CHANGES IN SOIL MICROBIAL CHARACTERISTICS WITH ELEVATED SALINITY

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ABSTRACT

Changes in microbial characteristics in soils with increasing salinity were measured in 30 soil samples belonging to Kattikhel and Dargai soil series occuring in Khyber Pakhtunkhwa of North West Pakistan during 2009. Microbial characteristics including microbial biomass C, microbial biomass N, C/N ratio in microbial biomass, N mineralization, nitrification, rate of CO_2 evolution and cumulative CO_2 production were measured. The soils used in the study were alkaline in reaction and had electrical conductivity (EC) gradient from 0.63-32.3 dS m^{-1}. All microbial indices showed a decreasing trend with increasing EC. The average microbial biomass C of soils decreased from 391 mg kg^{-1} in soils with EC of <4.0 dS m^{-1} to 209 mg in soils with EC of >12 dS m^{-1}. The same trend was observed for microbial biomass N, N mineralization, nitrification, rate of CO_2 evolution and cumulative CO_2 production with respect to elevated EC. The C/N ratio of soil microbial biomass increased with increasing salinity. These results suggested that soil microbial biomass were highly sensitive to salinity and can be used as indicator for management of salt affected soils.

Key Words: **Electrical conductivity, microbial biomass, mineralization, nitrification, C/N ratio**

Citation: Shah, S.A. and Z. Shah. Changes in soil microbial characteristics with elevated salinity. 2011. Sarhad J. Agric 27(2): 233-244

INTRODUCTION

Soil degradation through salinity and sodicity is of universal concern. Soil salinity adversely affects plant growth or function due to osmotic stress, ion toxicity or decreased absorption of essential nutrients (Lauchli and Epstein, 1990). High salts levels often causes poor physical and chemical soil characteristics including low aggregate stability, impervious subsoil layers, low infiltration rates, low hydraulic conductivities, and soil surface crusting which in turn prevent seedling emergence and inhibit plant growth (Richards, 1954; Lauchli and Epstein, 1990; Rhoades, 1990; Shainberg, 1990; Josan *et al.* 1998; Levy *et al.* 2002; Sardinha *et al.* 2003; Choudhary *et al.* 2004; Sharma and Minhas, 2005).

In the arid and semi-arid sub-tropical region of Pakistan, salinity is usually combined with high pH conditions, due to the presence and enrichment of calcium carbonate in the uppermost soil layers (alkaline saline soils) or to hydrolysis of sodium carbonate (sodic soils). In these regions, shallow water tables and improper irrigation practices often accelerate salinisation. Consequently, salinity affects 30% of arable land and is a major threat to plant growth (Sandhu and Qureshi, 1986; Qureshi and Barret-Lenard, 1998). Monovalent cations such as sodium play a very important role in deflocculating clay particles and consequently increasing the tendency to slake, disperse and swell under specific conditions, so that soils become impermeable and ultimately infiltration and percolation of water cease from the upper surface and within the soils (Keren, 2000; Qadir and Schubert, 2002).

High salts content not only affect physical and chemical properties of soil but also affect microbiological properties of soil. Increases in salinity have been shown to decrease soil respiration rates and the soil microbial biomass (Laura, 1973; Laura, 1976; Pathak and Rao, 1998). The reason for the reduced size and activity of the microbial community with increasing salinity is likely to be osmotic stress which is caused by large concentrations of salts in soil solutions (Galinski, 1995; Oren, 1999). Osmotic stress usually limits microbial growth and activity in saline soil, while under sodic condition, ion toxicities and adverse pH conditions may also inhibit microbial growth (Rietz and Haynes, 2003). Specific ion toxicities (e.g. those of Na and Cl) may also tend to inhibit microbial growth in saline soil (Zahran, 1997). The activity of exo-cellular enzymes involved in C (β-glucosidase) mineralization declined exponentially with increasing salinity (Rietz *et al.* 2001). Reduction in soil microbial biomass due to increased salinity caused a substantial exponential decline in potentially mineralizable N. The salinity induced reduction of fungi may reduce the decomposition of complex organic materials in saline soils (Bardan, 1994). The mineralization and immobilization of N (Bandyopadhyay and Bandyopadhyay, 1983), nitrification and ammonification (Wollenweber and Zechmeister-Boltenstern, 1989) were decreased in saline soils. Conditions which disturb the N cycle or that lead to the disappearance of nitrate from saline soil through the denitrification process might affect soil fertility and the existence of plants and microorganisms in these habitats. Increasing salinity and sodicity resulted in a progressively smaller, more stressed microbial community which was less metabolically efficient (Yuan *et al*. 2007). It is considered that agriculture induced salinity and sodicity not only influences the chemical and physical characteristics of soils but also greatly affects soil microbial and biochemical properties (Rietz and Haynes, 2003).

