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*Original Citation:*

Secondary salinity effects on soil microbial biomass / D. Egamberdieva; G. Renella; S. Wirth; R. Islam. - In: BIOLOGY AND FERTILITY OF SOILS. - ISSN 0178-2762. - STAMPA. - 46:(2010), pp. 445-449. [10.1007/s00374-010-0452-1]

*Availability:*

The webpage <https://hdl.handle.net/2158/396117> of the repository was last updated on

*Published version:*

DOI: 10.1007/s00374-010-0452-1

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## Secondary salinity effects on soil microbial biomass

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Received: 9 November 2008 / Revised: 13 February 2010 / Accepted: 15 February 2010 / Published online: 9 March 2010  
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**Abstract** Secondary soil salinization 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 ( $2.3 \pm 0.3$  dS m<sup>-1</sup>), moderately saline ( $5.6 \pm 0.6$  dS m<sup>-1</sup>), and strongly saline ( $7.1 \pm 0.6$  dS m<sup>-1</sup>) replicated fields, 2-mm sieved, and analyzed for pH, electrical conductivity, total C, organic C (C<sub>Org</sub>), and extractable C, total N and P, and exchangeable ions (Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>, Cl<sup>-</sup>, and CO<sub>3</sub><sup>2-</sup>), microbial biomass (C<sub>mic</sub>). The Na<sup>+</sup> and Cl<sup>-</sup> concentrations were 36–80% higher in strongly saline compared to weakly

saline soil. The C<sub>Org</sub> concentration was decreased by 10% and C<sub>Ext</sub> by 40% by increasing soil salinity, whereas decrease in C<sub>mic</sub> ranged from 18–42% and the percentage of C<sub>Org</sub> present as C<sub>mic</sub> 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 occurred 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 availability, enhancing macroaggregate formation. Thus, microbial parameters are sensitive indicators of changes of soil quality in response to management 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 percentage 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 degrees of salinity at Sayhunobod district (41°00'N, 64°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<sup>-1</sup> year<sup>-1</sup> as fertilizers. On average, the soil contained 43±9 g sand kg<sup>-1</sup>, 708±12 g silt kg<sup>-1</sup>, and 250±13 g clay kg<sup>-1</sup>, had the cation exchange capacity of 23.6±1 cmol<sub>+</sub> kg<sup>-1</sup>, 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 salinity levels based on electrical conductivity ( $E_C$ ): (1) weakly saline (2.3±0.3 dS m<sup>-1</sup>), (2) moderately saline (5.6±0.6 dS m<sup>-1</sup>), and (3) strongly saline (7.1±0.6 dS m<sup>-1</sup>) 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 cores (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:  $C_{mic}(\text{mg C kg soil}^{-1}) = (C_f - C_{uf}) K_{ec}^{-1}$  where,  $C_f$  is the 0.5 M K<sub>2</sub>SO<sub>4</sub> extractable organic C in chloroform fumigated soil,  $C_{uf}$  is the 0.5 M K<sub>2</sub>SO<sub>4</sub> 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 subtracting inorganic C (carbonate) from the  $C_t$ . The  $C_{Ext}$  was determined after K<sub>2</sub>SO<sub>4</sub> extraction of unfumigated field-moist soil. The content of extractable P, CO<sub>3</sub><sup>2-</sup>, Cl<sup>-</sup>, and the salt associated cations such as K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> 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 <sup>-1</sup>	pH	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup> (gkg <sup>-1</sup> )	CO <sub>3</sub> <sup>2-</sup>	N	P	C <sub>T</sub>	C <sub>Org</sub>	C <sub>Ext</sub> (mgkg <sup>-1</sup> )	Na <sup>+</sup>	Cl <sup>-</sup>
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

$E_C$  electrical conductivity,  $K$  exchangeable potassium,  $Ca$  exchangeable calcium,  $Mg$  exchangeable 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 degrees 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 replicates. Salinity effects on soil properties with a value of  $P \leq 0.05$  were considered significant.

