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ORIGINAL PAPER

Secondary salinity effects on soil microbial biomass

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Abstract Secondary soil salinilization is a big problem in irrigated agriculture. We have studied the effects of irrigation-induced salinity on microbial biomass of soil under traditional cotton (*Gossypium hirsutum* L.) monoculture in Sayhunobod district of the Syr-Darya province of northwest Uzbekistan. Composite samples were randomly collected at 0–30 cm depth from weakly saline (2.3±0.3 dS m^{-1}), moderately saline (5.6±0.6 dS m^{-1}), and strongly saline (7.1±0.6 dS m^{-1}) replicated fields, 2-mm sieved, and analyzed for pH, electrical conductivity, total C, organic C (C_{Org}), and extractable C, total N and P, and exchangeable ions (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, and CO_3^{2-}), microbial biomass (C_{mic}). The Na^{+} and Cl^{-} concentrations were 36-80% higher in strongly saline compared to weakly saline soil. The C_{Org} concentration was decreased by 10% and C_{Ext} by 40% by increasing soil salinity, whereas decrease in C_{mic} ranged from 18-42% and the percentage of C_{Org} present as C_{mic} from 8% to 26%. We conclude that irrigation-induced secondary salinity significantly affects soil chemical properties and the size of soil microflora.

Keywords Salt associated ions · Carbon fractions · Microbial biomass · Cotton · Uzbekistan

Introduction

Salinity is a major concern for irrigated agriculture in arid and semi-arid regions of the world (Vincent et al. 2006). In particular, secondary salinity developed from irrigation is widely responsible for reducing soil and water quality, limiting crop growth, and leading to the abandonment of agricultural lands (Shirokova et al. 2000; Egamberdiyeva et al. 2007). Indiscriminate flood irrigation with poor drainage facilities, deep plowing of marginal and naturally saline soils, overexploitation of groundwater, recycling of drainage outflows for irrigation, and monocropping of high water consumptive crops (e.g., cotton) are the major factors accelerating secondary soil salinization in region of Uzbekistan in Central Asia (Qushimov et al. 2007).

A massive expansion of irrigated agriculture occured during the 1960s making Uzbekistan one of the largest cotton producing countries in the world. The success was made possible through massive construction of thousands of kilometers of canals to divert river water for irrigating cotton. However, land suffering from various degrees of soil salinity is increased from about 48% of the total irrigated lands in 1990 to 64% in 2000.

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While the effects of salinity on soil properties and plant growth are well known (Garcia and Hernandez 1996; Nelson et al. 1997; Kaur et al. 1998; Nelson and Oades 1998), information related to irrigation-induced secondary salinity effects on soil biological properties are limited (Rietz and Haynes 2003; Sardinha et al. 2003; Tripathi et al. 2006).

Soil microflora plays an important role in maintaining and/or enhancing soil quality by regulating organic matter decomposition and nutrient avilablity, enhancing macroaggregate formation. Thus, microbial parameters are sensitive indicators of changes of soil quality in response to mangement practices or environmental stress (Powlson et al. 1987; Islam and Weil 2000; Rietz and Haynes 2003; Wang et al. 2008). Microbial biomass (C_{mic}) and the precentage of organic C (C_{org}) present as C_{mic} can be used to evaluate early warning of soil or ecosystems disturbances (Powlson et al. 1987; Anderson and Domsch 1993; Islam and Weil 2000; Pascual et al. 2000). Therefore, information on C_{mic} and relative ratios can be used as indicators for evaluating the effect of secondary salinization of soil and the effect of the used management practices to improve crop production (Garcia et al. 1994; Pascual et al. 2000).

The objectives of the study were to evaluate the effects of irrigation-induced salinity on C_{mic} and distribution of carbon, nitrogen, phosphorus, and exchangeable ions in irrigated soil under long-term cotton monoculture in Uzbekistan.

Material and methods

Description of the study area and soil sampling

Soil samples were collected from twelve conventionally tilled (0–40 cm depth) irrigated cotton fields affected by various degress of salinity at Sayhunobod district ($41^0 00'$N, $64^0 00'$E) of the Syr-Darya Province of northeast of Uzbekistan. According to the WRB-FAO (2006) classification, the soils of all the selected fields were identified as calcisol (silt loam seirozem) and were formed from loess, eluvial, and proluvial parent materials (FAO 1990). The soils have been cropped to cotton monoculture for the last 50-60 years under flood irrigation without proper drainage facilities using natural flow system. Urea, superphosphate, and muriate of potash were applied at 150-300 kg ha^{-1} $year^{-1}$ as fertilizers. On average, the soil contained 43±9 g sand kg^{-1}, 708±12 g silt kg^{-1}, and 250±13 g clay kg^{-1}, had the cation exchnage capacity of 23.6±1 $cmol_+$ kg^{-1}, with exchangeable Na percentage of 4.41, and Na absorption ratio of 0.32.