Microbial indicators are implemented in some soil monitoring programs in European countries. The most commonly used microbial indicators for soil health monitoring are microbial biomass, microbial quotient and soil respiration (Nielsen and Winding, 2002). The activity of the microbial biomass is commonly used to characterize the microbiological status of soil (Nannipieri *et al.* 1990). Similarly, increasing sodicity levels have had slight negative correlations with C mineralisation (Nelson *et al.* 1997), and caused a decrease in the amount of soil microbial biomass (Chander *et al.* 1994). According to Tripathi *et al.* (2006), a decrease in microbial biomass C and microbial activities with a rise in salinity is probably one of the reasons for poor crop growth in coastal saline soils. Higher amounts of carbonates and bicarbonates of mainly sodium in sodic soil and sodic water irrigated soil substantially deteriorate soil physical properties (such as soil permeability and soil aeration) due to swelling and dispersion of clay particles, in addition to increased pH, EC, and exchangeable sodium percentage (Ayers and Westcot, 1985; Minhas *et al.* 2007).

The central objective of the present research was to analyze the associations between soil chemical properties (pH, salinity indices and SAR) and soil biological properties in Khyber Pukhtunkhwa soils, investigating 30 typical alkaline and saline arable or cultivable waste soils. The hypothesis were: (1) increasing salinity and increasing alkalinity both have depressive effect on microbial biomass and activity indices and (2) increasing salinity and increasing alkalinity both influence N mineralization negatively and thus low N availability could be expected in these soils.

MATERIALS AND METHODS

Site Characteristics

A laboratory incubation experiment was conducted to evaluate microbial biomass and activities in salt affected soils collected from Charsadda and Mardan districts in March, 2009 (Table I). The Charsadda district is situated between 34°03’ and 34°38’ N and 71°28’ and 71°35’ E with main crops grown are tobacco, sugarcane, sugar beet and rice. The soils are mostly water logged and saline or saline sodic with heavy texture. Salt affected soils in district Charsadda have restricted drainage and leaching with shallow water table and saline ground irrigation. The mean maximum temperature in summer (May-August) is 45°C, minimum 25°C and average is 32°C. The mean maximum temperature in winter (December-February) is 20°C, minimum 4.1°C and average is 5.3°C. Mean annual precipitation in the area is 433 mm. Most of the rains are received during July-August in summer and Feb-March in winter season.

The Mardan district is situated between 34°05’ to 34°32’ N and 71°48’ to 72°25’ E. The soils are mostly waterlogged and saline or saline-sodic with poor drainage, restricted leaching, shallow water table and saline ground irrigation. Due to intensive cultivation and artificial irrigation, the area is humid. The summer season is extremely hot. The temperature reaches its maximum in the month of June i.e. 41.5 °C. A rapid fall of temperature occurs from October onwards. The coldest months are December and January. The mean minimum temperature recorded for the month of January is 2.1 °C. Most of the rainfall occurs in the months of July-August and December-January. Maximum rainfall for August is 126 mm.

Soil Sampling and Processing

Soil samples were collected from 30 different locations in districts Charsadda and Mardan. All the soil samples were taken from the surface 20 cm, with different salt concentrations (i.e. ECe of < 4.0 to 32 dSm^{-1}) in the month of March, 2009. Fields were either under wheat crops or fallow at the time of sampling. Soon after collection the samples were transferred to the Lab of Soil and Environmental Sciences Department in cool box and processed immediately for measurements of microbial activities and other soil properties. The samples were broken down by hand and passed through < 4.0 mm sieve whilst still moist.

Samples required for measurements of microbiological characteristics were kept moist and cool. However, part of soil samples were air-dried, ground and passed through < 2.0 mm sieve, and analyzed for soil EC_e (electrical conductivity of the saturation extract).

Laboratory Analysis

Microbiological Properties

Microbial Biomass C and N

Microbial biomass carbon and nitrogen were determined by the chloroform fumigation incubation method of Brookes *et al.* (1985) and Vance *et al.* (1987) as described in Horwath and Paul (1994). In this method, 50 g soil sample was fumigated with chloroform. After fumigation, the samples were inoculated with 1 g of respective unfumigated moist soil, and incubated in the presence of NaOH solution. The CO_2 evolved was trapped in NaOH solution and measured by titrating the NaOH solution against standard HCl. The moles of HCl used in titration determined the amount of NaOH remaining in the tube and the rest has been utilized while reacting with CO_2. The amount of CO_2 was calculated from the amount of NaOH reacted with CO_2 as 2 moles of NaOH react with 1 mole of CO_2 (or 1 mole of NaOH = 22g CO_2). The CO_2 evolution was also measured in un-fumigated soil incubated in similar way. Microbial biomass C and N were calculated as follows:

Calculation of Biomass C

The amount of CO_2-C produced from fumigation and unfumigated samples were used to calculate soil microbial biomass C using the following expression:

$$\text{Biomass C} = (F_c - U_{fc}) / K_c$$

Where:

F_c = CO_2 flush from fumigated soil samples

U_{fc} = CO_2 flush from unfumigated soil samples.

