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Interaction effects of irrigation by municipal wastewater and inorganic fertilisers on wheat cultivation in Bangladesh

M.A. Mojid [a], S.K. Biswas [a], G.C.L. Wyseure [b,*]

[a] Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[b] Division of Soil and Water Management, Department of Earth and Environmental Sciences, KU Leuven, Celestjnenlaan 200E, 3001 Leuven, Belgium

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ABSTRACT

The interaction effects of five irrigation water qualities formed with municipal wastewater (hereafter called wastewater) and two inorganic fertiliser levels on the growth and yield of wheat (*Triticum aestivum* L. cv Shatabdi) were explored in three consecutive growing seasons during 2007–2010. The experiment was set in a split-plot design with two factors and three replications. The five irrigation treatments – I_1: freshwater (groundwater extracted by tubewell) as control, I_2–I_4: diluted wastewater (having wastewater fraction of 0.25, 0.50 and 0.75, respectively) and I_5: raw/undiluted wastewater – were allocated to the main plots, and the two fertiliser levels – F_0: no fertiliser and F_1: recommended standard dose – were allocated to the sub-plots. The wastewater contained nitrogen (N), phosphorus (P) and potassium (K) at concentrations of 17.5, 3.7 and 10.3 mg L^{-1}, respectively, which correspondingly contributed 4.8–19.1, 3.8–15.1 and 5.4–21.7% of the recommended N, P and K. Wastewater exerted a significant ($\alpha = 0.05$) positive impact on most growth and yield variables and grain and biomass yields of wheat irrespective of the applied fertiliser dose. The highest values of the crop variables and yields were generally obtained in I_4F_1 (irrigation water containing 75% wastewater under the fertilised condition) and I_5F_0 (irrigation by raw wastewater under the non-fertilised condition). On average, over three years, the treatments that received 50–100% wastewater in irrigation (I_3F_1–I_5F_1) provided statistically identical results. Although wastewater always promoted leaf growth, its effectiveness in improving the leaf area index (LAI) decreased with its elevated quantity in irrigation. Raw wastewater promoted the highest leaf growth at 65 days after sowing (DAS) and provided the maximum LAI under both fertility treatments. The significantly different above-ground dry matters (ADM) among the irrigation treatments obtained at the later growth stages (95–110 DAS) exposed a delayed effectiveness of wastewater in the accumulation of shoot biomass. The raw wastewater contributed to producing the highest ADM under both fertility treatments. The most extensive root proliferation was in I_4F_1, which produced the highest grain and biomass yields; the grain yield increased in this treatment by 14% over I_1F_1. Both the grain and biomass yields in I_3F_1–I_5F_1 treatments were statistically similar. The highest water use efficiencies obtained in I_4F_1 and I_5F_0 depicted the most effective utilisation of irrigation water in these treatments.

1. Introduction

Irrigated agriculture currently consumes 70% of the world's developed freshwater and produces 40% of the food supply (Gleick, 2000); however, irrigated agriculture is facing a problem of water shortage, especially in arid and semi-arid regions. This problem is more extreme in developing countries because they use over 80% of their fresh water for irrigation. In Asia, much of the water scarcity is induced by overdrawing groundwater for agriculture, industry and domestic use, which leads to falling water tables. In Bangladesh, for example, water shortages have limited the irrigated area to only 62% of the cultivable land. Because of these conditions, Baterseh et al. (1989) suggested considering the use of non-conventional water resources, such as low-quality water, for agricultural and industrial use.

Among the low quality water sources, municipal wastewater is less expensive and considered attractive for irrigation in water-scarce regions (Al-Rashed and Sherif, 2000; Mohammad and Mazahreh, 2003). This wastewater is composed of 99.9% water together with small concentrations of suspended and dissolved organic and inorganic solids. It generally contains carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products. It may also include a broad spectrum of contaminants such as macro- and micronutrients for plants, salts and specific ions, and inorganic substances, including a number of toxic elements such as heavy metals. The composition of

* Corresponding author. Tel.: +32 16 329661; fax: +32 16 329760.
E-mail address: Guido.Wyseure@ees.kuleuven.be (G.C.L. Wyseure).

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wastewater, however, differs widely from place to place, even within a country. High energy costs, technology requirements and frequent problems with maintaining treatment plants render wastewater treatment ineffective for use in most developing countries. Consequently, as UNESCO (2003) reported, over 80% of the sewage generated in developing countries is discharged untreated into the environment, and approximately 50% of the population depends on polluted water sources for various uses. However, agricultural use of wastewater can tackle the problem of local water shortages and act as a treatment system to reduce environmental pollution (Jimenez, 2005). Haruvy (1997) agreed with this view and emphasised such use of wastewater to reduce treatment costs by utilising soil and crops as biofilters. Other investigators reported that the application of wastewater to croplands can, in addition to disposing of the wastewater safely, improve crop yield and the physical properties and fertility of soils (Pomares et al., 1984) by adding nutrients and organic matter (Jiménez-Cisneros, 1995; Siebe, 1998).

