Journal of the Indian Society of Soil Science, Vol. 66, No. 4, pp 386-391 (2018)
DOI: 10.5958/0974-0228.2018.00048.8

Irrigation-induced Salinization Effects on Soil Chemical and Biological Properties under Cotton-Wheat Rotation on Loamy Sand Soil in Northwest India

Pawitar Singh*, O.P. Choudhary and M.S. Mavi
Department of Soil Science, Punjab Agricultural University, Ludhiana, 141004, Punjab

Secondary soil salinilization is a major problem in irrigated agriculture. We studied the effects of irrigation-induced salinity on soil biological and chemical properties under cotton-wheat rotation at experimental farm, Punjab Agricultural University, Ludhiana, India. Sixty fresh soil samples were collected from 0-15 cm and 15-30 cm soil depth irrigated with different levels of saline water (EC 0, EC 3, EC 6, EC 9 and EC 12 dS m^{-1}). The soil samples were analyzed for soil chemical properties (pH, EC, SAR, soluble ions (Na^+, K^+, Ca^{2+} + Mg^{2+} and Cl^-), soil fertility parameters (organic C, available N and P) and biological properties namely, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), dehydrogenase activity (DHA) and cold water extractable carbon (CWEC). Increasing salinity of irrigation water significantly increased soil pH, EC, SAR, soluble Na^+ and Cl^- content and decreased organic C, N and P content at two soil depths. At highest salinity level, (EC 12 dS m^{-1}), DHA, MBC and CWEC decreased by 54.8, 52.9 and 45.6 per cent and MBN by 70 per cent compared to control at 0-15 cm soil depth. The results revealed that similar trend was observed in case of 15-30 cm soil depth for all biological properties but percentage decrease was more over control at highest salinity level of irrigation water. It may be concluded that at higher salinity levels (EC 9 and 12 dS m^{-1}), soil chemical and biological properties were more affected compared to low salinity levels.

Key words: Salinity, soil fertility, microbial biomass carbon, microbial biomass nitrogen, soil depth

Soil salinity is a part of natural ecosystems under arid and semi-arid conditions and an increasing problem in agricultural soil throughout world (Qadir *et al.* 2000). Primary salinization is a natural process of accumulation of salts in the soil profile that are released due to weathering of rocks and minerals particularly salt rich parent materials. Secondary salinity developed due to irrigation is widely responsible for reducing soil and water quality and limiting crop growth leading to abandonment of agricultural lands (Shirokova *et al*. 2000). Indiscriminate flood irrigation with poor drainage facilities, overexploitation of groundwater, recycling of drainage outflows for irrigation and mono-cropping of high water consumptive crops are the major factors accelerating secondary soil salinization in Mediterranean regions and in Central Asia (Qushimov *et al*. 2007). While the effects of soil salinity on soil properties and plant growth are well known (Nelson *et al*. 1997; Kaur *et al*. 1998), information related to irrigation-induced secondary salinity effects on soil biological properties is limited and inadequate (Rietz and Haynes 2003; Tripathi *et al*. 2006).

Soil microbial communities and their activity are greatly influenced by salinity because microbial processes in soils control ecological function and soil fertility (Rietz and Haynes 2003; Chowdhury *et al*. 2011). Soil microflora plays an important role in maintaining or enhancing soil quality by regulating organic matter decomposition, nutrient availability and enhancing macro-aggregate formation. The microbial biomass carbon (MBC) is an important component of soil organic matter (SOM) and comprises 1-3% of total organic carbon (TOC). It has a rapid turnover rate and is also considered to be a reservoir of labile nutrients. The microbial biomass and water-extractable pools of soil organic carbon (SOC) are considered sensitive indices that characterize changes in biological conditions caused by soil management practices. Microbial biomass is also a potential source of enzymes in soil. Among the

*Corresponding author (Email: pawitar88@gmail.com)

different enzymes in soils, dehydrogenase (DHA), β-glucosidase, urease and phosphatases are important in the transformation of different plant nutrients. The DHA reflects the total oxidative capacity of the microbial biomass and β-glucosidase is involved in the production of glucose, which constitutes an important energy source for the microbial mass. The phosphatases play an important role in the transformation of organic phosphorus (P) into inorganic forms more appropriate for plants. Urease predominates amongst the enzymes involved in the N cycle of the soil (Tabatabai 1994; Cookson 1999).

