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Impact of wastewater irrigation on soil physico-chemical properties, growth and water use pattern of two indigenous vegetables in southwest Nigeria

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ABSTRACT

The indiscriminate use of wastewater for irrigation as a result of freshwater shortage could impair soil functions and cause environmental pollution. The objective of this study was to evaluate soil physico-chemical properties, growth parameters and water use pattern of two indigenous vegetables irrigated with three kinds of wastewater in southwest Nigeria. The study was a 2 × 4 factorial (wastewater versus vegetable) pot experiment, laid out in randomized complete block design (RBCD) with three replications in a screen house. The tested vegetables were SM — Eggplant (*Solanum macrocarpon*) and CA — Spinach (*Celosia angentea*) while the wastewater treatments were abattoir wastewater (AW), bathroom, laundry wastewater (BW) cassava effluent (CE) and rainwater (RW) as control. The wastewaters were analyzed for physical, chemical and biological properties while the soil samples collected from the field at 0–20 cm soil layer and pots at 0–10 and 10–20 cm layer were analyzed for physico-chemical properties before and after the experiment, respectively. Soil hydrophobicity was determined using the water-droplet penetration time (WDPT) method, plant growth parameters were monitored every 5 days while leaf area was determined shortly before harvest. Consumptive water use was determined using the soil water balance technique. The wastewaters had moderate to very high degree of restriction for use in relation to salinity and sodicity. Except for CE treatment, wastewater irrigation increased the soil pH, Mg, K, Ca, TOC, TN and CEC at harvest. SAR surpassed the threshold value of 6 in the surface layer of CA soil irrigated with BW wastewater. Wastewater irrigation caused the occurrence of soil hydrophobicity, with the highest hydrophobic degree from CE treatment. The plant growth indices showed that the SM vegetable performed better under AW treatment while the CA vegetable performed better under BW treatment compared with RW treatment. The vegetables differed in relation to water use and there was no discernible trend among the different wastewater treatments as regards the temporal distribution of the consumptive water use. The CE wastewater had the most negative impact on both soil function and plant growth. The study showed that wastewater resources are valuable because of improvement of soil fertility and enhanced crop growth compared with rainwater, however they need to be managed with caution, preferably treatment, before reused in relation to soil functions and crop quality.

1. Introduction

The increase in world population has not only put pressure on limited water resources but also increased the volume of waste generation (Darvishi et al., 2010). However, most of the wastes generated are either not treated at all or partially treated, falling below the recommended standards before they are discharged into rivers, streams and lakes (Thapliyal et al., 2011). The increased competition for freshwater among urban and semi-urban centers, industries and agriculture has put agriculture, particularly irrigated agriculture under severe pressure as irrigation has been the largest user of water (van der Hoek et al., 2002). Therefore, the use of treated, partially-treated or untreated wastewater has received more attention (Yao et al., 2013). Kauser (2007) reported that at least one-tenth of the world's population is now consuming food produced by wastewater and it is estimated that about 200 million hectares in 50 countries are irrigated with raw or partially-treated wastewater (United Nations, 2003). Khalil and Kakar (2011) reported that 80% of the inhabitants in Pakistan are using untreated wastewater for irrigation. According to Jimenez and Asano (2008) and Qadir et al. (2007), the direct and indirect use of untreated wastewater in irrigated agriculture is increasing as a result of increasing

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global water scarcity, inadequate and inappropriate wastewater treatment and disposal, increased food insecurity and escalating fertilizer costs.

The reuse of wastewater for agriculture has become a common practice for many factors, very dominant among them is the nutrient load and environmental protection (McNeill et al., 2009). According to Al-Hamaiedeh and Bino (2010), wastewater is a valuable source of plant nutrients and organic matter. Nevertheless, it contains certain undesirable chemical constituents and pathogens that pose negative environmental and health threats (Papadopoulos, 1995). In this context, several studies have showed that the use of wastewater (treated and untreated) for irrigation has significantly changed soil properties (Wang et al., 2003; Rusan et al., 2007; Tabari et al., 2008; Chen et al., 2010; Alobaiby et al., 2010; Duan et al., 2010; Singh et al., 2012; Abegunrin et al., 2013; Mojiri et al., 2013; Yao et al., 2013). Wang et al. (2003) evaluated some physical, chemical, and biologic attributes of soil along a 100 m transect under a long-term reclaimed wastewater-irrigated field in Bakersfield, CA and its adjacent non-wastewater-irrigated control fields. Their results showed that the soils of both fields supported successful crop production; however the reclaimed wastewater irrigation slightly reduced the soil's capacity to hold nutrients. Rusan et al. (2007) analyzed soil and plant quality parameters to evaluate the long term effects of wastewater irrigation. The authors found that long-term wastewater irrigation increased the salt concentrations, organic matter and plant nutrients in the soil. In contrast, Singh et al. (2012) found that domestic wastewater irrigation had no significant effects on the properties of a clay soil except some slight changes in salt solubility and alkalinity. Abegunrin et al. (2013) also reported that soil conditions of a sandy loam Alfisol and plant growth indices were not significantly influenced by untreated wastewater irrigation, however the authors found lower soil pH and increased sodium adsorption ratio (SAR) some weeks after application.

