Asian Australas. J. Biosci. Biotechnol. 2016, 1 (3), 521-532

Asian-Australasian Journal of Bioscience and Biotechnology
ISSN 2414-1283 (Print) 2414-6293 (Online)
www.ebupress.com/journal/aajbb

Article

Impacts of irrigation with sugar mills' wastewater and fertilizer on soil chemical and solute-transport properties

Md. Shariot-Ullah*, Md. Touhidul Islam and Khalid Mahmud

Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

*Corresponding author: Md. Shariot-Ullah, Assistant Professor, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. E-mail: msu_iwm@bau.edu.bd

Received: 06 November 2016/Accepted: 11 December 2016/ Published: 28 December 2016

Abstract: Impact assessment of wastewater on soil is important to diagnose the potential of wastewater irrigation. By taking this idea into consideration, an experiment was conducted to investigate the chemical and solute-transport properties of soils collected from wheat fields irrigated with sugar mills' wastewater at North Bengal Sugar Mill (NBSM) and Faridpur Sugar Mill (FSM) of Bangladesh. Soil samples were collected from experimental sites where wheat was grown under both irrigation and fertilizer treatments. The split-plot design with three replications of irrigation (main plot) and fertilizer (sub-plot) were used. Irrigation and fertilizer treatments were defined as I_1 = irrigation with fresh water, I_2 = irrigation with mixed water (fresh water: wastewater = 1:1) and I_2 = irrigation with wastewater; F_1 = Full dose fertilizer, F_2 = Half dose fertilizer and F_3 = No application of fertilizer. Soil samples were chemically analyzed to find their chemical properties and a breakthrough experiment was done to find the solute transport properties. Significant effects were observed for soil chemical properties at both NBSM and FSM sites. At NBSM site, organic-C and S contents of soil increased under I_3 treatment, where as total-N, P, K and Mg contents increased under I_2 treatment. Similarly, Na and Ca contents at FSM site slightly went downunder I_3 treatment. Application of fertilizer also significantly affected soil properties at both sites. Under full dose fertilizer application (F_1) EC, P, K, S, Ca and Mg contents of the soil increased, however, Na content decreased at both sites. Interaction of irrigation and fertilizer treatments also had significant effects on all the soil chemical parameters except organic-C and total-N content of the soils at both sites. Among solute transport properties pore-water velocity, dispersion coefficient and mean solute travel time increased in I_3 compared to I_1 at NBSM site, but the reverse was observed at FSM site.

Keywords: wastewater; irrigation; sugar mills; soil; chemical properties; solute-transport properties

1. Introduction

Water is an indispensable factor to any crop for its survival, better development and bumper production. The biomass production inextricably depends on the need of water. The sufficient access to water is essential in raising productivity of agriculture. But, this valuable input is becoming scarce day by day. Scarcity of water is already a critical constraint to farming in many parts of the world. The scarcity of water already has affected almost all continents and more than 40 percent of the people on our planet. Now a days, 1.6 billion people live in countries or regions with absolute water scarcity and two-thirds of the world's population could be living under water stressed conditions by 2025 (FAO, 2012). The world is thirsty because of our increasing needs for food and water. At present, there are more than 7 billion people to feed on the planet and this number may expect to reach 9 billion by 2050 (FAO, 2012). At the global level, 70 percent of blue water withdrawals go to irrigation. Since agriculture is by far the largest water-use sector, accounting for about 70% of all water withdrawn worldwide from rivers and aquifers. In several developing countries, irrigation represents up to 95%

of all water withdrawn, and it plays a major role in food production and food security (CAWMA, 2007). Wastewater from industries like sugar factories, dairies, paper and pulp, tanneries and distilleries are rich sources of organic matter. Wastewater causes problem of organic pollution resulting in depletion of oxygen and odorous conditions at the outfalls of the effluents (Goel, 2011). In Bangladesh a large amount of effluent water is produced from fifteen sugar mills each year. This low quality water is not only a source of low cost irrigation water but also can be a good source of nutrients for plant due to its nutritive value. Beside positive impacts, wastewater has some negative impacts on soil physical and hydraulic properties and also on plant's physiology. Wastewater irrigation poses several threats to agricultural sustainability. Heavy metals derived from sewage can retard plant growth. Nitrogen in high concentrations, while usually beneficial to crops through its fertilizing properties, can also limit plant growth and crop yield (Baier and Fryer, 1973; Do Monte, 1998). Salinity and sodicity, however, are by far the most important sustainability constraints (Tillman and Surapaneni, 2002). The properties of wastewater clearly depend on its origin, but most wastewaters are higher in salts than traditional irrigation waters, with electrical conductivity roughly ranging from 0.6 to 1.7 dS/m (Feigin *et al.,* 1991). Discharge of this wastewater with a high TDS adversely affects aquatic life, renders the receiving water unfit for domestic use, damages or reduces crop yield if used for irrigation, and exacerbate corrosion in water systems and pipe (ETPI, 2001). The presence of oil, grease and other pollutants in the sugar mill's wastewater may have adverse impacts on crop yields (Akbar and Khwaja, 2006). 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). The chemical and solute-transport properties of soil, soil productivity and production of crops are considerably influenced by the quality of irrigation water. These problems can be minimized by managing wastewater in the field. In Bangladesh, research work on this field is still limited. So, there is a huge scope to conduct research in Bangladesh in the field of wastewater management and reuse in irrigation taking soil health into consideration. By taking this into consideration, it was decided to conduct this study to investigate the chemical and solute-transport properties of soil irrigated with sugar mills' wastewater of different dilutions. This study may help decision makers and planners to take decision on sugar mills' wastewater use for irrigating crops without any hazard of the soil health in Bangladesh.

2. Materials and Methods

The main purpose of the experiment was to evaluate the soil chemical and solute-transport properties to observe the effect of sugar mill's wastewater irrigation on irrigated soil. Irrigation treatments applied on wheat field. Wastewater has both positive and negative effect on crop by changing different soil properties. The chemical and solute-transport properties were measured in laboratory to investigate the suitability of soil chemical and solute-transport properties for the specific crop wheat. The soil type of the area is silty loam. Soil samples were collected from irrigated wheat fields (under investigation) of the sites after harvesting of the crop at 20 cm increments to a depth of 60 cm.