Thus, microbial parameters are sensitive indicators of changes of soil quality in response to management practices or environmental stress (Rietz and Haynes 2003; Wang *et al*. 2008; Setia *et al*. 2010).

Earlier Egamberdieva *et al*. (2010) evaluated the effect of irrigation-induced salinity on soil microbial biomass and soil chemical properties under mono-cropping cotton system for 0-30 cm soil, but they have not studied soil biological properties such as microbial biomass nitrogen (MBN), DHA and cold water extractable carbon (CWEC). Therefore, the present study was carried out to see the MBC, MBN, DHA and CWEC at two soil depths (0-15 and 15-30 cm) under long-term cotton-wheat rotation (major cropping system in saline water inflicted areas of southwestern Punjab) with five levels of saline irrigation water.

Material and Methods

Experiment details

Sixty fresh soil samples were collected from ongoing long-term (18 years) experiment at two soil depths (0-15 and 15-30 cm), irrigated with five salinity levels under cotton-wheat rotation at research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana, in semi-arid northwestern India (30°56′ N, 75°52′E 247 m above mean sea level). The experiment was laid out using randomized complete block design with three replications in thirty plots of size 2 m × 2 m. Each plot was effectively isolated from adjoining plots by polyethylene sheet lined to a 1 m depth and 0.5 m wide walkways all around to avoid lateral fluxes of water and salts. The soil at the experimental site was a well-drained sandy loam soil (Typic Ustochrept) with a water table always remaining below 10 m and had pH 7.3, EC 0.30 dS m^{-1} (measured in 1:2 soil: water suspension), organic carbon 2.9 g kg^{-1} and exchangeable sodium percentage (ESP) 4.2% in 0-30 cm soil depth before start of the experiment. Water used for irrigation in this study included good quality water (EC 0) having electrical conductivity of 0.5 dS m^{-1}. Four levels of poor quality saline water were synthesised by dissolving 1.77 g (EC 3), 3.50 g (EC 6), 5.31 g (EC 9) and 7.08 g (EC 12) of NaCl per liter in good quality water, respectively. The irrigation water was conveyed into a given plot through a 5-cm diameter hose-pipe attached to a drum through which a given depth of irrigation water can be applied. Each irrigation consisted of 60 mm water that was applied after the same amount of water had evaporated as measured from the USDA Class A pan. Depending upon the amount and distribution of rainfall received, number of irrigations given to cotton and wheat crop varied from 4 to 6 during crop growth period.

Soil analysis

Soil samples from each replication were taken with an auger (4 cm diameter) from 0-15 and 15-30 cm depths. Sixty moist soil samples were gently sieved through a 2-mm mesh and analyzed for soil biological properties. Another portion of the field-moist soil was air-dried at room temperature, ground and analyzed for chemical properties. The MBC was determined by the chloroform fumigation-extraction method (Vance *et al*. 1987). The MBC was calculated as follows: microbial biomass carbon (mg C kg^{-1} soil) = $(C_f - C_{uf})\, K_{ec}^{-1}$ 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}^{-1} is the conversion factor. The MBN is calculated as MBN = EN / kEN, where, EN = (total N extracted from fumigated soils) – (total N extracted from non-fumigated soils) and kEN = 0.54 (Brookes *et al.* 1985; Joergensen and Mueller 1996). Total N in the extracts was measured using the Kjeldahl method (Bremner and Mulvaney 1982; Brookes *et al.* 1985). The CWEC was determined by shaking 10 g of soil with 50 mL of distilled water for 30 min and then centrifuging for 10 min at 5000 rpm (Ghosh 2003). The organic carbon in the supernatant was measured by the dichromate digestion method (Walkley and Black 1934). The DHA was assayed by the method given by Casida *et al*. (1964). Soil samples were incubated with 2,3,5-triphenyl tetrazolium chloride at 37 °C for 24 h and the produ-ction of triphenyl formazan (TPF) was measured.

Organic carbon, available N and P was determined by Walkley and Black (1934), alkaline permanganate (Subbiah and Asija 1956) and 0.05*M* $NaHCO_3$ at pH 8.5 (Olsen *et al.* 1954) methods, respectively. Soluble ions were determined using the method described by Richards (1954). Soil texture was determined by standard international pipette method. The USDA size fractions for separation of sand (0.02-2.0 mm) by gravity sedimentation method of Day (1965) were followed. Sand was separated by using 70-mesh sieve. The clay (<0.002 mm) content was separated from silt using 0.1*N* solution of sodium hexametaphosphate as dispersing agent. Soil pH and EC in a 1:2 (w/v) soil-aqueous suspension were measured using potentio metric method and salt bridge method as described by Richards (1954).