### Results and discussion

The concentration of Ca<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>, CO<sub>3</sub><sup>2-</sup>, and Cl<sup>-</sup> was influenced significantly by soil salinity (Table 1) with no significant difference between moderately and strongly saline soils. The Ca<sup>2+</sup> was the dominant (> 60%) salt associated cation in all soils followed by Mg<sup>2+</sup>, K<sup>+</sup>, and Na<sup>+</sup>, respectively. However, soil pH did not vary significantly in response to salinity. Significantly higher concentration of Ca<sup>2+</sup>, K<sup>+</sup>, and Na<sup>+</sup> were associated with CO<sub>3</sub><sup>2-</sup> and Cl<sup>-</sup> and reflected a dominance of CO<sub>3</sub><sup>2-</sup> and Cl<sup>-</sup> in irrigation-induced saline soils under cotton monocropping. The dominance of CO<sub>3</sub><sup>2-</sup> and Cl<sup>-</sup> 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<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>, CO<sub>3</sub><sup>2-</sup>, and Cl<sup>-</sup> 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<sub>3</sub><sup>2-</sup>, Na<sup>+</sup>, and Cl<sup>-</sup> 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<sup>+</sup>, 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<sub>2</sub>).

The decrease in  $C_{mic}$  was related to toxic effect of Na<sup>+</sup> and Cl<sup>-</sup> 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)

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

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

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 decrease 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.

## References

- Anderson TH, Domsch KH (1993) The metabolic quotient for  $CO_2$  ( $qCO_2$ ) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils. *Soil Biol Biochem* 25:393–395
- Batra L, Manna MC (1997) Dehydrogenase activity and microbial biomass carbon in salt-affected soils of semiarid and arid regions. *Arid Soil Res Rehab* 11:295–303
- Böhme L, Böhme F (2006) Soil microbial and biochemical properties affected by plant growth and different long-term fertilization. *Eur J Soil Biol* 42:1–12
- Darrah PR, Nye PH, White RE (1987) The effect of high solute concentrations on nitrification rates in soil. *Plant Soil* 97:37–45
- DIN ISO 38414-S (1983) Deutsche Einheitsverfahren zur Wasser, Abwasser und Schlammuntersuchung: Schlamm und Sdediment. Beuth, Berlin
- DIN-ISO 10694 (1996) Bodenbeschaffenheit-Bestimmung von organischem Kohlenstoff und Gesamtkohlenstoff nach trockener Verbrennung (Elementaranalyse). Beuth, Berlin
- DIN ISO 19683 (1997) Bodenuntersuchungsverfahren im Landwirtschaftlichen Wasserbau–Bestimmung der Korngrößenzusammensetzung nach Vorbehandlung mit Natriumpyrophosphat bzw. nach Vorbehandlung mit Wasser. Beuth, Berlin
- DIN ISO 15178 (2001) Bodenbeschaffenheit–Bestimmung des Gesamt-Schwefels durch trockene Verbrennung (Elementaranalyse). Beuth, Berlin
- Egamberdiyeva D, Gafurova L, Islam KR (2007) Salinity effects on irrigated soil chemical and biological properties in the Syr-Darya basin of Uzbekistan. In: Lal R, Sulaimonov M, Stewart BA, Hansen D, Doraiswamy P (eds) *Climate change and terrestrial C sequestration in Central Asia*. Taylor and Francis, New York, pp 147–162
- FAO (1990) Guidelines for soil description. FAO, Rome
- Garcia C, Hernandez T (1996) Influence of salinity on the biological and biochemical activity of a calciorthid soil. *Plant Soil* 178:255–263
- Garcia C, Hernandez T, Costa F (1994) Microbial activity in soils under Mediterranean environmental conditions. *Soil Biol Biochem* 26:1185–1191
- Islam KR, Weil RR (2000) Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. *Soil Water Conserv* 55:69–78
- Islam KR, Mulchi CL, Ali AA (2000) Interactions of tropospheric  $CO_2$  or  $O_3$  enrichments and moisture variations on microbial biomass and respiration in soil. *Glob Chang Biol* 6:255–265
- Kaur B, Aggawal AK, Gupta SR (1998) Soil microbial biomass and nitrogen mineralization in salt affected soils. *Intern J Ecol Environ Sci* 24:103–111
- Landgraf D, Klose S (2002) Mobile and readily C and N fractions and their relationship to microbial biomass and selected enzyme activities in a sandy soil under different management systems. *J Plant Nutr Soil Sci* 165:19–16
- Muhhamad S, Muller T, Joergensen RG (2006) Decomposition of pea and maize straw in Pakistani soils along a gradient in salinity. *Biol Fertil Soils* 43:93–101
- Ndour NYB, Baudoin E, Guissè A, Seck M, Khouna M, Brauman A (2008) Impact of irrigation on soil nitrifying and total bacterial community. *Biol Fertil Soils* 44:797–800
- Nelson N, Oades JM (1998) Organic matter, sodicity, and soil structure. In: Sumner ME, Naidu R (eds) *Sodic soils: distribution, management and environmental consequences*. Oxford University Press, New York, pp 51–75
- Nelson PN, Barzegar AR, Oades JM (1997) Sodicty and clay type: influence on decomposition of added organic matter. *Soil Sci Soc Am J* 61:1052–1057
- Pankhurst CE, Yu S, Hawke BG, Harch BD (2001) Capacity of fatty acid profiles and substrate utilization to describe differences in soil microbial communities associated with increased salinity or alkalinity at three locations of South Australia. *Biol Fertil Soils* 33:204–217
- Pascual JA, Garcia C, Hernandez T (2000) Soil microbial activity as a biomarker of degradation and remediation processes. *Soil Biol Biochem* 32:1877–1883
- Powlson DS, Brooks PC, Christensen BT (1987) Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol Biochem* 19:159–164
- Qushimov B, Ganiev IM, Rustamova I, Haitov B, Islam KR (2007) Land degradation by agricultural activities in Central Asia. In: Lal R, Sulaimonov M, Stewart BA, Hansen D, Doraiswamy P (eds) *Climate change and terrestrial C sequestration in Central Asia*. Taylor and Francis, New York, pp 194–212
- Rietz DN, Haynes RJ (2003) Effects of irrigation-induced salinity and sodicty on soil microbial activity. *Soil Biol Biochem* 35:845–854
- Sardinha M, Müller T, Schmeisky H, Joergensen RG (2003) Microbial performance in soils along a salinity gradient under acidic conditions. *Appl Soil Ecol* 23:237–244
- SAS Institute (2001) SAS user's guide. R 8.2. SAS Institute, Inc, Cary
- Shirokova Y, Forkutsa I, Sharafutdinova N (2000) Use of electrical conductivity instead of soluble salts for soil salinity monitoring in Central Asia. *Irrig Drain Syst* 14:199–205

