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Research article

Varied effects of untreated textile wastewater onto soil carbon mineralization and associated biochemical properties of a dryland agricultural soil

Mahnaz Roohi [a], Muhammad Riaz [a, *], Muhammad Saleem Arif [a], Sher Muhammad Shahzad [b], Tahira Yasmeen [a], Muhammad Atif Riaz [c], Shermeen Tahir [c], Khalid Mahmood [c]

[a] Department of Environmental Sciences & Engineering, Government College University Faisalabad, 38000, Faisalabad, Pakistan
[b] Department of Soil & Environmental Sciences, University College of Agriculture, University of Sargodha, Pakistan
[c] Soil Science Division, Nuclear Institute for Agriculture and Biology (NIAB), Jhang Road, Faisalabad, Pakistan

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A B S T R A C T

Wastewater is an alternative, valuable and cost effective resource for irrigation in water-scarce arid and sami-arid regions of the world including Pakistan. Soils near urban centers are cultivated for vegetable and cash crops using untreated wastewater. Current study was performed with objectives of assessing impacts of untreated textile wastewater on some soil chemical, biological and enzymatic activities. The microcosm incubation study used a clay loam soil that received 0 (distilled-water), 25, 50 and 100% wastewater concentrations and incubated for 30 and 60 days under optimum temperature and moisture conditions. Soil respiration was measured periodically throughout the experiment over 60 days. After the incubation periods of 30- and 60-d, soils were destructively analyzed for pH, electrical conductivity (EC), water extractable organic matter (WEOM), microbial biomass carbon (MBC), microbial metabolic quotient (qCO_2) and dehydrogenase enzymatic activity. Results revealed that wastewater and incubation time significantly altered chemical, biological and enzymatic properties of soils. The observed large surge in soil respiration, at initial stage, was stimulated by dissolved organic matter in wastewater. Dehydrogenase activity increased significantly with increasing wastewater concentrations. Increase in qCO_2 with wastewater concentration and incubation time suggested more stress to microorganisms but also enhanced microbial activity under stress to synthesize biomass. We found significant positive ($R^2 = 0.64$, $p < 0.001$) relationship between soil respiration and MBC, however, correlation between WEOM and MBC was significant negative ($R^2 = 0.18$, $p < 0.01$) indicating a dynamic mismatch between carbon substrate, soil respiration and buildup of MBC pool. Wastewater concentration and incubation time interaction had significant ($p < 0.01$) effect on WEOM suggesting that WEOM accumulated over time and comparatively less utilized by microorganisms. Short- and long-term effects of untreated wastewater on soil physico-chemical and biological health should be assessed before its use for crop production.

1. Introduction

Arid and semi-arid agriculture is under pressure due to limited water availability for irrigation. In this context, wastewater has been considered a valuable, inexpensive and constantly available alternative water resource in such regions for crop production (WHO, 2006; Qadir et al., 2007). Application of wastewater is considered beneficial to the soil-plant systems due to the presence of substantial concentrations of nitrogen and phosphorus, and certain micronutrients (Filip et al., 2000; Petersen et al., 2003). However, management of the toxic substances present in wastewater pose a major challenge at the soil-microbe-plant interphase. Long-term effects of wastewater application on agroecosystems generally depend on the nature and concentrations of chemical constituents of the wastewater and physico-chemical properties of receiving soils (Lucho-Constantino et al., 2005; Ahmad et al., 2012).

* Corresponding author.
E-mail address: mr548@ymail.com (M. Riaz).

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Pakistan is an agricultural country and has started to experience acute freshwater shortage and droughts. After agriculture, the textile industry is the second largest sector and textile wastewater represents dominant part of the total industrial effluents in Pakistan, a trend similar to the global wastewater production (Faryal et al., 2007; Ghaly et al., 2014). More than 2 million tons of untreated wastewater are released into the earth's waters each day and almost 50 nations utilized this polluted water to irrigate the farming area of 20 million hectares (Hussain et al., 2002; Azizullah et al., 2011). An estimated 30% of the total 962,335 million gallons of untreated wastewater is utilized to irrigate 32,500 ha agricultural land in Pakistan on annual basis (Ensink et al., 2004; UN WWAP, 2009). Higher costs of wastewater treatment in Pakistan mean that only <8% wastewater receives primary treatment in large urban centers including Karachi, Lahore, Faisalabad, Multan and Rawalpindi (PWSS, 2002; Pak-SCEA, 2006). Higher chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved solids, macro- and micronutrients are distinguishing properties of untreated textile wastewater (Garg and Kaushik, 2008; Arif et al., 2016).