Statistical analysis

Significant variations in selected chemical and biological properties due to the effect of variable salinity levels were evaluated by the analysis of variance (ANOVA) using CPCS1 software. Pearson's correlation was calculated between soil chemical and biological properties for 0-30 cm soil depth for sixty soil samples at 5% level of significance.

Results and Discussion

Soil chemical properties

Increasing irrigation water salinity levels increased soil pH and EC at 0-15 and 15-30 cm soil depths (Table 1). Soil EC significantly and progressively increased from 0.61 in CW to 0.91, 1.88, 2.32 and 2.41 dS m^{-1} at 0-15 cm and from 0.54 in EC treatment to 0.83, 1.76, 2.20 and 2.35 dS m^{-1} under EC 3, EC 6, EC 9 and EC 12 dS m^{-1} salinity levels, respectively. Organic carbon, available N and P significantly decreased at two soil depths with increasing salinity of irrigation water. Average OC content decreased from 3.9 to 1.7 g kg^{-1} at 0-15 cm and 3.4 to 1.5 g kg^{-1} for 15-30 cm soil depth as salinity levels increased from EC 0 to EC 12 dS m^{-1}. Yuan *et al.* (2007) reported decrease in soil OC content from 10.7 to 3.1 g kg^{-1} as soil salinity increased from 0.3 to 23.1 mS m^{-1}. Compared to EC 0, available N decreased by 42.7 and 40.3% at highest level of salinity (EC 12 dS m^{-1}) at 0-15 and 15-30 cm soil depths. The presence of salts in soil affects N availability through inhibition of microbial N mineralization and immobilization processes and also due to increasing soil pH (Grattan and Grieve 1999). Available P content decreased from 45.6 kg ha^{-1} in control to 40.9, 36.7, 29.1 and 22.8 kg ha^{-1} at EC 3, 6, 9 and 12 dS m^{-1} for 0-15 cm soil depth and correspondingly from 37.8 to 32.4, 28.7, 24.2 and 20.7 at 15-30 cm soil depth at respective salinity level. Awad *et al.* (1990) reported that with increasing NaCl salinity from 10 to 100 mM in the solution culture, P activity decreased as a result of increased ionic strength and competition caused due to high Cl^- ions. The concentration of soluble Na^+, K^+ and Cl^- were significantly influenced by irrigation water salinity whereas significant differences were observed for $Ca+Mg^{2+}$ at two soil depths (Table 2). Soluble Na^+ content significantly increased and soluble K^+ content decreased with increasing salinity of irrigation water because saline waters dominated with NaCl suppressed potassium solubility. El-Boraie (1997) reported that soluble K^+ was decreased at increasing salinity levels. Sodium adsorption ratio (SAR) significantly increased from 1.8 to 15.5 and from 1.3

Table 1. Secondary salinity effects on soil pH, EC, SAR, organic C and available N and P content (0-15 and 15-30 cm soil depth)

Treatments	pH	EC (dS m^{-1})	SAR	OC (g kg^{-1})	N (kg ha^{-1})	P (kg ha^{-1})
			0-15 cm			
EC 0	7.20	0.61	1.8	3.9	146	45.6
EC 3	7.34	0.91	8.0	3.2	133	40.9
EC 6	7.80	1.88	10.8	2.7	121	36.7
EC 9	8.07	2.32	12.9	2.2	99.4	29.1
EC 12	8.20	2.41	15.5	1.7	83.6	22.8
LSD (5%)	0.05	0.04	2.8	0.44	1.12	4.8
			15-30 cm			
EC 0	7.29	0.54	1.3	3.4	135	37.8
EC 3	7.48	0.83	5.8	2.9	127	32.4
EC 6	7.88	1.76	8.2	2.3	113	28.7
EC 9	8.18	2.20	10.0	2.0	91.3	24.2
EC 12	8.27	2.35	12.5	1.5	80.5	20.7
LSD (5%)	0.05	0.02	2.0	0.48	2.60	5.1

Table 2. Secondary salinity effect on soluble ions (0–15 and 15-30 cm soil depth)