The climate of the area is continental with a yearly average rainfall of 200±36 mm and more than 90% of the total rain falling between October to May. The average minimum monthly air temperature is 0°C in January, the maximum of 37°C in July, and the soil temperature ranges between −2 and 35°C. The average highest relative humidity is slightly more than 80% in January and the minimum is less than 45% in June. The combination of high temperatures and low rainfall under continental climate makes irrigation essential for crop production.

The selected fields (3.5 ha each) were categorized into three different salinilty levels based on electrical conductivity (E_C): (1) weakly saline (2.3±0.3 dS m^{-1}), (2) moderately saline (5.6±0.6 dS m^{-1}), and (3) strongly saline (7.1±0.6 dS m^{-1}) soils. In each soil salinity category, four relatively uniform fields were selected as replicates followed by random demarcation of three subplots (1× 1 m) in each replicated field. From each subplot, three soil core (3.5 cm internal diameter) were sampled between plant rows (80 cm apart) at 0–30 cm soil depth before harvesting cotton in September 2005. Other three core samples were collected between plants (40 cm apart) within rows. The soil cores were pooled and mixed to obtain six composite samples for each replicated field, and twenty four replicated composite samples for each salinity level. Composite soil samples were placed in plastic bags, and brought to the laboratory.

Analyses

Soil moist samples were gently sieved through a 2-mm mesh (visible pieces of crop residues and roots were removed) and a portion of the field-moist soil was analyzed for $C_{mic.}$ Another portion of the field-moist soil was air-dried at room temperature, ground, and analyzed for chemical and physical properties.

The C_{mic} was determined on moist soils by the chloroform fumigation-extraction method (Vance et al. 1987). The C_{mic} was calculated as follows: $C_{mic}\left(\mathrm{mg\,C\,kg\,soil}^{-1}\right) = \left(C_f - C_{uf}\right)\mathrm{K}_{ec}^{-1}$ where, C_f is the 0.5 M K_2SO_4 extractable organic C in chloroform fumigated soil, C_{uf} is the 0.5 M K_2SO_4 extractable organic C in unfumigated soil, and K_{ec} is the conversion factor. The ratio C_{mic}/C_{org} was calculated.

Soil texture was determined according to DIN 19683 (1997), soil pH and E_C were measured potentiometrically in a 1:5 (*w*/*v*) soil-aqueous suspension. Contents of total soil carbon (C_t) and total nitrogen (N_t) were determined after dry combustion using a CNS elemental analyzer (LECO Corporation, St. Joseph, MI, USA) according to DIN ISO 10694 (1996), and DIN ISO 15178 (2001), respectively. The C_{Org} content was calculated after substacting inorganic C (carbonate) from the C_T. The C_{Ext} was determined after K_2SO_4 extraction of unfumigated field-moist soil. The content of extractable P, CO_3^{2-}, Cl^{-2}, and the salt associated cations such as K^+, Na^+, Ca^{2+}, Mg^{2+} were

Table 1 Irrigation-induced secondary salinity effects on pH, salt associated ions, total, organic, extractable C, total N and P concentration in soil under cotton monoculture (0–30 cm depth)

Soil salinity	E_C dSm^{-1}	pH	K^+	Ca^{+2}	Mg^{+2} (gkg^{-1})	CO_3^{2-}	N	P	C_T	C_{Org}	C_{Ext} ($mgkg^{-1}$)	Na^+	Cl^-
Weakly saline	2.3	7.9	5.92	53.4	23.7	16.1	1.06	1.30	24.8	8.69	22.1	600.2	52.0
Moderately saline	5.6	7.8	6.45	57.9	22.9	17.2	1.01	1.22	25.4	8.15	17.3	739.2	84.1
Strongly saline	7.1	7.9	6.58	67.4	24.6	17.6	0.95	1.23	24.8	7.19	12.5	813.1	94.2
LSD ($p \leq 0.05$)		ns	0.24	3.3	ns	1.1	0.06	ns	ns	0.62	4.13	91	35

EC electrical conductivity, *K* exchangeable potassium, *Ca* exchangeable calcium, *Mg* exchanageable magnesium, *Na* exchangeable sodium, CO_3 carbonate, and *Cl* chloride, C_T total C, C_{Org} total organic C, C_{Ext} 0.5 M neutral potassium sulfate extractable C, *N* total nitrogen, and *P* total phosphorus

analyzed according to DIN 38414–S (1983). Soil moisture was determined gravimetrically after heating the field-moist soil at 105°C for 24 h until a constant weight was obtained.

Statistical analysis

Significant variation in C_{mic} and selected chemical properties due to the effects of various degress of salinity were evaluated by the analysis of variance (SAS 2001). Due to a lack of significant difference between soil samples collected from “in-between plant rows” vs.”in-between plants”, both soil samples were included as replicats. Salinity effects on soil properties with a value of $P \leq 0.05$ were considered significant.