One of the environmental risks associated with wastewater (ww) irrigation is hydrophobicity, determined by soil water repellency (SWR). Soil water repellency is a wide spread phenomenon which has been documented in various regions, climates, soils and land uses (Doerr et al., 2000; Ritsema and Dekker, 2003; Vogelmann et al., 2013), caused by organic compounds derived from living or decomposing plants or microorganisms which coat soil particle surfaces and aggregates. In Israel, the undesired non-continuous wetting conditions along tree rows have prompted research toward water repellency resulting from wastewater irrigation (Levy and Assouline, 2011). Tarchitzky et al. (2007) identified changes in water distribution patterns in wastewater irrigated orchards, and reported the occurrence of SWR at ww-irrigated sites, which they attributed to the differences in the soil organic carbon (SOC) content of the topsoil. The authors also observed narrower subsurface wetting zones in ww-irrigated soils. The negative effects of this reduced wetting include decreased rates of water infiltration, leading to greater runoff, and consequently less water retention and the development of preferential flow paths, with potential reduction in soil water efficiency and severe implications to the environment and food security (Hallett et al., 2011). Tabatabaei et al. (2007) reported that the continuous use of wastewater for irrigation significantly altered water infiltration into the soil due to blocking of water transmission pores by organic matter. The reduced soil water efficiency, altered water infiltration and lower water retention as well as increased surface runoff will have significant implication for crop water use and soil water balance. However, there is paucity of information on soil water balance (for example Zulu et al., 1996) of soils irrigated with wastewater. Studies on the practice of using untreated wastewater for irrigation is still limited (Khalil and Kakar, 2011), therefore there is the need for more knowledge for better understanding of the impacts of untreated wastewater on soil with a view to developing site-specific irrigation water management.

According to Areola et al. (2011), the issue of wastewater irrigation goes beyond the physical, chemical and biological qualities of the wastewater and that of the soil, equally important are the different types of crops being cultivated. Thus, because wastewaters contain appreciable amount of nutritional ingredients (Sacks and Bernstein, 2011) which play an important role in plant growth development and metabolic processes by improving the soil fertility (Tiwari et al., 2003; Kiziloglu et al., 2007), wastewaters (either treated or untreated) have been used by farmers for irrigating their lands and cultivate crops. In this context, several studies have been conducted to evaluate the performance of variety of crops irrigated with wastewaters discharged from various sources (Erfani et al., 2001; Tak et al., 2010; Mojiri and Amirossadat, 2011; Akhtar et al., 2012; Abegunrin et al., 2013), however crops behave differently to wastewater due to differences in salt tolerance.

Although treatment is always considered as the only safe option for the ecosystem and excellent treatment options exist which remove all harmful elements and bring nutrient loading and heavy metals within safe limits, however lack of funds for wastewater collection and treatment, inadequate planning and lack of regulations on the use of wastewater have become a challenge for most developing nations like Nigeria. In Nigeria, including this region where this study was conducted, most of the streams and rivers dry during the four to five months of drying season. Since this is a yearly occurrence, a large proportion of the farmers rely on wastewaters for vegetable production. Such untreated wastewater is used without recourse to soil and water pollution, with the latter occurring after the onset of rainfall. Despite the widespread use of wastewater as an important source for irrigation in Nigeria, the impact of wastewater on soil properties is not fully understood, thus research that highlights the influence and effect of wastewater irrigation on soil quality is still lacking in the country. Therefore, studies that will recommend management options rather than promoting the use of harmful wastewaters are needed.

We hypothesized that (1) wastewater irrigation significantly alter soil physical and chemical properties, (2) there is no difference in the performance of two indigenous vegetables cultivated using wastewater irrigation and (3) water repellency increases due to wastewater irrigation, and hence affects crop water use and soil water balance. Therefore, the objectives of this study were to evaluate the effects of cassava effluent, abattoir and bathroom wastewater irrigation on (i) soil physico-chemical properties, (ii) growth parameters and (iii) water use pattern of two indigenous vegetables in southwest Nigeria.

2. Materials and Methods

2.1. Experimental site

The experiment was conducted between August and September 2013 in the screen house of the Department of Agricultural Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (Latitude 8° 10′N and Longitude 4° 10′E at an altitude of 342 m above the mean sea level) in southwest Nigeria. The location is characterized by bimodal rainfall pattern, with peaks in June and September and a phenomena break in the month of August. The mean annual rainfall is about 1200 mm while the mean maximum and minimum temperatures are 33 and 28 °C, respectively. The relative humidity of the area is relatively high (74%) throughout the year except in January when dry wind (harmattan) blows from the north (Olaniyi, 2006). The soil of the area is classified as a Hapludalf (SSS, 2010), with a sandy loam texture. Some physical and chemical properties of the 0–20 cm layer of the soil used for the experiment are presented in Table 1.

2.2. Experimental design

The study was a two × four factor (wastewater versus type of vegetable) experiment, laid out in a randomized complete block design (RBCD) with three replications. The vegetable factor consisted of SM — Eggplant (*Solanum macrocarpon*) known as *Igbagba* or *Igbo* in Yoruba