Treatments	Na	Ca+Mg	K	Cl
		0-15 cm		
EC 0	0.9	0.49	6.3	0.5
EC 3	3.9	0.47	5.3	2.5
EC 6	5.0	0.43	4.9	4.0
EC 9	5.7	0.39	3.4	5.1
EC 12	6.3	0.33	3.0	6.2
LSD (5%)	0.14	NS	0.59	0.65
		15-30 cm		
EC 0	0.6	0.44	5.7	0.4
EC 3	2.6	0.41	5.1	1.9
EC 6	3.6	0.38	3.5	3.5
EC 9	4.1	0.34	2.8	4.7
EC 12	4.8	0.29	2.2	6.0
LSD (5%)	0.14	NS	0.20	0.65

Table 3. Secondary salinity effect on DHA, MBC, MBN and CWEC (0-15 and 15-30 cm soil depth)

Treatments	DHA	MBC	MBN	CWEC
		0-15 cm		
EC 0	33.2	236	94.4	66.0
EC 3	29.8	187	78.5	61.8
EC 6	25.1	166	55.6	50.4
EC 9	21.3	127	29.3	43.7
EC 12	15.0	111	22.2	35.9
LSD (5%)	3.3	3.7	3.3	6.9
		15-30 cm		
EC 0	26.2	225	80.4	51.3
EC 3	23.5	173	59.5	48.7
EC 6	19.3	138	42.3	39.2
EC 9	13.5	110	24.8	32.5
EC 12	9.9	87	18.6	27.1
LSD (5%)	4.5	2.5	2.6	5.8

DHA (µg TPF h^{-1} g^{-1} soil), MBC, MBN and CWEC were measured in mg kg^{-1} units

to 12.5 due to increase in EC from control to 12 dS m^{-1} for 0-15 and 15-30 cm soil depths, respectively. Mahdy (2011) reported that SAR increased from 5.29 to 8.27 with increasing salinity of irrigation water from 0.5 to 8.70 dS m^{-1}. Fard *et al.* (2007) also reported that increasing irrigation water salinity resulted in increased SAR and effects were more in surface as compared to sub-surface soil layer. Soluble Cl^- content increased from 0.5 in EC 0 (control) to 2.5, 4.0, 5.1 and 6.2 me L^{-1} at 0-15 cm and 0.4 in control to 1.9, 3.5, 4.7 and 6.0 me L^{-1} at EC 3, 6, 9 and 12 dS m^{-1}, salinity levels, respectively. Soluble Cl^- content increased due to addition of NaCl through saline irrigation water. Similar results were also reported by Mahdy (2011).

Soil biological properties

Soil biological properties were adversely affected due to salinity of irrigation water (Table 3). The DHA significantly decreased by almost 2 times at 0-15 cm and 3 times for 15-30 cm soil depth at EC 12 dS m^{-1} salinity level compared with control. This decrease in DHA may be due to lower MBC present in highly saline soils (Garcia *et al.* 1994). Batra and Manna (1997) observed that DHA decreased significantly from 48.8 to 21.5 µg TPF h^{-1} g^{-1} soil as salinity of soil saturation extract increased from 28 to 40.8 dS m^{-1} in 0-15 cm soil layer. Tripathi *et al.* (2007) observed that DHA activity decreased by 26.1, 44.4 and 74.4 per cent, respectively during monsoon, winter and summer season at ECe 6.9 dS m^{-1} over control. They reported that more decrease in DHA in summer season due to lesser MBC due to soil desiccation and increased salinity. Compared to EC 0, mean MBC decreased by 20.6, 29.4, 46.2 and 52.8 per cent at 0-15 cm and 22.8, 38.4 50.8 and 61.0 per cent for 15-30 cm soil depth at EC 3, 6, 9 and 12 dS m^{-1} salinity levels, respectively. Decrease in MBC caused due to toxic effects of Na and Cl on soil microflora (Pankhurst *et al.* 2001; Ndour *et al.* 2008) as well as due to osmotic effects (Rietz and Haynes 2003).