Wheat was cultivated at two different sugar mill sites - North Bengal Sugar Mill (NBSM) and Faridpur Sugar Mill (FSM) sites under different irrigation and fertilizer levels. The experiments were set in a split-plot design with three replications of the two factors (irrigation and fertilizer). Irrigation was applied in main plots and fertilizer was distributed in sub plots. The plot size was 3 m × 2 m. Irrigation had three treatments:

I_1 = irrigation with fresh water,

I_2 = irrigation with mixed water (fresh water: wastewater = 1:1) and

I_3 = irrigation with wastewater

Fertilizer also had three treatments:

F_1 = Full dose fertilizer,

F_2 = Half dose fertilizer and

F_3 = No application of fertilizer

After soil collection and sample preparation, different properties of soil mainly the chemical and solute-transport properties were measured. Soil samples were chemically analyzed for pH; EC; organic-C; total-N; available P and S; exchangeable K, Na, Ca and Mg. The EC and pH of the soils were determined at soil to solution ratio of 1:2.5 in an aqueous suspension of soil using a combine electrical conductivity and pH meter. For this measurement, 20 g of each air dried soil was taken into separate conical flasks of 100 ml capacity, and

50 ml distilled water was added with each soil. The soil-water mixture was shaken by using a shaker at 200 rpm for 10 min. Then, the conical flasks were kept undisturbed for 10 min and shaken again at the same rpm and for the same time. The soil-water mixtures, called the saturation paste, were kept undisturbed in a control room for 5 h to attain equilibrium at 25^0C. The saturation extract was separated from the saturation paste carefully. The EC and pH of the saturation extracts were measured by the combined conductivity and pH meter. Other chemical properties of the soil samples were determined in the Soil Analytical Laboratory of Bangladesh Rural Advancement Committee (BRAC), Gazipur. A few parameters were analyzed in the Humboldt Soil Testing Laboratory of the Department of Soil Science, Bangladesh Agricultural University, Mymensingh.

A breakthrough experiment was done to determine theimpacts of irrigation with sugar mills' wastewater on the solute-transport properties of soil. A constant rate of water flow through the soil columns was established by using a peristaltic pump before starting an experiment. Water was spread uniformly over the surface of the soil using a thick layer of absorbing cloth. The surface of the soil in the upper columns and the annular surfaces of soils in the lower columns were covered with a PVC sheet to prevent evaporation. The whole system reached equilibrium with the applied and drainage water in two weeks. The equilibrium condition was confirmed from the identical rates of the soil-water content measured by TDR. At equilibrium, a pulse of $CaCl_2$ solution (2 g $CaCl_2$ mixing with 3 ml water) was applied on the surface of each soil columns. The applied solution dispersed and moved through the soil profile with the moving water. The datalogger was programmed to scan the TDR sensors for measuring the volumetric water content and EC at the pre-selected time intervals (usually 1 hour). These measurements were continued until the whole of the applied salt was leached out from the upper columns.

A breakthrough curve (BTC) is the plot of concentration or its equivalent quantity verses time. By analyzing a BTC, the transport parameters of a solute are determined. There are several methods for analyzing BTCs. Transfer-function (Mojid*et al.*, 2004) is a well-accepted method for this and was used in this study. The following solute-transport parameters were determined:

V = velocity of solute, cm/h
τ = travel time of solute, h
N_d = mass dispersion number
D = dispersion coefficient, cm^2/h
R = solute retardation factor
P = Peclet number
λ = dispersivity, cm

The obtained data from the experiment has been analyzed statistically by using Mstat-C to assess the significant effects and the variation in the results. The measured data was accumulated based on field and lab research. So the quality of information is authentic and unique in nature.

3. Results and Discussion

After doing research the obtained results on soil chemical and solute-transport properties are interpreted extensively with required figures and tables in this section.

3.1. Effects of irrigation water quality and fertilizer on soil chemical properties

3.1.1. Electrical conductivity

Electrical conductivity, EC, under fresh water, mixed water and wastewater irrigated soils of North Bengal Sugar Mill, NBSM and, Faridpur Sugar Mill, FSM, sites are provided in Table 1 (a & b). At NBSM site, EC decreased from 0.184 dS/m under fresh water to 0.170 dS/m under wastewater irrigation. The EC under wastewater irrigation reduced significantly (p=0.05) compared to that under fresh and mixed water irrigations. At FSM site, EC increased by 5.3%, from 0.132 dS/m under fresh water irrigation to 0.139 dS/m both under mixed water and wastewater irrigations. The EC values under the irrigation treatments were statistically identical at the FSM site. Saleh*et al.* (2009) reported an increasing trend of EC due to wastewater irrigation. EC for the three fertilizer treatments – full dose, half dose and no application of fertilizer – are listed in Table 2 (a & b).

At NBSM site, EC increased by 2.3% and 6.9% under half dose and full dose fertilizer application, respectively compared to no application of fertilizer. The ECs under full and half dose fertilizer were however statistically similar, but both were significantly different from no application of fertilizer. At FSM site, a similar trend in EC was found. The EC was increased by 2.3% and 9.92% under half dose and full dose fertilizer, respectively compared to no application of fertilizer. For the interaction between irrigation and fertilizer, the highest value of

EC (0.203 dS/m) was observed at NBSM site under the combination of mixed water irrigation with full dose fertilizer. Similar result was found in the case of FSM site, the highest EC (0.150 dS/m) was also obtained for the combination of mixed water irrigation with full dose fertilizer, and the second highest EC (0.140 dS/m) was obtained under the combination of wastewater irrigation with full dose and half dose fertilizer application, respectively (Table 3 (a & b)). The values of EC for these two treatment combinations were statistically similar but significantly different from other combinations. Soil EC was directly related to the total salt concentration in the soil. So, the increasing trend of EC might occur due to increased application of fertilizer.

3.1.2. pH

The highest soil pH (8.13) was obtained under fresh water and the lowest (8.05) was obtained under wastewater irrigation at NBSM site. At FSM site, the highest pH (8.33) was obtained under wastewater and the lowest (8.31) was obtained under mixed water irrigation (Table 1 (a & b)). At both sites, with wastewater application, a decreasing trend in soil pH was observed.

