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Spatial and temporal variability in microbial activities of coastal acid saline soils of Goa, India

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Abstract

The aim of the present investigation was to study the spatio-temporal variability of the microbial activities in coastal saline soils (locally called *Khazan*) of Goa, India (west coast region). The coastal soil salinity is a major constraint for reduced crop yields and abandonment of farming in these areas. Three replicated global positioning based soil samples (0–0.20 m depth) from each of four salinity groups i.e. non-saline (EC = 0.08 ± 0.06 dS m^{-1}), weakly saline (EC = 2.04 ± 0.06 dS m^{-1}), moderately saline (EC = 3.50 ± 0.57 dS m^{-1}) and strongly saline (EC = 5.49 ± 0.49 dS m^{-1}) during three seasons–monsoon, post-monsoon and pre-monsoon were collected. Soil microbial activity in terms of soil microbial carbon (MBC), MBC as a fraction of soil organic carbon (SOC) (MBC/SOC), basal soil respiration (BSR), metabolic quotient (qCO_2) and soil enzyme activities–dehydrogenase, phosphatase and urease was tested. In all the seasons, the soil cationic composition depended significantly ($p < 0.01$) on salinity levels and the exchangeable sodium (Na) was the second most dominant among the tested cations. The MBC, MBC/SOC and BSR reduced significantly with increasing salinity, whereas qCO_2 increased with increased salinity levels. In general, MBC, MBC/SOC and BSR and soil enzyme activities were observed as: salinity levels–strongly saline < moderately saline < weakly saline < non-saline and season–post–monsoon > monsoon > during pre-monsoon season. The mean MBC and MBC/SOC of non-saline soils were 1.61 and 2.28 times higher than that of strongly saline soils, whereas qCO_2 of strongly saline soils was 2.4 times higher than that of non-saline soils. This indirectly indicates the salinity stress on the soil microorganisms. Irrespective of season, the soil enzyme activities decreased significantly ($p < 0.05$) with increasing salinity levels. Suitable countermeasures needs to be taken up to alleviate the depressive salinity effect on the microbial and activity for the sustainable crop production in the coastal saline soils of Goa, India.

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1 Introduction

Soils are very important and non-renewable resource and a key factor of the earth system. This is evident from the functions that soil performs. The important functions of the soils are: (1) it is a habitat for biodiversity, (2) filters the contaminants in the water (acts as a natural filter), (3) Support the man-made structures, (4) supports plant for food and nutritional security, (5) it is an important ally to combat climate change by storing very high amount of carbon in it, etc. Thus, it offers services, resources and goods to the human society. Soils play a pivotal role in the hydrological, biological and geological earth system cycles. But this natural resource has been experiencing different types of degradation. Among different degradations processes, soil salinity and sodicity are a one of the global environmental problems which seriously limit the productivity of cultivated land (Mao et al., 2014). The salt affected soils occupy approximately 3 % of the world's total geographical area i.e. 402 and 434 million hectare (Mha) lands are classiffed as saline and sodic, respectively (Singh, 2015) making them unproductive. The area under salinization in world has been increasing continually (Drake et al., 2015). Soil salinity is one of the most important abiotic stresses responsible for reduced crop production (Plant et al., 2013). In India, about 6.74 Mha of soils are affected with soil salinity, of which 1.25 Mha is in coastal areas (CSSRI, 2014). Intrusion of saline water either directly through sea or estuaries indirectly, seepage for the salt water reservoirs and intentional stoppage for the fish or prawn farming are important reasons for coastal soil salinity in Goa, India. The area under these soils has been increasing due to the natural and anthropogenic activities. This has led to development of a typical characteristic in these soils i.e. presence of salinity and acidity simultaneously. These soils are locally called as "Khazan" and occupy nearly 18 000 ha area, of which 12 000 ha is under monoculture of rice in monsoon season only. These soils are often left fallow in the rabi (post-monsoon season) because of high salinity levels and no availability of irrigation water. Farmers have started abandonment of agriculture on such soils due to low rice productivity (1.5 to 2.0 t ha^{-1}). This might be basically due to excessive soil

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salinity causing adverse crop growing conditions and unfavorable biotic and abiotic soil factors (Tripathi et al., 2007).

Although the effects of salinity and sodicity on soil properties (Qadir et al., 2007) and crop growth has been studied widely but little is known about their possible effects on soil microbial activities. Rapid and accurate techniques for salinity and sodicity appraisal has now also being developed considering the importance of the problem e.g. electromagnetic induction (EMI) technique (Ganjegunte et al., 2014). They recorded significant correlation between the EMI measured and laboratory analyzed saturated paste electrical conductivity and sodium absorption ratio. Development of rapid salinity and sodicity appraisal techniques indicates the increasing problems of salinity worldwide. Soil microorganisms are key drivers of organic matter decomposition (Quails and Raines, 1992), nutrient cycling, energy transformation (Coleman et al., 1985); and formation of aggregates and structures. They play a pivotal role in maintaining and improving soil quality (Egamberdieva et al., 2010). Therefore, understanding of microbial activities in salt-affected soils is of paramount importance (Singh, 2015) from crop production point of view. Effect of salinity (electrical conductivity) and sodicity (exchangeable sodium percentage) has been studied by several workers and have noted both positive and negative effect on microbial activity. Thus, reconciliation of the proper mechanism is yet to be explained properly (Singh, 2015). Changes in soil physical processes affect water and air movement and available water capacity (Oster and Jaywardane, 1998), osmotic and matric potential and reduces microbial activity (Reitz and Haynes, 2003; Sardinha et al., 2003) and inflicts an adverse effect on plant growth and yield. These could also be due to the direct toxic effects of salts on microbial communities (Reitz and Haynes, 2003) or vegetation (crop, grass and tree) (Wong et al., 2010), which in turn, causes the decreased organic matter inputs (crop residue, litter and fine roots) in the soil and, consequently, reduces the microbial activities (Singh et al., 2015). At high soil salinity and sodicity, the availability of organic matter and metabolic energy required for microbial assimilation is reduced, the microbial cell lysis takes place and soil becomes poor in microbial activities (Singh, 2015). While the ef-