A significant body of knowledge elaborate notable impacts on soil physical, chemical, biological and biochemical properties in response to application of treated and untreated wastewater. However, changes in such soil properties strongly depend on the time duration for which the soils have been irrigated with wastewater. Increase in soil salinity and resultant decrease in soil aggregate stability and hydraulic conductivity has been observed after irrigating the soil with treated municipal wastewater (Qian and Mecham, 2005; Rusan et al., 2007). Angin et al. (2005) found increase in soil organic matter and major cations after irrigation with untreated wastewater. In addition, numerous studies have reported positive, negative and neutral effects of wastewater on soil properties, and ultimately on the soil health, in a wide variety of agroecosystems (e.g. Schipper et al., 1996; Rutkowski et al., 2007; Chen et al., 2008; Mosse et al., 2012; Morugán-Coronado et al., 2013).

Changes in soil biological and microbiological properties including microbial biomass carbon (MBC), respiration of total microbial populations, microbial metabolic quotient (qCO_2) and enzymatic activities are often used indicators to monitor both short- and long-term effects of wastewater on soil quality (Anderson and Domsch, 1990; Brookes, 1995; Ramirez-Fuentes et al., 2002; Gianfreda et al., 2005; Adrover et al., 2012). Increase in soil respiration after application of treated wastewater has been reported earlier (Meli et al., 2002). However, in contrast, Brzezinska et al. (2006) found decrease in soil respiration rate in Eutric Histosol soils after irrigation with municipal wastewater. In agricultural soils, MBC is generally related to soil organic matter contents and any change in organic matter status of the soil could alter MBC (Houot and Chaussod, 1995). Increases in MBC in wastewater treated soil are related to carbon contents in wastewater. For example, positive effects of wastewater and sewage sludge on MBC have been observed which were dependent on the rate of application (Fernandes et al., 2005; Singh and Agrawal, 2012). Activities of a large number of soil enzymes including dehydrogenase, urease, alkaline phosphatase, catalase and glucosidase are generally measured to investigate the changes in potential activities of soil microorganisms in response to wastewater application. Dehydrogenase activity represent an overall metabolic status of the soil and is an important indicator of microbial activity (Nannipieri et al., 2002). Activity of dehydrogenase enzyme is usually higher in wastewater irrigated soil and strongly depend on concentrations of wastewater (Garcia-Gil et al., 2000; Arif et al., 2016). Moreover, activities of soil enzymes are very sensitive to the concentrations of toxic substances and salts, especially heavy metals present in wastewater. For example, Mikanova (2006) reported that higher concentrations of heavy metals in wastewater inhibited the activities of urease, dehydrogenase, arylsulfatase and invertase enzymes.

A large number of studies investigated the effects of treated and untreated wastewater on growth, development and yield of crops elsewhere (e.g. Kaushik et al., 2005; Khalid et al., 2013) and in Pakistan (Khan and Joergensen, 2009). However, very limited work is reported on how untreated textile wastewater may affect soil physico-chemical and biological properties in low fertility status agricultural soils in Pakistan. Treatment costs of wastewater are still not affordable especially in the developing countries which lead to disposal of untreated wastewater to agricultural areas (Friedel et al., 2000). A very recent study from Arif et al. (2016) found contrasting effects of untreated textile wastewater on soil nitrogen and phosphorus pools, and certain soil enzymatic activities in a 60-d incubation study. However, soil respiration, MBC and qCO_2 were not measured in their study.

We, therefore, designed a laboratory microcosm study, using untreated textile wastewater at varied application rates, with following objectives:

- how untreated textile wastewater affect soil C mineralization, MBC, qCO_2 and dehydrogenase activity at different concentration-based application rates;
- whether incubation time, in a rather short-scale study, affect soil physico-chemical and biological properties; and
- how nature and strength of relationships between soil properties are affected by untreated wastewater.

2. Materials and methods

2.1. Soil sampling, preparation and pre-experimental analysis

Soil for this study was collected from an agricultural field plot under wheat-fallow cultivation at Nuclear Institute for Agricultural and Biology Faisalabad Pakistan (31.4187° N, 73.0791° E). The field plot falls in sub-tropical monsoon climate and the average rainfall at the site is ca. 200 mm year^{-1} with high seasonal variations. At the time of sampling, soil was under fallow rotation and had not received chemical fertilizer for several weeks. Soil belonged to the Lyallpur series and classified as aridisol-fine-silty, mixed, hyperthermic ustalfic.

Soil samples were collected from the plough layer (0–15 cm depth) in April, 2012 at five points from the visibly uniform and vegetation-free field-plot with a sharp stainless steel spade. Individuals soil samples were sorted out to remove any coarse debris, living plant parts, and other visible material (roots or stones) by hand picking in the field. Soil samples were, then, air dried and sieved through a 2 mm mesh and resultant soils were mixed thoroughly to get a uniform composite sample of homogenous nature. Soil was stored in plastic bags and kept in the dark at room temperature until used in microcosm experiments. Subsamples were drawn from the composite sample for determination of pre-experimental physico-chemical parameters of soil using standard protocols described in Table 1. In addition, water-holding capacity of the soil was also measured following a method described by Jarrell et al. (1999) so that the incubation experiment could be performed at 70% of the field water capacity.

2.2. Sampling and analysis of textile wastewater

Samples of untreated textile wastewater were collected from a functional textile industry located at Khurrianwala in Faisalabad