K_c = constant value i.e. 0.45. (Jenkinson and Ladd, 1981)

Calculations of Biomass N

Microbial biomass N was calculated from the amount of mineral N produced in the fumigated and unfumigated soil samples using the following equation:

$$\text{Biomass N} = (F_n - U_{fn}) / K_n$$

Where:

F_n = flush of NH_4-N from fumigated soil.

U_{fn} = NH_4-N mineralized during 10 days from unfumigated soil.

K_n = 0.54 (Jenkinson, 1988)

Total Mineral N (NH_4-N, NO_3-N)

Total mineral N in soil samples was determined by the steam distillation method as described by Mulvaney (1996). Twenty g soil was shaken with 100 ml of 1 M KCl and distilled with MgO alone for NH_4-N or MgO and Devarda's alloy for NH_4-N + NO_3-N. The distillate was collected in 5 ml boric acid mixed indicator solution following by titration against 0.005 M HCl. A blank was run simultaneously.

Nitrate N was determined by difference as follows:

Nitrate N (mg N kg^{-1} soil) = Mineral N (mg N kg^{-1} soil) – Ammonium N (mg N kg^{-1} soil)

Mineralizable N (mg N kg^{-1} soil)

The un-fumigated samples were analyzed for total mineral N before incubation (day 0) and after incubation (day 10). The amount of mineralizable N was calculated by difference as follows:

Mineralizable N = Total mineral N at day 10 – Total mineral N at day 0.

Other Soil Properties

Soil saturation extract was obtained through a vacuum pressure apparatus from soil saturation paste as described by (Gardner, 1986). Electrical conductivity (EC) in saturation extract was determined by Rhoades (1996) using EC meter (WTW, Germany).

Statistical Analysis

The results presented in the tables are arithmetic means and expressed on an oven dry basis (24 h at 105 °C). Pearson correlation coefficients were determined among variables. Correlations between soil microbial parameters with EC were graphically represented.

Table-I *Soil sample location, series name, tillage condition, type of irrigation, cover crop, crop condition and physiographic position of salt affected soils of KPK province.*

Sample location	Soil series	Tillage condition	Type of Irrigation	Cover crop	Crop condition	Physiographic position
Majoka Faqirabad	Kattikhal	Uncultivated	---	Bare field	---	Basin
behind PPC (Pak	soil series	Uncultivated	---	grasses	---	Basin
paper mill) near		bare field	Rain water	grasses	---	Basin
Govt. boys		Eucalyptus field	Tube well	Eucalyptus	Moderate	Gentle slope
primary school on		Barley field	Tube well	Barley	Poor	Gentle slope
Charsadda nisata		Spinach field	Tube well	Spinach	Poor	Gentle slope
road.		Wheat field	Tube well	Wheat	Moderate to good	Level
Nazo Kalli about	Dargai soil	Wheat field	Canal	Wheat	Very poor	Level
300m at the east	series	Wheat field	Canal	Wheat	Very poor	Level
of Aziz Abad		Wheat field	Canal	Wheat	Very poor	Level
police post on		Wheat field	Canal	---	Very poor	Level
main Nissata-		Wheat field	Canal	Wheat	Poor to moderate	Level
Dosehra mardan		---	---	---	Fallow	Level
road.		---	---	---	Fallow	Level
Bajavro kali on	Dargai soil	Cultivated fallow	Canal irrigation	Fallow	---	Level
Dosehra-Gulabad	series	Cultivated fallow	Canal irrigation	Fallow	---	Level
road district		Shaftal grown field	Canal irrigation	Shaftal	Moderate to good	Level
charsadda.		Shaftal grown field	Canal irrigation	shaftal	Moderate to good	Level
		Uncultivated	---		---	Basin
		Cultivated fallow	Canal irrigation	Fallow	---	Basin
Ahmad village on	Kettikhal	Cultivated	Canal irrigation	Wheat	---	Basin
Qasimi road	soil series	Cultivated	Canal irrigation	Wheat	Poor	Basin
Mardan.		Cultivated	Canal irrigation	Wheat	---	Basin
		Cultivated	Canal irrigation	Wheat	poor	Basin
Daftari (SCARP	Kattikhel	Uncultivated	---	---	---	Channels
offices) Sher	soil series	Uncultivated	---	Drab grass	---	Channels
Zaman kali on		Uncultivated	---	Drab grass	---	Channels
Qasimi road		Uncultivated	---	Drab grass	---	Channels
Mardan		Wheat grown field	Tube well irrigation	Wheat	Moderate to good	Level
		Wheat grown field	Tube well irrigation	wheat	Moderate to good	Level

RESULTS AND DISCUSSION

Various soil microbial attributes were measured in soils of varying electrical conductivity ranges for assessing the impact of salinity on soil microbiological properties. A depressive effect of salinity was observed for all microbial indices including microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), N-mineralization and nitrification.