The obtained pH values at both sites were statistically similar. Tabriz *et al.* (2011) also reported a reducing trend of pH under irrigation with sugar mill's wastewater. For fertilizer treatments, soil pH reduced more under full dose fertilizer (8.07) than under half dose fertilizer (8.11) at NBSM site. Also, a decreasing trend in soil pH was observed at FSM site. The highest pH (8.33) was obtained under no fertilizer application and the lowest (8.31) was obtained under full dose fertilizer (Table 2 (a & b)). The pH values found at both sites were statistically identical. For the interaction effect, pH was the highest (8.18) under wastewater irrigation with half dose fertilizer application and the lowest pH (7.95) was found under wastewater irrigation with no application of fertilizer at NBSM site. The highest pH (8.35) was obtained at FSM site under wastewater irrigation with full dose fertilizer and the lowest pH (8.28) was obtained under fresh water irrigation with full dose fertilizer application (Table 3 (a & b).

So, application of fertilizer was the main reason to change soil pH of the experimental sites. Wastewater had also some effects to lower soil pH. Phosphoric acid and sulpher were used in sugar mill during sugar production. A fraction of which was released to the wastewater. This was also the reason to lowering soil pH. An increased soil pH enhanced availability of macronutrients to plants. On the other hand, in acidic soils, phosphorus availability is low. BARC (2005) classified soil as very strongly acidic, strongly acidic, slightly acidic, neutral, slightly alkaline, strongly alkaline and very strongly alkaline depending on pH values as <4.5, 4.5−5.5, 5.6−6.5, 6.6−7.3, 7.4−8.4, 8.5−9.0 and >9.0, respectively. Generally, for adequate availability of nutrients in soils, pH of 6.0−7.0 is considered optimum. Although the observed soil samples were slight alkaline, the sugar mill's wastewater improved the availability of nutrients by making the soil slight acidic with reduced pH.

3.1.3. Organic-C

A decreasing trend in organic-C with increasing quantity of wastewater was observed at NBSM site (Table 1 (a & b)). Due to application of wastewater, organic-C decreased from 0.742% under fresh water to 0.699% under wastewater irrigation. The observed organic-C under the three irrigation treatments was statistically identical. On the other hand, an increasing trend in organic-C was observed due to application of wastewater at FSM site. The organic-C increased by 11.24 and 3.92% under mixed and wastewater irrigation, respectively compared to fresh water irrigation. These values under the irrigation treatments were also statistically identical. Saleh *et al.* (2009) and Friedel *et al.* (2000) also found increased organic-C in wastewater irrigated soil. For fertilizer treatments, a decreasing trend in organic-C was observed at NBSM site, but there was a systematic trend at FSM site. The organic-C contents under the fertilizer treatments were statistically similar at both the sites. Yan *et al.* (2007) reported increased organic-C in soil due to the application of phosphorus and potassium fertilizers. In the case of interaction of irrigation and fertilizer, the highest organic-C (0.803%) was obtained under the combination of fresh water irrigation with half dose fertilizer application, and the second highest (0.783%) was obtained under wastewater irrigation with full dose fertilizer application and mixed water irrigation with half dose fertilizer application at NBSM site. The lowest value was obtained under the combination of wastewater irrigation with half dose fertilizer application (0.573%). All the observed organic-C contents at each site were however statistically identical. On the contrary to NBSM site, the highest organic-C was observed under wastewater irrigation with full dose fertilizer application (1.30%) and the lowest organic-C (0.573) was obtained under wastewater irrigation with half dose fertilizer application at FSM site (Table 3). The organic-C contents under fresh water and mixed water irrigations were statistically similar, but under wastewater irrigation, it was significantly different from other irrigation treatments. The organic matter content of a soil is often used as an index of soil fertility. It influences the physical, chemical and biological properties of the soil. Less than 2% organic matter in the soil is generally considered to be "insufficient", 2.5% as "fair", and more than 5% as "plenty" (Sun and Hsieh, 1992). The organic-C of the experimental soils was below 2%, but application of sugar mill's wastewater in irrigation would increase soil fertility by increasing organic matter content in the soil.

Table 1 (a). Quality parameters of soils of the experimental field under irrigation by fresh water, mixed water and wastewater at North Bengal Sugar Mill area.

Irrigation water	EC dS/m	pH	Org.-C (%)	Tot.-N %	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
Fresh water	0.184a	8.129a	0.742a	0.098a	6.774a	81.2ab	8.5b	85.8a	496.1b	105.2a
Mixed water	0.183a	8.077a	0.704a	0.079b	6.181a	77.0b	11.0ab	86.7a	670.9a	85.5a
Wastewater	0.170b	8.046a	0.699a	0.089ab	7.854a	87.2a	13.9a	74.7b	518.0b	112.4a
$LSD_{0.05}$	0.013	0.101	0.194	0.013	4.482	9.43	4.64	10.87	48.18	31.72

Table 1 (b). Quality parameters of soils of the experimental field under irrigation by fresh water, mixed water and wastewater at Faridpur Sugar Mill area.

Irrigation water	EC dS/m	pH	Org.-C %	Tot.-N %	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
Fresh water	0.132a	8.317a	0.943a	0.087a	24.04ab	143.8b	8.6b	110.2a	508.3a	113.0a
Mixed water	0.139a	8.310a	1.049a	0.088a	27.14a	158.7a	11.5b	105.3ab	385.8b	120.3a
Wastewater	0.139a	8.329a	0.980a	0.083a	20.90b	138.2b	19.5a	96.4b	380.1b	111.3a
$LSD_{0.05}$	0.013	0.059	0.275	0.041	4.408	33.11	5.94	11.77	61.76	25.10

In a column, numbers with same letter do not differ significantly, while those with dissimilar letters differ significantly at 5% level of significance (as per DMRT).

Table 2 (a). Quality parameters of soils of the experimental field under full dose, half dose and no application of fertilizer at North Bengal Sugar Mill area.

