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Effects of waste water irrigation on soil properties and soil fauna of spinach fields in a West African urban vegetable production system☆

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ABSTRACT

The usage of inadequately processed industrial waste water (WW) can lead to strong soil alkalinity and soil salinization of agricultural fields with negative consequences on soil properties and biota. Gypsum as a soil amendment to saline-sodic soils is widely used in agricultural fields to improve their soil physical, chemical and hence biological properties. This study aimed at analysing the effects of intensive WW irrigation on the structure and composition of soil-dwelling arthropods on spinach fields (*Spinacia oleracea* L.) in a West African urban vegetable production system. We used gypsum as a soil amendment with the potential to alleviate soil chemical stress resulting in a potentially positive impact on soil arthropods. A total of 32 plots were established that showed a gradient in soil pH ranging from slight to strong soil alkalinity and that were irrigated with WW ($n = 12$) or clean water (CW; $n = 20$), including eight plots into which gypsum was incorporated. Our study revealed a high tolerance of soil-dwelling arthropods for alkaline soils, but spinach fields with increased soil electrical conductivity (EC) showed a reduced abundance of Hymenoptera, Diptera and Auchenorrhyncha. Arthropod abundance was positively related to a dense spinach cover that in turn was not affected by WW irrigation or soil properties. Gypsum application reduced soil pH but increased soil EC. WW irrigation and related soil pH affected arthropod composition in the investigated spinach fields which may lead to negative effects on agronomical important arthropod groups such as pollinators and predators.

1. Introduction

In many cities of Sub-Saharan Africa, urban agriculture heavily relies on the use of industrial waste water (WW) for crop irrigation. But even treated WW frequently does not meet the international standards for agricultural use developed by WHO, FAO and UNEP with potential consequences for ecosystem health and functions (Corcoran, 2010). Particularly of concern in industrial WW used for agriculture is its often high level of sodium and potassium. High concentrations of both salts may cause, due to their accumulation in the soil, strong soil alkalinity leading to a pH above 8.5 (Soil Survey Division Staff, 1993). This may be accompanied by adverse effects on soil structural properties resulting in a compaction layer with low infiltration capacity (Dastorani et al., 2008; Hussain et al., 2002; Sou et al., 2013). In conjunction with high amounts of nitrates, potassium and chloride, sodium is a major driver for salinization processes in soils. This may add to the often reported problems of West African soils that suffer from poor native soil fertility, low organic carbon, low water-holding and cation exchange capacity, surface crusting and high soil surface temperatures (Bationo and Buerkert, 2001). Gypsum, or calcium-sulfate-dihydrate ($Ca[SO_4]\cdot 2H_2O$), has been often used as an amendment in saline-sodic agricultural fields to improve their soil physical and chemical properties. As gypsum dissolves, it releases calcium ions that displace sodium on the clay colloids in alkaline soils thereby improving soil structure (Shainberg et al., 1982). Given these biophysical constraints to plant growth the preservation of soil biological properties is likewise important to secure nutrient turnover, help to suppress soil borne diseases and pests and to maintain bioturbation (Postma-Blaauw et al., 2010; Whitford, 1996). Many studies showed the important role of ground dwelling arthropods

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for nutrient cycling, pedoturbation and sediment transport (Butler, 1995; Garcia and Niell, 1991; Nichols et al., 2008). Particularly ants and termites are known to affect physical and chemical soil properties. The presence of ants can alter soil pH whereby the pH of alkaline soils can be decreased and that of acid soils increased (Frouz and Jilková, 2008). It is well recognized that extreme soil properties such as strong soil alkalinity and high soil salinity influence not only plant performance but also below-ground and above-ground communities of soil biota that are interlinked. However, our understanding about the mechanisms behind the effects of aboveground-belowground feedbacks is still very limited (De Deyn and Van der Putten, 2005; Scherber et al., 2010). Most studies examined invertebrate responses on effects of increased soil pH and soil salinity within the framework of urban ecology (Dunxiao et al., 1999; McIntyre et al., 2001; Santorufo et al., 2012) whereas our knowledge about industrial waste water as driving forces for arthropod distribution within agricultural soils is scarce.

Furthermore, the West African region had received so far little attention regarding the effects of agricultural practises on soil biodiversity, although in Burkina Faso up to 90% of the population depends on agriculture as their main source of income generation.

Hence, this study aimed to analyse the effects of intensive waste water irrigation on the structure and composition of soil-dwelling arthropods found on spinach fields (*Spinacia oleracea* L.) in a West African urban vegetable production system, using gypsum as a soil amendment to alleviate alkalinity-induced stress with potentially positive effects on soil arthropods.

2. Material and methods

2.1. Study site

The study was carried out at Kossodo, a municipal district of Ouagadougou, the rapidly growing capital of Burkina Faso with currently about 1.5 million inhabitants. Ouagadougou lies in the Sudan Savannah characterized by a hot and dry climate with an average annual temperature of 28 °C and a unimodally distributed annual rainfall of 780 mm. The rainy season lasts from late May to mid-October; the study itself was performed in December 2015, the early dry season.