Microbial Biomass Carbon

The results showed that soil microbial biomass carbon ranged from 147 to 516 (mg kg^{-1}) for all the thirty soils analyzed (Table II) We observed that the level of soil microbial biomass C was lowest in soils with highest EC. The microbial biomass ranged from 317 to 516 (mg kg^{-1}) in soils with EC of <4.0 dS m^{-1}, 313 to 391 (mg kg^{-1}) in soils with EC between 4.0-8.0 dS m^{-1}, 264 to 310 (mg kg^{-1}) in soils with EC between 8.0-12.0 dS m^{-1} and 147 to 275 (mg kg^{-1}) in soils with EC of greater than 12.0 dS m^{-1}. These results indicated that salinity had negative effect on MBC of soil. Microbial biomass C decreased proportionally with increasing salinity (Fig 1). Pearson correlation coefficient between soil electrical conductivity (EC) and microbial biomass carbon was found to be negative (r = -0.89, p = 0.05, n = 30). Rietz and Hayness (2003) also found negative exponential relationship of microbial biomass carbon with soil EC. Reports in the literature showed that MBC content ranged from 100 to 600 mg kg^{-1} in non saline soils (Powlson *et al.* 1987; Sparling, 1997; Anderson, 2003) and 125 to 445 mg kg^{-1} in saline soils (Tipathi *et al.* 2006). Our results are in line with these findings. Tripathi *et al.* (2006) found that higher ECe (upto 16 dS m^{-1} in coastal saline soils) caused significant decrease in MBC content.

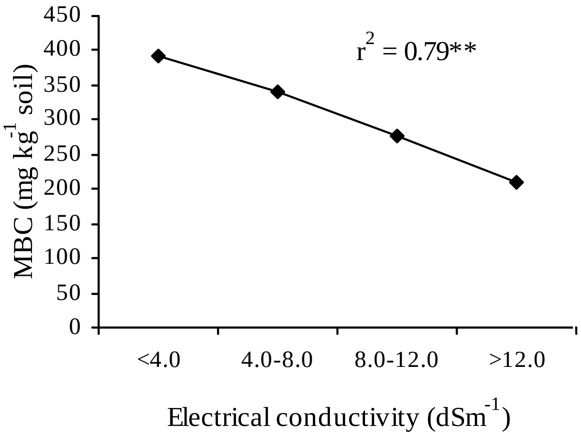

Fig. 1 Relationship of soil MBC with electrical conductivity

Microbial Biomass Nitrogen

The results showed that soil MBN content varied significantly with soil EC , and ranged from 19.0-170.2 (mg kg^{-1}) with average value of 79.8 (mg kg^{-1} soil) for all the soils under study. We observed that the level of soil microbial biomass N was lowest in soils with highest EC. The microbial biomass N ranged from 46.7 to 170.2 (mg kg^{-1}) in soils with EC of <4.0 dS m^{-1}, 38.1 to 66.4 (mg kg^{-1}) in soils with EC between 4.0-8.0 dSm^{-1}, 22.8 to 51.5 (mg kg^{-1}) in soils with EC between 8.0-12.0 dS m^{-1} and 19 to 34.9 (mg kg^{-1}) in soils with EC of greater than 12.0 dS m^{-1}. It was observed that soil MBN decreased proportionally with increasing salinity (Fig 2). There was a significant negative exponential relationship between EC and MBN (r = -0.74, p =0.05, n = 90). A strong negative correlation value (r = -0.82, p =0.05, n = 33) between MBN and soil EC was found by Yuan *et al.* (2007). Similar results were found by Rietz and Hayness, (2003) and Sardinha *et al.* (2003). Low average soil MBN content (11.0 mg kg^{-1}) was found by Muhammad *et al.* (2008) in saline and alkaline soils from the Pakistani Punjab. Microbial biomass decreased with increasing level of salinity, underlying the detrimental effect of salinity on soil microorganisms (Rajab, 1993).