Fertlizer	EC dS/m	pH	Org.-C %	Tot.-N %	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
Full dose	0.186a	8.073a	0.700a	0.080b	8.092a	85.8a	11.9a	81.3a	656.1a	111.7a
Half dose	0.178ab	8.113a	0.720a	0.092a	6.656ab	81.6ab	11.9a	83.6a	578.8a	100.6ab
No fertilizer	0.174b	8.064a	0.726a	0.093a	6.062b	77.9b	9.5a	81.3a	450.0b	90.7b
$LSD_{0.05}$	0.010	0.056	0.122	0.010	1.644	4.68	3.07	4.16	90.12	14.10

In a column, numbers with same letter do not differ significantly, while those with dissimilar letters differ significantly at 5% level of significance (as per DMRT).

Table 2 (b). Quality parameters of soils of the experimental field under full dose, half dose and no application of fertilizer at Faridpur Sugar Mill area.

Fertlizer	EC dS/m	pH	Org.-C %	Tot.-N %	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
Full dose	0.144a	8.307a	1.110a	0.090a	24.47a	151.7a	16.7a	102.7a	475.9a	117.0a
Half dose	0.134ab	8.321a	0.914a	0.082a	26.27a	143.8a	12.5a	103.6a	340.0b	120.7a
No fertilizer	0.131b	8.328a	0.948a	0.086a	21.34a	145.2a	10.4a	105.8a	458.3a	107.0a
$LSD_{0.05}$	0.010	0.033	0.225	0.010	5.138	10.63	7.17	7.27	58.23	18.84

In a column, numbers with same letter do not differ significantly, while those with dissimilar letters differ significantly at 5% level of significance (as per DMRT).

Table 3 (a). Interaction effects of irrigation and fertilizer on the quality parameters of soils of the experimental field at North Bengal Sugar Mill area.

Treatment	EC dS/m	pH	Org.-C (%)	Total-N (%)	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
I_1F_1	0.183bc	8.17a	0.640a	0.080cd	7.9ab	84.9ab	7.7c	85.3abc	565abc	121.2ab
I_1F_2	0.177bc	8.17a	0.803a	0.103ab	5.8b	79.3bc	9.8bc	89.3ab	529bcd	90.8c
I_1F_3	0.193ab	8.04bcd	0.783a	0.110a	6.6b	79.3bc	7.9c	82.7bcd	395d	103.7bc
$I_2 F_1$	0.203a	8.09abc	0.680a	0.073d	6.4b	79.3bc	11.0bc	81.3bcd	723a	80.0c
$I_2 F_2$	0.183bc	7.99cd	0.783a	0.087bcd	6.3b	80.0bc	10.8bc	86.7ab	704a	90.1c
$I_2 F_3$	0.163d	8.14ab	0.650a	0.077cd	5.8b	71.7c	11.0bc	92.0a	586abc	86.34c
$I_3 F_1$	0.170cd	7.95d	0.780a	0.087bcd	9.9a	93.2a	17.0a	77.3cde	681ab	134.1a
$I_3 F_2$	0.173cd	8.18a	0.573a	0.087bcd	7.8ab	85.7ab	15.1ab	74.7de	504cd	120.9ab
$I_3 F_3$	0.167cd	8.01cd	0.743a	0.093abc	5.8b	82.8b	9.6bc	72.0e	370d	82.1c
LSD 005	0.018	0.097	0.211	0.018	2.848	8.11	5.32	7.99	156.10	24.43

Table 3 (b). Interaction effects of irrigation and fertilizer on the quality parameters of soils of the experimental field at Faridpur Sugar Mill area.

Treatment	EC dS/m	pH	Org.-C (%)	Total-N (%)	P ppm	K ppm	S ppm	Na ppm	Ca ppm	Mg ppm
I_1F_1	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab	0.143ab
I_1F_2	0.127b	8.33ab	0.903ab	0.080a	26.6ab	146.1abc	7.2bc	117.3a	431bc	111.7ab
I_1F_3	0.127b	8.34ab	1.020ab	0.087a	18.8ab	142.6bc	6.4c	101.3bc	513ab	110.8ab
$I_2 F_1$	0.150a	8.29b	1.123ab	0.093a	28.4a	164.9a	14.3abc	98.7c	398c	117.1ab
$I_2 F_2$	0.137ab	8.32ab	1.040ab	0.087a	27.1ab	152.4abc	9.4bc	97.3c	346c	143.1a
$I_2 F_3$	0.130b	8.33ab	0.983ab	0.083a	25.9ab	158.7ab	10.8abc	120.0a	413bc	100.8b
$I_3 F_1$	0.140ab	8.35a	1.300a	0.083a	18.3b	147.5abc	23.5a	97.3c	449bc	117.4ab
$I_3 F_2$	0.140ab	8.32ab	0.800b	0.080a	25.0ab	132.9c	21.0ab	96.0c	243d	107.2ab
$I_3 F_3$	0.137ab	8.32ab	0.840b	0.087a	19.3ab	134.3c	13.9abc	96.0c	449bc	109.4ab
$LSD_{0.05}$	0.018	0.056	0.389	0.018	8.900	18.42	12.42	12.59	100.90	32.63

In a column, numbers with same letter do not differ significantly, while those with dissimilar letters differ significantly at 5% level of significance (as per DMRT).

Table 4. Coefficients of determination (r^2) and root-mean-square errors (RMSEs) between the measured and estimated BTCs at NBSM and FSM sites under fresh water and wastewater irrigation.

Statistical parameter	Solute-transport in the soil at			
	North Bengal Sugar Mill site		Faridpur Sugar Mill site	
	Fresh water irrigation	Wastewater irrigation	Fresh water irrigation	Wastewater irrigation
Coefficient of determination r^2	0.983	0.974	0.963	0.99
Root-mean-square error, RMSE	0.0948	0.1259	0.1212	0.063

Table 5. Solute-transport parameters through soils of the experimental fields irrigated by wastewater and fresh water at North Bengal Sugar Mill and Faridpur Sugar Mill areas under no fertility condition.

