organic matter in T_1 retarded physiological processes in the plants and, consequently, reduced the crop yield. The grain yield showed an increasing trend to the tune of 24, 57, 52 and 45% in 2007–2008 and 48, 139, 189 and 141% in 2008–2009 for treatments T_2 T_3, T_4 and T_5, respectively over T_1. T_5 provided the highest straw yield (7.93 t ha^{-1}) in 2007–2008 and T_4 provided such yield (6.23 t ha^{-1}) in 2008–2009 crop period. T_1 always provided the lowest straw yield of wheat. Similar results were found by Tan *et al.* (1983), Al-Omran *et al.* (2005) and Ismail and Ozawa (2007). The biological yield of wheat increased significantly in the finer textured soils compared to T_1 (Table 4) in both the growing seasons. This yield increased by 23, 47, 48 and 52% in treatments T_2, T_3, T_4 and T_5, respectively in 2007–2008 crop period and by 66, 138, 184 and 150%, respectively in 2008–2009 crop period over T_1. The enhanced vegetative growth in terms of plant height and number of tillers per plant due to the increased quantity of fine soil particles increased straw yield, which together with yield attributing characters, improved the biological yield. The harvest index of wheat, however, remained unaffected by the soil amendment.

Table 4. Yield parameters of wheat under five soil treatments during 2007 – 2008 and 2008 – 2009 crop periods

Treatment	No. of grains spike^{-1}		1000-grain weight, g		Grain yield, t ha^{-1}		Biological yield, t ha^{-1}		Harvest index	
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
T_1	30^{C}	37^{B}	41.6^{A}	42.8^{A}	3.8^{B}	2.1^{D}	8.8^{C}	4.3^{D}	0.43^{A}	0.48
T_2	32^{B}	42^{A}	43.9^{A}	44.3^{A}	4.7^{AB}	3.0^{C}	10.8^{B}	7.1^{C}	0.43^{A}	0.42
T_3	33^{A}	45^{A}	42.4^{A}	42.3^{A}	5.9^{A}	4.9^{B}	12.9^{A}	10.2^{B}	0.45^{A}	0.48
T_4	33^{A}	44^{A}	42.8^{A}	42.8^{A}	5.7^{A}	5.9^{A}	13.0^{A}	12.2^{A}	0.44^{A}	0.49
T_5	34^{A}	45^{A}	40.5^{A}	39.0^{A}	5.4^{A}	4.9^{B}	13.4^{A}	10.7^{B}	0.41^{A}	0.46
CV (%)	7.77	4.12	5.59	8.45	12.12	7.23	8.74	6.36	8.43	4.64
$LSD_{(0.05)}$	1.37	3.30	4.44	6.72	1.16	0.57	1.94	1.07	0.06	—

Common letter(s) within the same column do not differ significantly at 5% level of significance.

Water use efficiency

The quantity of water used in the plots (applied irrigation + effective rainfall ± soil moisture deficit) varied in different treatments. The highest quantity of water (31.85 cm in 2007–2008 and 25.60 cm in 2008–2009) was used in T_1 and the lowest (20.37 cm in 2007–2008 and 10.88 cm in 2008–2009) was used in T_5 (Table 5). The irrigation requirement and hence the total water used in a plot decreased with the increasing silt loam of the treatments. As compared in Table 5, T_3 provided the highest water use efficiency, WUE, in 2007–2008 crop period, while T_5 provided such WUE in 2008–2009. T_1 always provided the lowest WUE and it gradually increased with increasing quantity of silt loam since the treatment with high clay content consumed small amount of water. The increasing WUE with increasing clay content was also reported by Ismail and Ozawa (2007). Treatment T_2 saved 1 to 13.6% and T_3– T_5 saved 29.4 to 57.5% irrigation water compared to T_1. These results also closely agreed with finding of Ismail and Ozawa (2007) that could save 45 to 64% of irrigation water in the clay-amended treatments compared to the control case.

Table 5. Components of water requirement, field water use efficiency and water saving in relation to control in different treatments during 2007–2008 and 2008 – 2009 crop period

Treatment	Irrigation plus effective rainfall, cm		Soil water deficit, cm		Total water used, cm		Grain yield, kg ha-1		Water use efficiency, kg ha-1 cm-1		Water saving, %	
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
T_1	33.0	26.7	-1.18	-1.10	31.85	25.60	3755	2052	118	80	—	—
T_2	32.8	23.3	-1.25	-1.13	31.54	22.12	4648	3038	147	137	1.0	13.6
T_3	21.9	18.7	-1.36	-1.28	20.53	17.42	5882	4897	287	281	35.5	32.0
T_4	23.9	15.5	-1.44	-1.18	22.49	14.27	5677	5923	252	415	29.4	44.3
T_5	21.4	12.0	-1.06	-1.12	20.37	10.88	5417	4928	266	453	36.0	57.5

Conclusion

Amendment of loamy sand by silt loam improved soil structure by increasing porosity and altering the pore size distribution. The soil-water content and organic matter of the finer textured soils were considerably higher than that of loamy sand. A small increase in silt loam remarkably improved soil-water distribution, the rate of which, however, decreased with further increase in silt loam. The improved soil structure reduced saturated hydraulic conductivity and increased field capacity. The increased soil water and organic matter in the finer textured soils stimulated growth of wheat and caused significant ($p = 0.05$) increase in leaf area index, plant height, number of total and effective tillers per plant, spike length, number of spikelets per spike, number of grains per spike, grain yield and biological yield compared to loamy sand. Elevated soil-water retention and organic matter helped increasing the grain and straw yields and hence biological yield of wheat; the amended soils produced 1.2 to 2.8 times higher grain and biological yields compared to loamy sand. The irrigation requirement and total water used in a treatment increased with decreasing silt loam. The amended soils, except for the lowest amendment, saved 29.4 to 57.5% irrigation water. Loamy sand always provided the lowest water use efficiency that gradually increased with increasing quantity of silt loam.

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