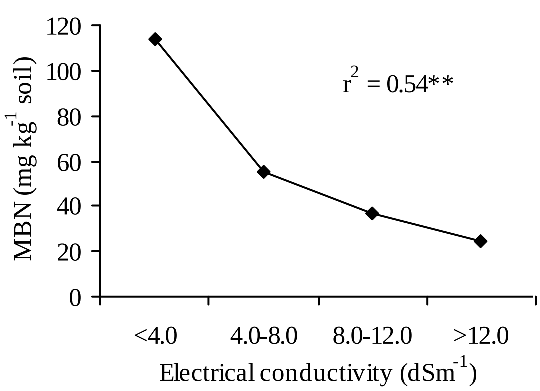

Fig. 2 Relationship of soil MBN with electrical conductivity

Microbial Biomass C:N Ratio

Our results showed that C:N ratio in microbial biomass increased with increasing salinity, unlike the other soil microbial parameters which showed a depressive effect with increasing salinity. We found that C:N ratio in microbial biomass ranged from 2.5 to 8.9 in soils with EC <4.0 dS m^{-1}, 2.5 to 8.9 in soils with EC between 4.0-8.0 dS m^{-1}, 5.8 to 11.9 in soils with EC between 8.0-12.0 dS m^{-1} and 4.9 to 15.1 in soils with EC value of >12.0 dS m^{-1}. Microbial biomass C:N ratio showed positive relationship with soil EC (r = 0.61, p = , n =90) (Fig 3). A low microbial biomass C:N ratio (4.36-7.67) was found by Yaun *et al.* (2007). Low N availability in combination with high C availability has been shown to increase microbial biomass C:N ratio in pure cultures of soil fungi and soil bacteria (Anderson and Domsch, 1980). For example, strongly increased microbial biomass C:N ratio has been observed in a German soil after glucose addition (Chander and Joergensen, 2007), and Rasul et al. (2008) found that average C:N of the microbial biomass was 18.0 in the sugar filter cake and biogenic waste compost treated soils.

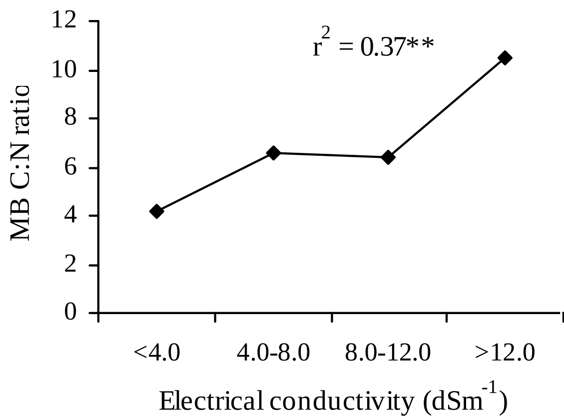

Fig. 3 Relationship of soil MB C:N ration with electrical conductivity

Nitrogen Mineralization

The results indicated that N mineralization varied considerably with salinity. Nitrogen mineralization ranged from 10.3 to 63.1 mg kg^{-1} in soils with EC of <4.0 dS m^{-1}, 13.9 to 22.9 mg in soils with EC between 4.0-8.0 dS m^{-1}, 5.2 to 19.9 mg in soils with EC between 8.0-12.0 dS m^{-1} and 1.9 to 26.3 mg in soils with EC of greater than 12.0 dS m^{-1}. These results suggested that nitrogen mineralization showed negative relationship with salinity and decreased proportionally with increasing salinity (Fig 4). Potentially mineralizable N is describing as a sensitive measure of the active soil organic N pool, which is the fraction accessible to soil organisms and enzymes (Yuan *et al.* 2007). Our results demonstrated that soil N mineralization was negatively affected by salinity. The Spearman correlation coefficient (r = -0.57, p =0.05, n = 90) calculated between EC and N mineralization showed that N mineralization decreased with increasing salinity. Salinity may inhibit organic matter decomposition directly by suppressing microbial growth and activity. Soil microbial biomass controls turnover and mineralization rate of organic substrate in the soil (Killham, 1994), and increased salinity has been shown to decrease soil respiration rates and soil microbial biomass (Laura, 1973; Laura, 1976; Pathak and Rao, 1998), likely due to the stress placed on the microbial population in response to changes in osmotic potential (Batra and Manna, 1997). Under osmotic stress, microorganisms enhance their survival by channelling the consumed C and N into biomass production or cell proliferation, which naturally results with a decline in the rate of C and N mineralization (Killham *et al.* 1990). Sarig *et al.* (1993) reported that irrigation with saline water (EC = 5 dS m^{-1}) increased the accumulation of C and N in the microbial biomass, but decrease the rate of C and N mineralization. The soil microbial biomass itself is an important pool readily mineralizable organic N in soils as well (Bonde *et al.* 1988), and low potentially mineralizable N may be linked to low microbial biomass N due to saline environment. Furthermore, N mineralization may be affected by species composition of soil microorganisms, as species differ in their ability to degrade various organic compounds. Of concern is that salinity-induced bacterial dominance may inhibit the decomposition of complex organic material in saline soils (Badran, 1994).