Parameter	Solute-transport parameters at			
	North Bengal Sugar Mill		Faridpur Sugar Mill	
	Fresh water irrigation	Wastewater irrigation	Fresh water irrigation	Wastewater irrigation
Pore-water velocity, V (cm/h)	0.16	0.26	0.27	0.20
Travel time, τ (h)	125.0	78.0	74.4	102.5
Mass dispersion number, N_d	0.020	0.016	0.065	0.060
Dispersion coefficient, D (cm^2/h)	0.065	0.083	0.347	0.236
Peclet number, P	49.1	61.5	15.5	16.5
Dispersivity, λ (cm)	0.41	0.33	1.29	1.21
Retardation factor, R	1	1	1	1

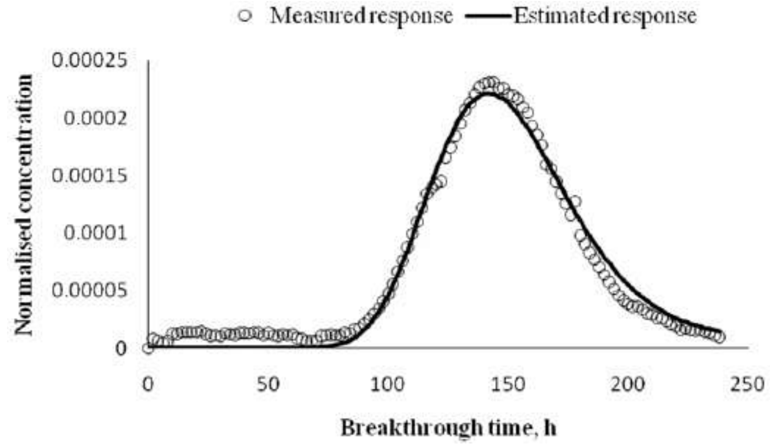

Figure 1. Measured and estimated BTCs for fresh water irrigated soil of the experimental field at North Bengal Sugar Mill area.

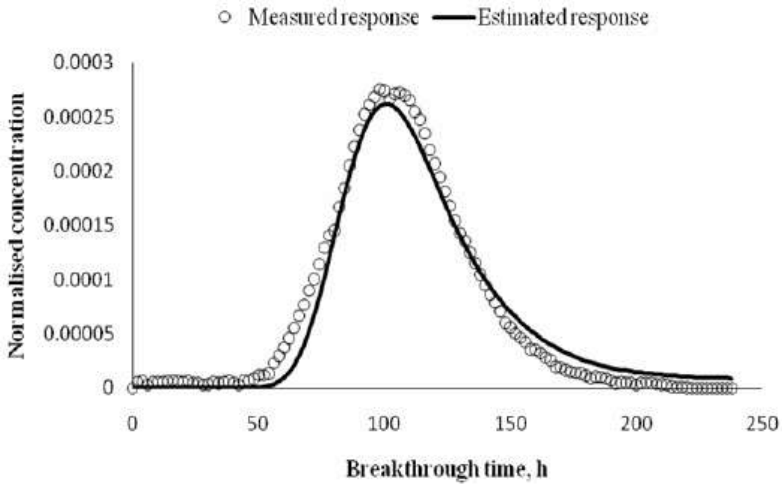

Figure 2. Measured and estimated BTCs for wastewater irrigated soil of the experimental field at North Bengal Sugar Mill area.

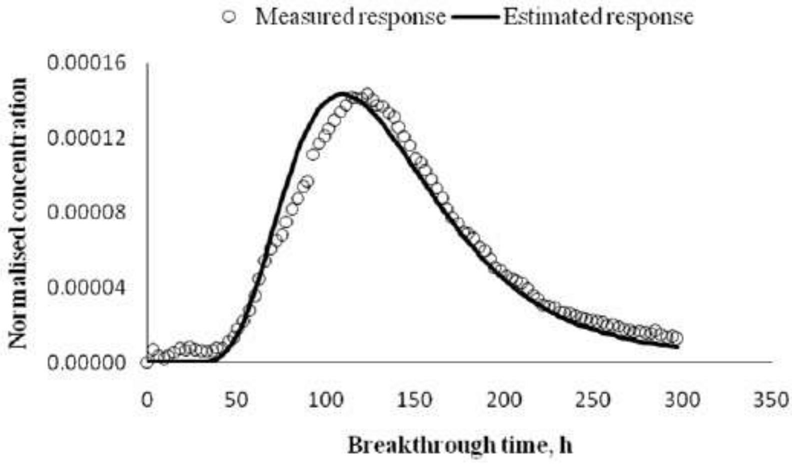

Figure 3. Measured and estimated BTCs for fresh water irrigated soil of the experimental field at Faridpur Sugar Mill area.

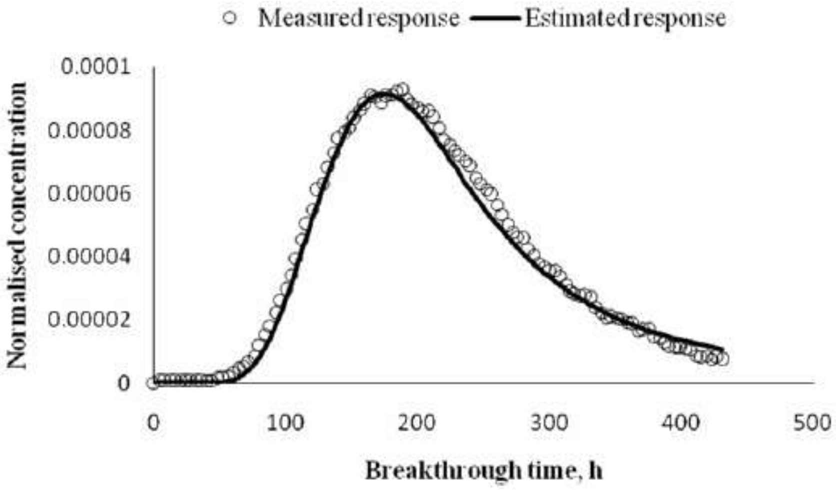

Figure 4. Measured and estimated BTCs for wastewater irrigated soil of the experimental field at Faridpur Sugar Mill area.