The use of wastewater for irrigation has now become a reality rather than a matter of choice. As Huibers and Van Lier (2005) and Drechsel et al. (2006) reported, such a reality exists not only in arid and semi-arid regions but also in humid areas where seasonal water shortage occurs. In some semi-arid areas, wastewater is the only water source for the urban and peri-urban agriculture that are the livelihoods of millions of poor people who require irrigation to produce high-value crops (Drechsel et al., 2006). Moreover, wastewater is produced during the dry season and is therefore considered to be more reliable than other sources. Municipal wastewater, mostly untreated, is used to irrigate 10% of the world's crops (Scott et al., 2004). Many urban and peri-urban farmers divert this wastewater in a partially treated, diluted or untreated form and use it to grow a range of crops (Ensink et al., 2002). They often deliberately prefer untreated/undiluted wastewater because it provides nutrients or is more reliable and cheaper than other water sources (Keraita and Drechsel, 2004; Scott et al., 2004). In the case of soils with poor fertility, wastewater is an important source of nutrients for crop production (Kiziloglu et al., 2007). Wastewater irrigation has a degree of similarity to fertigation, which is a common practice with solid-set irrigation systems such as drip irrigation. Adding fertiliser to the irrigation water has also been tested with surface irrigation (Playán and Faci, 1997). One important question is whether irrigation by wastewater has sufficient similarity with fertigation, allowing the management models proposed by Styczen et al. (2010) to be used.

Several studies (Pescod, 1992; Al-Salem, 1996; Yadav et al., 2002) have shown that land application of municipal wastewater as the water and/or nutrient source for crop production can represent a sustainable and complementary alternative, although such practice is still affected by problems with public acceptance (Pollice et al., 2004). The majority of the research on wastewater reuse in agriculture has focused on treated or partially treated wastewater. Smits et al. (2009) report a participatory study with stakeholders around Rajshahi, a major town in Bangladesh. One of their interesting conclusions was that the "*Concentration of nutrients, pathogens or other contaminants is not as severe as originally thought, but reduction of the levels of coliform and solid waste in the canals is recommended. The use of wastewater was found to have only a limited impact on yields, alongside many other factors, which require further research*". The effects of untreated and diluted wastewater on crops, both in combination with fertiliser doses, have rarely been studied in experimental field conditions. Although such information is very important for planning irrigation by wastewater, studies have not provided such information for developing countries such as Bangladesh. This study was therefore planed to (i) evaluate the effects of irrigation by municipal wastewater on the growth and yield of wheat, (ii) quantify the contribution of wastewater to fertilisation needs, and (iii) develop an effectual management practice for the use of wastewater in irrigation.

2. Materials and methods

2.1. Experimental site

These experiments were performed with wheat over three consecutive years (November–March of 2007–2008, 2008–2009, 2009–2010) at an experimental field at Bangladesh Agricultural University at Mymensingh in Bangladesh. The site was located in the Agro-Ecological Zone (AEZ) 9, situated at 24.75°N latitude and 90.50°E longitude. The field, which consisted of silt loam underlain by sandy loam, belongs to the old Brahmaputra floodplain (BARC, 2005). The major properties of the top soil were as follows: organic matter = 0.48%, pH = 6.8, field capacity = 38.19% (v/v), permanent wilting point = 18.37% (v/v), bulk density = 1.33 g cm^{-3} and electrical conductivity (EC) of saturation extract (soil:water = 1:2.5) = 0.62 dS m^{-1}. The climate is sub-tropical with an average annual rainfall of 242 cm, which is concentrated over the months of May–September. The summer is hot and humid, and the winter (November–February) is moderate, with only occasionally a small amount of rainfall in some years. The daily maximum temperature during the temperate months of April–May varies from 28.8 to 35.9 °C. January is the coldest month, with a daily minimum temperature of 9.6–12.9 °C. A total rainfall of 131.3 mm occurred in three events (30.6, 5.4 and 95.3 mm in January, February and March, respectively) during the 2007–2008 wheat season (November–March); however, the experimental crop was protected from the rainfall. There was no rainfall during the wheat season of the two following years.

2.2. Wastewater collection and analysis

Samples of municipal wastewater were collected once a month during the three experimental seasons at a location 1.5 km downstream of the outlet of the main sewage system of Mymensingh town. This location was the closest to the experimental field by road. It is noted that November–April is the major irrigation season in Bangladesh. Subsequently, there is a monsoon and flood season during which soils are leached. Samples of freshwater were collected from an existing borehole well in the experimental field that extracted groundwater at a depth of 100 m. The wastewater was mostly generated from the water used in households, restaurants, educational institutes, offices and hospitals; there was no major industrial source. The major chemical properties of the water samples were measured, mostly, with a DR/890 Colorimeter (Hach Co., USA). The concentrations of B, Fe, K, NO_3-N, PO_4-P, Na, Pb, Cu, Zn and Cd in the wastewater were below their threshold values set by the FAO (1992) for safe use in agriculture; only Mn exceeded the allowable limit. The EC of freshwater was 0.39 dS m^{-1}, and that of wastewater varied between 0.55 dS m^{-1} and 1.05 dS m^{-1}. The EC, which is dependent on the sodium adsorption ratio (SAR), often exceeded the FAO-recommended threshold values. The wastewater was slightly alkaline, with a pH of 7.33. There was no elevated level of heavy metals in the wastewater, and hence, no attention was focused on soil contamination by such metals. During the dry season irrigation period, the properties of the wastewater remained almost unchanged. Due to dilution with rainfall and flood water, the concentration of various chemical constituents in wastewater during the monsoon season would be much smaller than that during the dry season. The details of the wastewater quality parameters of Mymensingh sewage are found in Mojid et al. (2010).