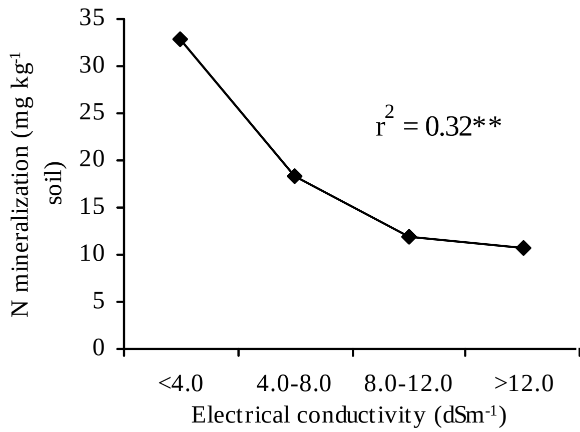

Fig. 4 Relationship of soil N mineralization with electrical conductivity

Table-II ***Microbiological properties of salt affected soils (0-20cm)***

EC(dSm^{-1})	No. of soils in the category		MBC (mg kg^{-1})	MBN (mg kg^{-1})	Biomass C/N	N-Mineralization (mg kg^{-1})	Nitrification (mg kg^{-1})
≤4.0	17	min	317.3	46.7	2.5	10.3	-2.7
		max	516.3	170.2	8.9	63.1	73.7
		mean	391.0	113.8	4.2	32.9	31.3
		CV	42.6	32.4	1.2	14.3	20.6
4.0-8.0	3	min	313.3	38.1	5.2	13.9	7.9
		max	390.8	66.4	8.9	22.9	23.9
		mean	340.5	55.6	6.6	18.4	15.4
		CV	33.6	11.7	1.5	3.0	5.7
8.0-12.0	4	min	263.9	22.8	5.8	5.2	-11.3
		max	301.5	51.5	11.9	19.9	19.2
		mean	276.3	36.8	8.1	11.8	1.2
		CV	12.6	8.2	1.9	4.1	9.0
>12.0	6	min	146.8	19.0	4.9	1.9	-19.2
		max	274.9	34.9	15.1	26.3	10.1
		mean	208.7	24.8	10.5	10.7	-5.4
		CV	32.8	4.6	3.1	9.2	8.2

Nitrification

Nitrification process in soil showed negative relationship with soil salinity. The rate of NO_3-N formation showed decreasing trend with increasing salinity. The results showed that soil nitrification ranged from -2.7 to 74 mg NO_3-N kg^{-1} in soils with EC of <4.0 dS m^{-1}, 7.9 to 23.9 mg in soils with EC between 4.0-8.0 dS m^{-1}, -11.3 to 19.2 mg in soils with EC between 8.0-12.0 dS m^{-1} and -19.2 to 10.1 mg in soils with EC of greater than 12.0 dS m^{-1} (Table II). (Fig 5) showed that the rate of NO_3-N formation decreased proportionally with increasing salinity. Pearson correlation coefficient for nitrification (the oxidation of NH_4-N to NO_3-N) with salinity (r = -0.64, p = n = 90) showed that nitrification was significantly reduced by increasing salinity. The literature showed that both nitrification and N mineralization were inhibited by high salinity levels (Laura, 1976; Pathak and Rao, 1998). Quanzhong and Guanhua (2009) found an increase in NH_4-N and a decrease in NO_3-N with increasing salinity. However, nitrification was more sensitive to salinity than mineralization (McClung and Frankenberger, 1985; McCormick and Wolf, 1980; Westerman and Tucker, 1974; Martikainen, 1985).

Rate of Soil Respiration

The data obtained on rate of soil respiration during 2, 5, 7 and 10 days of incubation periods are presented in Table III. Our results showed that the rate of CO_2 evolution decreased with increasing salinity levels. The effect of salinity on rate of CO_2 evolution was more pronounced during the first two days of incubation period. However, differences between soils with different salinity levels become narrower as incubations advanced to 10 days.

Table-III *Rate of CO_2 evolution ($mg\ kg^{-1}\ d^{-1}$) in soils of different salinity levels during different incubation periods*

EC (dSm^{-1})	No. of soils in this category		Carbon dioxide evolution (CO_2) Incubation period (days)			
			2	5	7	10
≤4.0	17	min	10.0	5.0	8.1	2.7
		max	25.1	16.5	18.0	9.0
		mean	18.3	9.5	13.1	6.1
		CV	3.7	2.5	3.5	1.6
4.0-8.0	3	min	13.2	5.1	7.6	5.9
		max	17.8	7.9	9.4	7.6
		mean	14.9	6.6	8.4	6.6
		CV	2.0	1.0	0.6	0.7
8.0-12.0	4	min	8.8	7.0	6.5	4.0
		max	10.6	8.2	9.4	5.7
		mean	9.8	7.5	7.6	4.8
		CV	0.7	0.5	1.0	0.6
>12.0	6	min	1.8	1.8	4.3	2.0
		max	14.1	10.4	7.0	5.7
		mean	7.0	5.1	5.6	3.7
		CV	3.3	2.8	0.7	1.3