3.1.4. Total-N

Total-N content decreased with wastewater application at NBSM site; the highest total-N was obtained under fresh water irrigation (0.098%) and the lowest (0.079%) was under mixed water irrigation. The total-N contents under mixed water and wastewater irrigations were statistically identical. At FSM site, total-N increased under wastewater irrigation. It increased by 1.15% under mixed water irrigation (Table 1). The total-N contents under the irrigation treatments at FSM site were statistically identical. For fertilizer treatments, there was a decreasing trend in total-N from no application of fertilizer to full dose fertilizer application at NBSM site. The highest value (0.093%) was obtained under no application of fertilizer and the lowest (0.080%) was obtained under full dose fertilizer application. The total-N under full dose fertilizer application was significantly higher compared to the other two fertilizer treatments. At FSM site, under full dose fertilizer application, the total-N increased by 4.65% (Table 2). For interaction, the highest total-N (0.110%) was obtained under the combination of fresh water irrigation withno application of fertilizer and the lowest value (0.073%) was obtained under mixed water irrigation with full dose fertilizer application at NBSM site. At FSM site, the highest total-N (0.093%) was under the combination of fresh water irrigation with full dose fertilizer application and mixed water irrigation with full dose fertilizer application and the lowest value (0.080%) was obtained under fresh water and wastewater irrigations with half dose fertilizer application (Table 3). So, application of fertilizer had the main effect to increase total-N content in soils. According to SRDI (1993), N content in soil up to 0.075% is considered low, 0.076−0.150% as medium, and 0.151−0.30% as good and above this range as excess for a soil. It is thus revealed that fresh or mixed water irrigation with full dose fertilizer application has better effects on soil in terms of their N content.

3.1.5. Phosphorus

Phosphorus, P, increased in the soil by 15.94% under wastewater irrigation compared to fresh water irrigation. The lowest P (6.181 ppm) was obtained under mixed water irrigation at NBSM area. The observed P values under the irrigation treatments were statistically identical. At FSM site, P increased by 18.95% under mixed water irrigation but decreased by 13.06% under wastewater irrigation compared to fresh water irrigation (Table 1). The P value under mixed water irrigation was significantly different from the value under wastewater irrigation. Saleh *et al.* (2009) and Tabriz *et al.* (2011) reported an increased soil P under wastewater irrigation. For fertilizer treatments, an increasing trend of P was obtained at both sites. At NBSM site, P increased by 33.49% and 9.79% under full dose and half dose fertilizer application, respectively. There was no significant difference in P under the fertilizer treatments. At FSM site, the increase in P was 15.02% and 29.86% under full and half dose fertilizer application, respectively (Table 2). There was also no significant difference among the values under fertilizer treatments in this site. For interaction, the highest P (9.933 ppm) was obtained under the combination of wastewater irrigation with full dose fertilizer application and the lowest (5.803 ppm) was obtained under the combination of mixed water irrigation with no application of fertilizer at NBSM site. At FSM site, the highest P (28.39 ppm) was obtained under the combination of mixed water irrigation with full dose fertilizer application and the lowest value (18.34 ppm) was obtained under wastewater irrigation with full dose fertilizer application (Table 3). It is thus revealed that wastewater and fertilizer both have significant effects to increase soil P. The Phosphorus content in the soil below 12 ppm is considered low, 13−25 ppm as medium, and 26−75 ppm as good and above this range as excess for soil (SRDI, 1993). So, depending on P content, the wastewater irrigated soil at FSM site was in better condition than at NBSM site.

3.1.6. Potassium

Potassium, K, content in soil was increased by 7.44% under wastewater irrigation at NBSM site. On the other hand, soil K increased by 10.36% under mixed water irrigation at FSM site (Table 1). The observed values of K under wastewater irrigations were significantly different from mixed and fresh water irrigations at both sites. Saleh *et al.* (2009) and Friedel *et al.* (2000) reported increased K content in soil due to the effect of wastewater irrigation. An increasing trend in soil K content was observed under fertilizer treatments. At NBSM site, soil K increased by 10.09% and 4.74% under full dose and half dose fertilizer application, respectively. But, in case of FSM site, K increased by 4.48% under full dose fertilizer application (Table 2). There was significant difference between the values of soil K under fertilizer treatments at NBSM site. But, at FSM site, there was no significant difference among the values of K under fertilizer treatments. At NBSM site, the highest value (93.22 ppm) was obtained under the combination of wastewater irrigation with full dose fertilizer application and the lowest K (71.70 ppm) was obtained under mixed water irrigation with no application of fertilizer. At FSM site, the highest value of K (164.9 ppm) was observed under the combination of mixed water irrigation with full dose fertilizer application and the lowest (132.9 ppm) was under wastewater irrigation with half dose fertilizer application (Table 3). Fertilizer treatments slightly affected the soil K content. The fertilized plots showed slightly greater K than the unfertilized plots. Soil Resource Development Institute (SRDI) (1993) reported that K content in soil up to 78 ppm is considered low, 81.9−156 ppm as medium and 159.9−585 ppm as good and above 585 ppm as excess. So, at FSM site, wastewater irrigation with recommended dose of fertilizer improved soil K content more than the soil at NBSM site.

3.1.7. Sulphur

Sulphur, S, content increased with the application of wastewater. At both the sites, there was an increasing trend of S content in soil. At NBSM site, the S content of soil increased by 29.43% and 64.30% under mixed water and wastewater irrigation, respectively compared to fresh water irrigation. In case of FSM site, similar trend was observed; S content increased by 68.64% and 125.54% under mixed and wastewater irrigations, respectively (Table 1). At NBSM site, there was a significant difference among the values of S under the irrigation treatments. At FSM site, the values of S significantly differed from each other. With the increasing fertilizer an increasing trend in S content was observed at both sites. At NBSM site, S content in soil was increased by 25.14% and 25.24% under half dose and full dose fertilizer application, respectively. At FSMsite, it increased by 20.77% and 61.35%, respectively under half and full dose fertilizer application (Table 2). There were no significant differences among S contents under the fertilizer treatments. At NBSM site, the highest S content (17.02 ppm) was obtained under the combination of wastewater irrigation with full dose fertilizer. At FSM site, the highest S content (23.50 ppm) was also found under the combination of wastewater irrigation with full dose fertilizer application. The lowest S (7.70 ppm) at NBSM site was obtained under the combination of fresh water irrigation with full dose fertilizer application. At FSM site, the lowest S (6.4 ppm) was under the combination of fresh water irrigation with no application of fertilizer (Table 3). The increase in S content was pronounced under fertilizer treatments due to the application of sulphurous fertilizer. There was also a contribution of wastewater to improve S content of the soil. S content in the soil below 12 ppm is ranked as low, 13−25 ppm as medium, 26−75 ppm as good and above this range as excess (SRDI, 1993). On the basis of S content in soil, the wastewater affected soil was in good condition.