Results and discussion

The concentration of Ca^{+2}, K^+, Na^+, CO_3^{2-}, and Cl^- was influenced significantly by soil salinity (Table 1) with no significant difference between moderately and strongly saline soils. The Ca^{2+} was the dominant (> 60%) salt associated cation in all soils followed by Mg^{+2}, K^+, and Na^+, respectively. However, soil pH did not vary significantly in response to salinity. Significantly higher concentration of Ca^{2+}, K^+, and Na^+ were associated with CO_3^{-2} and Cl^- and reflected a dominance of CO_3^{-2} and Cl^- in irrigation-induced saline soils under cotton monocropping. The dominance of CO_3^{-2} and Cl^- contents is probably responsible for higher E_C in strongly saline than weakly saline soil (Garcia and Hernandez 1996). In the studied soils, the salt that moved to the surface had a high Ca^{+2}, K^+, Na^+, CO_3^{2-}, and Cl^- concentration.

The C_{Org}, C_{Ext}, N, and P concentrations also depended on soil salinity (Tables 1, 2). However, there was no significant difference in C_{Org}, N, and P concentrations between moderately and strongly saline soils. The adverse effects of irrigation-induced salinity on the C_{Org} content is probably due to gradual dispersion of soil aggregates which may have left organic matter unprotected, and therefore, more susceptible to microbial degradation. However, lower concentration of organic matter in strongly than weakly saline soil can also depend on the reduced crop growth and consequently the reduced C input to soil

Irrigation-induced salinity significantly affected $C_{mic;}$ on average, the C_{mic} was the lowest in strongly saline soil, intermediate in moderately saline soil, and the highest in weakly saline soil (Table 2). The salinity effects on C_{mic} were more drastic (~30%) between strongly and moderately saline soils than (18%) between weakly and moderately saline soils. Consequently the percentage of C_{Org} present as C_{mic} decreased (8-18%) significantly in response to soil salinity. The CO_3^{2-}, Na^+, and Cl^- concentration significantly decreased C_{mic} which may be related to microbial stress; the higher consume of organic per unit of C_{mic} may depend on the need to maintain cell integrity and release Na^+, both processes consume metabolic energy (e.g., ATP; Utsugi et al. 1998) and increase the proportion of labile C respired for microbial biomass unit (qCO_2).

The decrease in C_{mic} was related to toxic effect of Na^+ and Cl^- on soil microflora (Darrah et al. 1987; Garcia and Hernandez 1996; Svarachorn et al. 1998; Pankhurst et al.

Table 2 Irrigation-induced salinity effects on microbial biomass in soil under cotton monoculture (0–30 cm depth)

Soil salinity (E_C)	C_{mic} ($mgkg^{-1}$)	Percentage of C_{Org} present as C_{mic}
Weakly saline (2.3 dS m^{-1})	346.5	3.86
Moderately saline (5.6 dS m^{-1})	284.3	3.56
Strongly saline (7.1 dS m^{-1})	201.5	2.85
LSD ($p \leq 0.05$)	19.2	0.25

E_C electrical conductivity, C_{mic} microbial biomass C, C_{Org} total organic C

2001; Sardinha et al. 2003; Rietz and Haynes 2003; Ndour et al. 2008) as well as due to the osmotic effect (Batra and Manna 1997; Svarachorn et al. 1998; Rietz and Haynes 2003). The C_{mic} responds more quickly to the changes in soil ecosystems than the C_{Org} content, which includes organic pools with a slow turnover due to their association with clays and metals (Böhme and Böhme 2006).

The positive and significant relationship of C_{mic} with C_{Org} suggests that C_{mic} can be used as a sensitive and early indicator of changes in the availability of C_{Org} especially the active organic pool (Powlson et al. 1987; Landgraf and Klose 2002; Islam and Weil 2000, Islam et al. 2000). Since organic matter and microbial activity are typically related to each other (Tables 1 and 2), a significant descrease in organic matter probably intensifies the adverse effects of salinity on C_{mic} (Muhhamad et al. 2006).

In conclusion, irrigation-induced secondary salinity significantly affects soil chemical properties and the C_{mic}. A significantly higher concentration of Ca^{+2}, Na^{+}, CO_3^{2-}, and Cl^{-} with an associated decrease in C and N availability suggests that CO_3^{2-} and Cl^{-} associated Ca^{+2} and Na^{+} salts were responsible for soil salinity and subsequently exerting adverse effects on microbial biomass. Thus, a smaller C_{mic} pool under stress and modified structure of microbial communities may have occurred in saline soils. It may be possible to increase C_{mic} by organic amendments to soil and thus this may be a useful management of irrigated saline soil for cotton production.

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