Table 4. Pearson's Correlation between soil chemical and biological properties for 0-30 cm soil depth (n=60)

	pH	EC	SAR	OC
DHA	-0.94**	-0.92**	-0.91**	0.95**
MBC	-0.97**	-0.96**	-0.98**	0.98**
MBN	-0.99**	-0.98**	-0.96**	0.98**
CWEC	-0.97**	-0.96**	-0.91**	0.95**

**Significant at 1%

Microbial biomass N showed the same trend as that of MBC with increasing salinity of irrigation water. It decreased from 94.4 to 22.2 mg kg^{-1} and from 80.4 to 18.6 mg kg^{-1} at 0-15 cm and 15-30 cm as salinity levels increased from EC 0 to EC12 dS m^{-1}. Shah and Shah (2011) reported decrease in MBN from 113.8 (EC_{soil} < 4 dS m^{-1}) to 24.8 mg kg^{-1} (EC_{soil} > 12 dS m^{-1}) in saline soils. Yuan *et al* (2007) also reported decrease in MBN from 32.8 to 17.4 mg kg^{-1} as soil salinity increased from 0.32 to 5.2 mS m^{-1}. Compared to control, CWEC decreased by about 50% at EC 12 dS m^{-1} in both soil depths. Since organic matter and microbial activity are typically related to each other (Tables 1 and 3), a significant decrease in organic carbon probably intensifies the adverse effects of salinity on soil microbial biomass (Muhhamad *et al.* 2006). All three soil chemical properties (pH, EC and SAR) are highly and significantly correlated with biological properties (Table 4); the effect of soil pH and EC were pronounced and was similar to the effect of soil OC on all biological parameters. It suggests that soil EC and pH should be considered as indicator of changes in biological soil health in soil salinized due to irrigation with saline waters.

In conclusions, at higher salinity levels (EC 9 and 12 dS m^{-1}), adverse effect on soil chemical and biological properties were pronounced compared with low salinity levels (below 6 dS m^{-1}).

References

Awad, A.S., Edwards, D.G. and Campell, L.C. (1990) Phosphorus enhancement of salt tolerance of tomato. *Crop Science* **30**, 123-128.

Batra, L. and Manna, M.C. (1997) Dehydrogenase activity and microbial biomass carbon in salt-affected soils of semiarid and arid regions. *Arid Soil Research Rehabilitation* **11**, 295-303.

Bremner, J.M. and Mulvaney, C.S. (1982) Total Nitrogen. In *Methods of Soil Analysis*, *Part 2. Chemical and Microbiological Properties* (A.L. Page, R.H. Miller and D.R. Keeney, Eds.), American Society of Agronomy, Madison, Wisconsin, USA, pp. 595-624.

Brookes, P.C., Landman, A., Pruden, G. and Jenkinson, D. S. (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method for measuring microbial biomass nitrogen in soil. *Soil Biology and Biochemistry* **17**, 837-842.

Casida, L.E., Klein, D.A. and Santoro, T. (1964) Soil dehydrogenase activity. *Soil Science* **98**, 371-376.

Choudhary, O.P., Gill, J.K. and Bijay-Singh (2013) Water-extractable carbon pools and microbial biomass carbon in sodic water-irrigated soils amended with gypsum and organic manures. *Pedosphere* **23**, 88-97.

Chowdhury, N., Marschner, P. and Burns, R. (2011) Response of microbial activity and community structure to decreasing soil osmotic and matric potential. *Plant and Soil* **344**, 241-254.

Cookson, P. (1999) Special variation in soil urease activity around irrigated date palms. *Arid Soil Research and Rehabilitation* **13**, 155-169.

Day, P.R. (1965) *Particle fractionation and particle size analysis. Methods of Soil Analysis*. Madison, Wisconsin, USA, pp. 545-567.

Egamberdieva, D., Renella, G., Wirth, S. and Islam, R. (2010) Secondary salinity effects on soil microbial biomass. *Biology and Fertility of Soils* **46**, 445-449.

El-Boraie, F.M. (1997) A study on the water management under arid conditions. *M.Sc. Thesis*, Faculty of Agriculture, in Shams University, Egypt.

Fard, B.M., Heidarpour, M. Aghakhani, A. and Feizi, M. (2007) Effects of irrigation water salinity and leaching on soil chemical properties in an arid region. *International Journal of Agriculture and Biology* **9**, 466-469.

Garcia, C., Hernandez, T. and Costa, F. (1994) Microbial activity in soils under Mediterranean environmental conditions. *Soil Biology and Biochemistry* **26**, 1185-1191.

Ghosh, B.N. (2003) Relationship between microbial biomass and extractable organic carbon in pine forest and agricultural soils in mid-hills of N-W Himalayas. *Journal of the Indian Society of Soil Science* **51**, 301-304.

Grattan, S.R. and Grieve, C.M. (1999) Salinity mineral nutrient relations in horticultural crops. *Science Horticulture* **78**, 127-157.