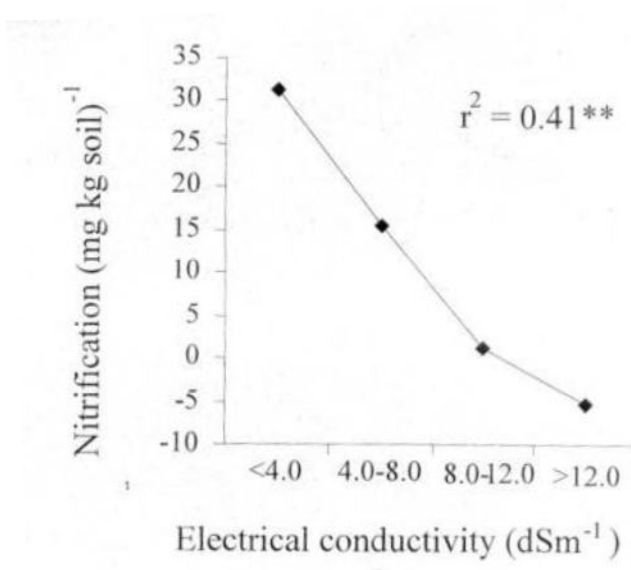

Fig. 5 Relationship of soil nitrification with electrical conductivity

Our results showed that rate of CO_2 evolution during 2 days of incubation period ranged from 10.0-25.1 mg kg^{-1}soil d^{-1} with average value of 18.3 mg kg^{-1} soil d^{-1} for soils with EC value of <4.0 dS m^{-1}, 13.2-17.8 mg kg^{-1} soil d^{-1} with average value of 14.9 mg kg^{-1} soil d^{-1} in soils with EC between 4.0-8.0 dS m^{-1}, 8.8-10.6 mg with mean value of 9.8 mg in soils with EC between 8.0-12.0 dS m^{-1} and 1.8-14.1 mg kg^{-1} soil d^{-1} with mean value of 7.0 mg for soils having EC >12.0 dS m^{-1}.

However, the rate of CO_2 evolution measured at 10^{th} day of incubation period ranged from 2.7-9.0 with average value of 6.1 mg kg^{-1} soil d^{-1}, 5.9-7.6 with average value of 6.6 mg with EC between 4.0-8.0 dS m^{-1}, 4.0-5.7 with mean value of 4.8 mg kg^{-1} soil d^{-1} with EC between 8.0-12.0 dS m^{-1} and 2.0-5.7 with mean value of 3.7 mg kg^{-1} soil d^{-1} with EC >12.0 dS m^{-1}. Overall, the relationship between rate of soil respiration and salinity during 10 days of incubation period was negative (Fig 6). It is clear from the figure that CO_2 evolution was reduced with increasing salinity. The effect of salinity was more evident during early days of incubation. Differences among salinity treatments however narrowed down with increasing incubation period. Reason could be that the reserve of easily decomposable C would be exhausted in the less saline treatments during early days of incubation.

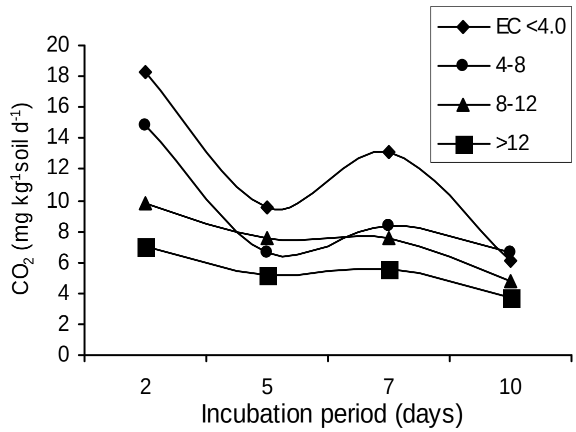

Fig. 6 Influence of salinity on soil respiration during 10 days of incubation period

Cumulative Soil Respiration

The results obtained on cumulative CO_2 production in salt affected soils during 2, 5, 7 and 10 days of incubation period are given in Table IV. It was observed that cumulative CO_2 production during 2 days of incubation period ranged from 20.0-50.2 mg kg^{-1}soil with average value of 36.5 mg in soils with EC value of <4.0 dS m^{-1}, 26.4-35.7 mg with average value of 29.8 mg in soils with EC from 4.0-8.0 dS m^{-1}, 17.6-21.2 mg with average value of 19.6 mg in soils with EC between 8.0-12.0 dS m^{-1} and 3.6-28.1 mg with average value of 14.0 mg in soils with EC >12.0 dS m^{-1}.