In 2006, at Kossodo a flat area of 35 ha was turned over to cultivation following the creation of a nearby microphyte sewage treatment plant for the WW of a tannery, brewery and slaughterhouse. After installation local farmers soon experienced yield declines in vegetables and initial studies showed strong increases of soil pH to alkaline values as a consequence of the accumulation of sodium and bicarbonates (Sou et al., 2013).

Within the Kossodo area, an experimental side (N 12°25′44.277″ W 1°28′22.394″; 300 m asl, WGS 84) of around 4 ha comprising vegetable fields on soils with different levels of soil alkalinity was established to test effects of gypsum as soil amendment on WW affected soils. The overall aim of these experiments was to investigate the effects of different water qualities and gypsum application on soil health and plant performance. The increase in soil pH of vegetable fields was a result of farmers' WW irrigation schemes and seasonal flooding with WW from blocked and overflowing channels in previous years. Surveys revealed that fields with a pH lower than 7.8 were rainfed and only cultivated during the rainy season. Fields with a soil pH between 7.8 and 8.5 were rainfed and irrigated additionally in times of low rainfall to prolong the cropping season for two or three months. Fields with a soil pH higher than 8.5 were cultivated most of the year and were irrigated regularly with industrial WW resulting in very strongly alkaline soils.

2.2. Experimental design and arthropod sampling

In total twelve fields were selected that showed a gradient in soil pH ranging from slight soil alkalinity (pH 6.8–7.5, Soil Survey Division Staff, 1993) to strong and very strong soil alkalinity (pH > 8.5). All fields were split into three plots, each sized 5 × 6 m. Two plots per field were chosen whereby one plot represented the control and was irrigated with clean water (CW; tap water). The second plot was irrigated with industrial WW. In the third plot of spinach fields with pH higher than 7.8 (n = 8) gypsum was incorporated into soil at the beginning of the rainy season, fifteen weeks before spinach sowing. Depending on soil pH, fields received two different quantities of gypsum with 0.68 kg m^{-2} for fields with soil pH between 7.8 and 8.5 (n = 4), and 1 kg m^{-2} for fields with soil pH higher than 8.5 (n = 4). Plots with gypsum as a soil amendment were irrigated with CW. Clean water (pH 8.9) and industrial WW (pH 9.2) did not differ significantly in their pH but varied widely in their salinity (EC) caused by their sodium, phosphorous and potassium concentration as well as their Total Chemical Oxygen Demand (TCOD; Table 1). For both water qualities spinach fields were irrigated three times per week with an average amount of 12 l m^{-2}.

Fertilization of spinach fields was carried out one day before sowing and 26 days after sowing using 800 g m^{-2} of animal manure (dry matter) and 65 g m^{-2} NPK (15:15:15). To compensate the higher nitrogen content of WW, fields irrigated with clean water were additionally fertilized with 1.8 g m^{-2} urea applied 20 days after sowing.

Soil pH (KCl) and soil electrical conductivity (EC) were measured before, during and after spinach cultivation. Based on these measurements, the turnover rate of pH (soil pH change) and EC (soil EC change) per week was calculated and used to ascertain the soil pH and soil EC at the time of arthropods sampling.

Fresh matter (FM) of spinach leaves was used as a parameter for ground coverage and was measured by harvesting the marketable spinach leaves of six subplots per plot sized 0.75 × 0.40 m each (total size 1.8 m^2) at 39 days after sowing.

Ground active arthropods were sampled using three roofed pitfall traps (diameter top opening = 12 cm) per plot (in total 96).

Table 1
Average chemical composition of clean water and industrial waste water used for irrigation of spinach fields in the urban vegetable production system of Kossodo, Ouagadougou (Burkina Faso) compared with information on the typical range in irrigation waters after Ayers and Westcot (1985) and FAO (1992).

Paramter [unit]	Clean water	Waste water	Usual range in irrigation water
pH (KCl)	8.9	9.2	6.0–8.5
Salinity, EC [$dS \cdot m^{-1}$]	0.2	2.3	0–3
Total Nitrogen [$mg \cdot l^{-1}$]	3.3	4.4	0–10
Chloride [$mEq \cdot l^{-1}$]	0.25	0.17	0–30
Total Chemical Oxygen Demand (TCOD) [$mg \cdot l^{-1}$]	26.7	885	20–200
Magnesium [$mEq \cdot l^{-1}$]	0.5	0.6	0–5
Phosphorus [$mg \cdot l^{-1}$]	0.5	19	0–2
Potassium [$mg \cdot l^{-1}$]	10.4	53.9	0–2
Sodium [$mEq \cdot l^{-1}$]	0.5	21.9	0–40