3.1.8. Sodium

Sodium content, Na, in soil increased by 1.04% under mixed water irrigation and decreased by 12.95% under wastewater irrigation compared to fresh water irrigation at NBSM site. But, at FSM site, there was a decreasing trend in Na content. Na content was decreased by 4.45% and 12.49% under mixed and wastewater irrigation, respectively (Table 1). At NBSM site, the Na contents in soil under fresh water and mixed water irrigation were significantly different from the value under wastewater irrigation. At FSM site, there was no significant difference among Na contents in the soil under irrigation treatments. For fertilizer treatments, Na content (81.33 ppm) remained unchanged under full dose fertilizer application but increased by 2.74% under half dose fertilizer application compared to no application of fertilizer. In case of FSM site, a complete decreasing trend was obtained. With the increase of fertilizer, Na content was decreased by 2.08% and 2.93% under half dose and full dose fertilizer application, respectively (Table 2). The values of Na content were statistically identical at both sites. For interaction, the highest Na content (92.00 ppm) was found under the combination of mixed water irrigation with no application of fertilizer and the lowest value of Na content (72.00 ppm) was observed under the combination of wastewater irrigation with no application of fertilizer at NBSM site. At FSM site, the highest Na content (120.0 ppm) was obtained under mixed water irrigation with no application of fertilizer and the lowest Na content (96.00 ppm) was found under wastewater irrigation with no application of fertilizer (Table 3). The wastewater application was responsible to reduce the soil Na content.

3.1.9. Calcium

Calcium content, Ca, in soil increased by 35.23% and 4.40% under mixed water and wastewater irrigation, respectively compared to fresh water irrigation at NBSM site. Neilsen *et al.* (1991) also reported the same phenomena, that is, increased Ca content under wastewater application. On the other hand, a decrease in Ca content was observed at FSM site. Ca content decreased by 24.09% and 25.22% under mixed and wastewater irrigation, respectively compared to fresh water irrigation (Table 1). The observed value of Ca content under fresh water irrigation was significantly different from the other two values at NBSM site. At FSM site, there was also significant difference among the observed Ca values under irrigation treatments. For application of fertilizers, Ca content increased at NBSM site and only small fluctuation in Ca content was observed at FSM site. The Ca content in soil was increased by 45.8% and 22.26% under full dose and half dose fertilizer application, respectively at NBSM site. In case of FSM site, Ca content increased by 3.84% under full dose fertilizer and decreased by 25.81% under half dose fertilizer application (Table 2). The highest Ca content (723 ppm) was obtained under the combination of mixed water irrigation with full dose fertilizer application at NBSM site. At FSM site, the highest Ca content (581 ppm) was found under the combination of fresh water irrigation with full dose fertilizer application. The lowest value of Ca content (370 ppm) obtained under the combination of wastewater irrigation with no fertilizer application at NBSM. At FSM site, it (243 ppm) was found under the combination of wastewater irrigation with half dose fertilizer application (Table 3). So, application of fertilizer, especially gypsum (containing Ca content) had the main effect to increase Ca content in soil.

3.1.10. Magnesium

Magnesium content, Mg, in soil of experimental field varied slightly. Mg content at NBSM site decreased by 18.75% under mixed water irrigation and increased by 6.84% under wastewater irrigation. At FSM site, Mg content in soil increased by 6.46% under mixed water irrigation and decreased by 1.50% under wastewater irrigation (Table 1). Neilsen*et al.* (1991) observed a decreased Mg content due to wastewater application. At both the sites, there was no significant difference among the values of Mg content in soil. For fertilizer application at NBSM site, Mg content was increased by 23.13% under full dose fertilizer application and 10.89% under half dose fertilizer application. On the other hand, Mg content at FSM site increased by 9.35% under full dose fertilizer application and 12.80% under half dose fertilizer application (Table 2). The value of Mg content under half dose fertilizer application was statistically similar with those under other fertilizer treatments at both experimental sites. For interaction at NBSM site, the highest value of Mg content (134.1 ppm) was obtained under the combination of wastewater irrigation with full dose fertilizer application and the lowest value (79.97 ppm) was obtained under the combination of mixed water irrigation with full dose fertilizer application. At FSM site, the highest (143.1 ppm) and lowest (100.8 ppm) values of Mg were observed for the combinations of mixed water irrigation with half dose fertilizer application and no application of fertilizer, respectively (Table 3). Wastewater irrigation thus improved the Mg content in soil. Fertilizer treatment had also some influences to increase this parameter too.

3.2. Effects of wastewater on solute-transport properties of soil

3.2.1. Measured and estimated BTCs

Figures 1–4 compare the measured and estimated breakthrough curves, BTCs in the soils irrigated with fresh water and wastewater at NBSM and FSM sites.

The coefficient of determination (r^2) and root-mean-square errors (RMSEs) between the measured and estimated BTCs are listed in Table 4. The large coefficients of determination and small RMSEs for the fitting of BTCs under fresh water irrigation and wastewater irrigation at indicate that a great proportion of variance was accounted for by the model.The fits explained 98.3 and 97.3% of the total variation in the data about the average for freshwater irrigation and wastewater irrigation respectively at NBSM site, and 96.3 and 99.0%, respectively at FSM site (Table 4). Beside this, the standard errors of the regressions were closer to zero. This indicates good fit between the measured and estimated BTCs in soils of both experimental sites.