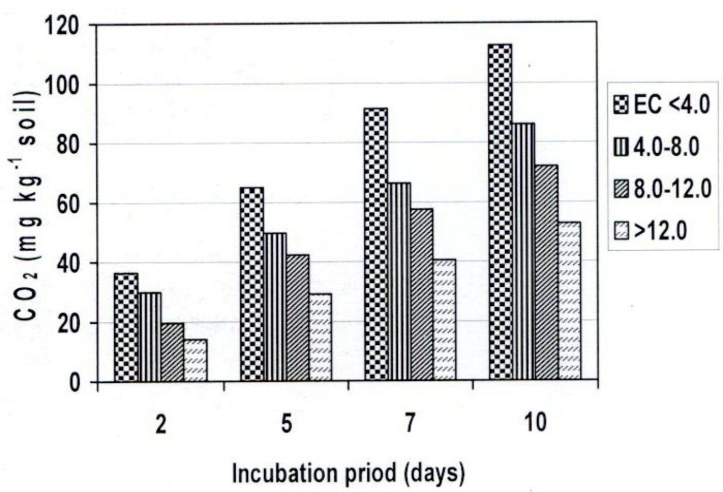

Fig. 7 Salinity effect on cumulative CO_2 production during 10 days of incubation period

The average CO_2 production during 5 days of incubation period was 65.0 mg kg^{-1}soil in soils with soil EC value of <4.0 dS m^{-1}, 49.5 mg in soils with EC between 4.0-8.0 dS m^{-1}, 42.3 mg with EC between 8.0-12.0 dS m^{-1}, and 29.2 mg in soils with EC of >12.0 dS m^{-1}. Similarly, the mean cumulative CO_2 production during 7 days was 91 mg kg^{-1} in soils with EC of <4.0 dS m^{-1}, 66.3 mg in soils with EC between 4.0-8.0 dS m^{-1}, 58 mg in soils with EC between 8.0-12.0 dS m^{-1} and 40.3 mg in soils with EC value of >12.0 dS m^{-1}. During 10 days of incubation period the corresponding values for cumulative CO_2 production were 113 mg in soils with EC values of <4.0 dS m^{-1}, 86.1 mg in soils with EC between 4.0-8.0 dS m^{-1}, 72.0 mg in soils with EC between 8.0-12.0 dS m^{-1} and 52.8 mg in soils with EC of >12.0 dS m^{-1}. These results demonstrated that cumulative CO_2 production in soils showed depressing trend with increasing salinity (Fig 7).

It is evident from these results that cumulative CO_2 production decreased with increasing salinity. An increase in EC from 4.0-5.0 dSm^{-1} caused a reduction of 4.96% in CO_2 production. A significant and negative Pearson coefficient was found between cumulative CO_2 production and soil EC (r = -0.79, p = n = 90). Vanessa *et al.* (2008) reported that soil respiration was highest (56-80 mg kg^{-1}soil) in low salinity treatments and lowest (1-5 mg kg^{-1} soil) in the mid salinity treatments. Laura, (1974) also reported that total microbial activity (as measured by CO_2 evolution) was generally depressed as soil salinity increased. Similar results were found by Trapathi *et al.* (2006) where basal soil respiration exponentially decreased with increasing salinity. Rietz *et al.* (2001) found that irrigation-induced salinity decreased the size and activity of the soil microbial community. Zahran (1997) showed that saline soil environments harbor taxonomically diverse microbial groups which exhibit modified physiological and structural characteristics under saline conditions. Pankhurst *et al.* (2001) found that agriculture induced salinity caused a shift towards a less active, less functionally diverse, bacterial dominated community. According to Trapathi *et al.* (2006) a decrease in MBC and microbial activities with a rise in salinity is probably one of the reasons for poor crop growth in coastal saline soils.

CONCLUSION AND RECOMMENDATIONS

Increasing soil salinity, combined with high soil pH, showed negative effect on all microbial indices including MBC, MBN, basal soil respiration, nitrification and net nitrogen mineralization. Our results indicates that soils with the highest salinity level showed the lowest soil microbial biomass and activities, while soils with low salinity levels showed no effect on soil microbial indices. Microbial biomass C:N ratio was the only soil microbial properties which showed positive response to increasing soil salinity. Our results showed that the rate of CO_2 evolution decreased with increasing salinity levels. The effect of salinity on rate of CO_2 evolution was more pronounced during the first two days of incubation period. However, differences between soils with different salinity levels become narrower as incubations advanced to 10 days. MBC, MBN, basal soil respiration net nitrification and net N mineralization strongly affected with SAR and ESP and the relationship is depressive. Carbonates and bicarbonates of all the soils analyzed showed little response to all analyzed biological parameters. It is concluded from the correlation data that all biological parameter, except soil microbial biomass C: N ratio decreased with increasing salinity.

ACKNOWLEDGEMENT

This study was sponsored by the Higher Education Commission (HEC), Islamabad under 5000 Indigenous Ph.D program.

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