Joergensen, R.G. and Mueller, T. (1996) The fumigation extraction method to estimate soil microbial biomass: calibration of the kEN value. *Soil Biology and Biochemistry* **28**, 33-37.

Kaur, B., Aggarwal, A.K. and Gupta, S.R. (1998) Soil microbial biomass and nitrogen mineralization in salt affected soils. *International Journal of Ecology and Environment Science* **24**, 103-111.

Mahdy, A.M. (2011) Soil properties and wheat growth and nutrients as affected by compost amendment under saline water irrigation. *Pedosphere* **21**, 773-781.

Muhhamad, S., Muller, T., Joergensen, R.G. (2006) Decomposition of pea and maize straw in Pakistani soils along a graident in salinity. *Biology and Fertility of Soils* **43**, 93-101.

Ndour, N.Y.B., Baudoin, E., Guissè, A., Seck, M., Khouna, M. and Brauman, A. (2008) Impact of irrigation on soil nitrifying and total bacterial community. *Biology and Fertility Soils* **44**, 797-800.

Nelson, P.N., Barzegar, A.R. and Oades, J.M. (1997) Sodicity and clay type: influence on decomposition of added organic matter. *Soil Science Society of American Journal* **61**, 1052-1057.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. (1954) Estimation of available phosphorus by extraction with sodium bicarbonate. *United States Department of Agriculture Circular* **939**.

Pankhurst, C.E., Yu, S., Hawke, B.G. and Harch, B.D. (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. *Biology and Fertility Soils* **33**, 204-217.

Qadir, M., Ghafoor, A. and Murtaza, G. (2000) Amelioration strategies for saline soils: a review. *Land Degradation and Development* **11**, 501-521.

Qushimov, B., Ganiev, I.M., Rustamova, I., Haitov, B. and Islam, K.R. (2007) Land degradation by agricultural activities in Central Asia. In *Climate Change and Terrestrial C Sequestration in Central Asia* (R. Lal, M. Sulaimonov, B.A. Stewart, D. Hansen and P. Doraiswamy, Eds.), Taylor and Francis, New York, USA, pp. 194-212.

Richards, L.A. (1954) *Saline and Alkali Soils*. United SDA Agric Handbook 60, pp. 49-50.

Rietz, D.N. and Haynes, R.J. (2003) Effects of irrigation-induced salinity and sodicity on soil microbial activity. *Soil Biology and Biochemistry* **35**, 845-854.

Setia, R., Marschner, P., Baldock, J. and Chittleborough, D. (2010) Is CO_2 evolution in saline soils affected by an osmotic effect and calcium carbonate? *Biology and Fertility of Soils* **46**, 781-792.

Shah, S. and Shah, Z. (2011) Changes in soil microbial characteristics with elevated salinity. *Sarhad Journal of Agriculture* **27**, 233-243.

Shirokova, Y., Forkutsa, I. and Sharafutdinova, N. (2000) Use of electrical conductivity instead of soluble salts for soil salinity monitoring in Central Asia. *Irrigation and Drainage System* **14**, 199-205.

Subbiah, B.V. and Asija, G.L. (1956) A rapid procedures for the estimation of available nitrogen in soils. *Current Science* **25**, 259-260.

Tabatabai, M.A. (1994) Soil enzymes. In *Methods of Soil Analysis*. Part 2. *Microbial and Biochemical Properties* (R.W. Weaver, J.S. Angel and P.S. Bottomley, Eds.), Soil Science Society America, Madison, WI, USA, pp. 775-833.

Tripathi, S., Chakraborty, A., Chakrabarti, K. and Bandyopadhyay, B.K. (2007) Enzyme activities and microbial biomass in coastal soils of India. *Soil Biology and Biochemistry* **39**, 2840-2848.

Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, A. and Bandyapadhyay, K.B. (2006) Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils* **42**, 273-277.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. (1987) An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* **19**, 703-710.

Walkley, A. and Black, C.A. (1934) An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-39.

Wang, V.N.L., Dalal, R.C. and Greene, R.S.B. (2008) Salinity and sodicity effects on respiration and microbial biomass of soil. *Biology and Fertility of Soils* **44**, 943-953.

Yuan, B.C., Li, Z.Z., Liu, H., Gao, M. and Zhang, Y.Y. (2007) Microbial biomass and activity in salt affected soils under arid conditions. *Applied Soil Ecology* **35**, 319-328.

Received 5 July 2018; Accepted 15 December 2018