3.2.2. Solute-transport parameters

The major solute-transport parameters are pore-water velocity, V, dispersion coefficient, D, mean solute travel time, τ, mass-dispersion number, Nd, Peclet number, P, and dispersivity, λ. These parameters for fresh water irrigated and wastewater irrigated soils of the experimental fields at North Bengal Sugar Mill, NBSM and Faridpur Sugar Mill, FSM, areas are listed in Table 5. The pore-water velocity, V, in freshwater irrigated and wastewater irrigated soils was 0.16 and 0.256 cm/h at North Bengal Mill area, respectively. The corresponding value of V at Faridpur Sugar Mill area was 0.27 and 0.20 cm/h. The pore-water velocity through the wastewater-irrigated soil increased at the North Bengal sugar mill area but decreased at the Faridpur sugar mill area compared to fresh water irrigated soil. Mean travel time of solute, τ, under fresh water irrigated and wastewater irrigated soils were 125.0 and 78.0 h, respectively at NBSM site and 74.4 and 105.5 h, respectively at FSM site. At NBSM site, τ decreased under wastewater irrigation but at FSM site, it increased due to irrigation with wastewater. These results were due to that fact that V and D (described below) decreased at NBSM site and increased at FSM site due to irrigation by wastewater. These results imply that the soil of NBSM site requires longer time to reclaim than the soil of the other site.
The dispersion coefficient, D, which indicates how fast a solute is dispersed in a soil was 0.065 cm^2/h under fresh water irrigation and 0.083 cm^2/h under wastewater irrigation at NBSM site. The corresponding value of D was 0.347 and 0.236 cm^2/h at FSM site. Dispersivity, λ, under fresh water and wastewater irrigation was 0.41 and 0.33 cm, respectively at NBSM site, and 1.29 and 1.21 cm, respectively at the other site. Due to irrigation by wastewater, the dispersion coefficient increased at NBSM site while it decreased at FSM site. The dispersivity decreased at both sites. This parameter indicates the extent to which a solute spreads in a soil and has implication to estimate areal extent of a pollutant (salt, toxic materials, etc.) in a region. A larger λ in wastewater irrigated soil implied that wastewater caused an increasing spread of dissolved chemicals in soils. An increased pore-water velocity, dispersion coefficient and dispersivity implied that any pollutant added to the soil through wastewater irrigation is relatively easily removable compared to the soil through which these pollution transport parameters decreased due to irrigation by wastewater. Due to textural differences, the opposite behavior of the wastewater irrigated soils at the two experimental sites might occur. The two dimensionless parameters: mass dispersion number, Nd, and Peclet number, P, were derived solute-transport parameters. These parameters are indirectly related to the solute-transport process.

4. Conclusions

Wastewater caused an increase in soil EC but decrease in soil pH. It raised phosphorus, potassium, sulpher, magnesium, nitrogen and organic-C content in the soil. These increased chemical constituents improved soil fertility. Both wastewater and fertilizer application reduced sodium content in soil. It also has negative impacts: may develop salinity problem in the soil, low crop yields due to excess of soluble salts in water health risks for irrigators and communities with prolonged contact with untreated wastewater and consumers of vegetables irrigated with wastewater, groundwater contamination, and build-up of pollutants in soil. Wastewater retarded the movement of solute through soil depending on soil texture. Irrigation by sugar mill's wastewater did not significantly alter the physical and hydraulic properties of the irrigated soil. So, it may be used as a source of irrigation and fertilizer in the crop field without any hazard of the soil health.

Conflict of interest

None to declare.

References

Akbar NM and MA Khwaja, 2006. Study on effluence from selected sugar mills in Pakistan: Potential environmental, health and economic consequences on excessive load. Sustainable Development Policy Institute (SDPI), Islamabad.

Baier, DC and WB Fryer, 1973.Undesirable plant responses with sewage irrigation. J. Irrig. and Drain. Div., Proc. Am. Soc. Civil Engrs., 99:133–142.

BARC (Bangladesh Agricultural Research Council), 2005.Fertilizer Recommendation Guide. BARC, Farmgate, New airport Road, Dhaka–1215., p.9.

CAWMA (Comprehensive Assessment of Water Management in Agriculture), 2007. Water for food, water for life: A comprehensive assessment of water management in agriculture. London, UK: Earthscan, and Colombo, Sri Lanka: International Water Management Institute, pp.645.

Do Monte MM, 1998. Agricultural irrigation with treated wastewater in Portugal 1998.Wastewater reclamation and reuse. (Ed. T. Asano). CRC Press. pp. 827–876.

ETPI (Environmental Technology Program for Industry), 2001. Environmental report on sugar sector. Monthly Environmental News 5, Issue 7 (July):11−27.

FAO (Food and Agriculture Organization), 2012.Water and Food Security. UN Water, World Water Day, 22nd March 2012.

Feigin A, I Ravina and J Shalhevet, 1991. Irrigation with treated sewage effluent: Management for Environmental Protection. Berlin; New York : Springer-Verlag. References

Friedel JK, T Langer, C Siebe and K Stahr, 2000. Effects of long-term wastewater irrigation on soil organic matter, soil microbial biomass and its activities in central Mexico. Biol. Fertile Soils., 31:414–421.

Goel PK, 2011. Water Pollution (Causes, Effects and Control). New Age International (P) Limited, Publishers. pp.58.

Miller CJ, N Yesiller, K Yaldo and S Merayyand, 2002.Impact of soil type and compaction conditions on soil water characteristic. J. Geotech. Geoenviron. Eng., ASCE.,128:733–742.

Mojid MA, DA Rose and GCL Wyseure, 2004.A transfer-function method for analyzing breakthrough data in the time domain of the transport process. European J. Soil Sci., 55:699−711.

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

Neilsen GH, DS Stevenson, JJ Fitzpatrick and CH Brownlee, 1991.Soil and sweet cherry responses to irrigation with wastewater. Can. J. Soil Sci., 71:31–41.

Saleh AS, A Salam and J Khalil, 2009. Effect of irrigation with reclaimed wastewater on soil properties and olive oil quality. Jordan J. Agril. Sci., 5:128–141.

SRDI (Soil Resource Development Institute), 1993. Land and soil resource use guide line. Ministry of Agriculture, Government of Peoples Republic of Bangladesh.p.64.

Sun PMH and SC Hsieh, 1992. The establishment of a sustainable agricultural system in Taiwan. Department of Agriculture and Forestry, Taiwan Provincial Government, Chung-Hsing New Villa, Nantou,Taiwan, ROC., p.16.

Tabriz SS, MAMojid and GCL Wyseure, 2011. Irrigation suitability of North Bengal Sugar Mill’s effluent and its impact on soil properties. J. Bangladesh Agril. Univ., 9:283–290.

Tillman RW and ASurapaneni, 2002. Some soil related issues in the disposal of effluent on land. Aust. J. Exp. Agric., 42:225–235.

Yan D, D Wang and L Yang, 2007.Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. Biol. Fertil. Soils. Springer-Verlag., 44:93–101.