- Svarachorn A, Shinmyo A, Tsuchido T, Takano M (1998) Autolysis of *Bacillus subtilis* induced by monovalent cations. *Appl Microbiol Biotechnol* 30:299–304
- Tripathi S, Kumari S, Chakraborty A, Gupta A, Chakrabarti A, Bandyapadhyay KB (2006) Microbial biomass and its activities in salt-affected coastal soils. *Biol Fertil Soils* 42:273–277
- Utsugi S, Sakamoto M, Murata M, Motoyoshi F (1998) *Arabidopsis thaliana* vegetative storage protein (VSP) genes: gene organization and tissue-specific expression. *Plant Mol Biol* 38:565–576
- Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass C. *Soil Biol Biochem* 19:703–707
- Vincent B, Marlet S, Vidal A, Bouarfa S, Wu J, Yang J, N'Diaye MK, Kuper M, Zimmer D (2006) Water and soil salinity management and salt redistribution in irrigation systems. In: Combating global soil and land degradation IV. Salinization, sodification and other forms of degradation in agricultural and native ecosystems. Proc. 18th World Congress of Soil Science, Philadelphia, PA, USA. July 9–15
- Wang VNL, Dalal RC, Greene RSB (2008) Salinity and sodicity effects on respiration and microbial biomass of soil. *Biol Fertil Soils* 44:943–953
- WRB-FAO (2006) World reference base for soil resources 2006. World Soil. Resources Reports No. 103. Rome