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fects of salinity under high pH soils of arid and semi-arid region (e.g. soil with secondary salinization or irrigation induced salinity) on soil physical and chemical properties are very well documented (Keren, 2000), the information on soil biological activity are limited (Reitz and Haynes, 2003) and less intensively studied in soils with high salinity and low soil pH (e.g. coastal saline soils). In the recently reported review by Singh (2015) on effect of soil salinity and sodicity on microbial activities extensively reviews the saline and sodic soils of the arid and semi-arid region. The effects of salinity or sodicity on microbial activities in coastal saline soils of the world is relatively less investigated and reported. The effects of salinity under low soil pH on microbial activity in terms of soil microbial biomass (MBC), MBC as a fraction of soil organic carbon (SOC) (MBC/SOC), basal soil respiration (BSR), metabolic quotient (qCO_2), enzyme activities–dehydrogenase, acid and alkaline phosphatase and urease are still poorly understood (Iwai et al., 2012). These parameters also act as a sensitive indicators of soil quality changes due to management or environmental stress (Powlson et al., 1987; Reitz and Haynes, 2003; Egamberdieva et al., 2010). Reduced microbial activities like MBC, soil microbial biomass nitrogen, BSR, fluorescein diacetate hydrolyzing and other enzyme activities due in response to salinity has been reported in literature (Reitz and Haynes, 2003; Tripathi et al., 2006; Shah and Shah, 2011; Iwai et al., 2012). Management studies on saline soils reveal that organic materials or amendments could improve the physical, chemical and biological properties of the degraded soils (e.g. saline soils) with poor soil fertility (Srivastava et al., 2014; Wu et al., 2014). Over past few centuries, site-specific remediation technologies for managing salt affected soils have been developed (Mao et al., 2014). These method include leaching, tillage management, application of organic and chemical amendments, physical land modifications etc. Novel products like bio-augmented organic amendments (vermicompost – pre-enriched with plant growth promoting fungi mixed with pressmud and *Azadirechta indica* seed cake) found to boost the wheat yield and soil enzyme activities under sodic soils (Srivastava et al., 2014). Singh et al. (2014) showed that continuous tillage and cropping on sodic soils is useful to restore them physically and chemically. The application of chemical

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amendments like gypsum in loamy sand, sandy loam and clay loam at 25, 50 and 75 % gypsum requirement rate proved as cost-effective technique to reduce salinity levels in sodic soils (Ahmad et al., 2015). Oo et al. (2013) observed that application of compost and vermicompost as a soil conditioner alleviates the salinity stress and improves the maize productivity. Thus, there are numerous management strategies to manage salt-affected soils of the world. But, to decide the location specific remediation strategy, accurate assessment of the salt affected soils is very important.

Considering the limited research available on the effect of coastal soil salinity on microbial activities and need of sustainable management of these soils, the present investigation was carried out to generate primary information on microbial activities in coastal saline soils. There are no such reports available with reference to west coast of India. The objective of the study was to study the effect of salinity in three different seasons–monsoon, post–monsoon and pre–monsoon season on MBC, MBC/SOC, basal soil respiration (BSR), metabolic quotient (qCO_2) and enzyme activities–dehydrogenase, phosphatase and urease. The outcomes of the study would be useful to develop the countermeasures for sustainable management of these soils.

2 Materials and methods

2.1 Site description and climate

Twelve different sites with variable salinity levels in coastal region of Goa were selected. Detailed description of study site has been given in Table 1. It was also ensured at the time of sampling that, the source of the salinity to the sampling site was either saline water intrusion or seepage from nearby saline water source. Washing of salts is normally observed in rainy season (monsoon), whereas evapo–transpiration causes accumulation of salts in soil up to high levels during post rainy season. It was also ensured during the site selection that there are sources of pollution or contamination from point or non-point sources. Climate of Goa is warm and humid for most of the time in

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a year. This is evident from the pattern of last 10 year average rainfall and evaporation rate (Fig. 1a) and the study year 2013–2014 (Fig. 1b). Very high rainfall and low evaporation rate was observed in July 2013 (1606 and 68 mm, respectively), the trend was reverse during the post rainy season (December 2013 (0 and 127 mm, respectively) and May 2014 (144 and 158 mm, respectively)). During the study year, the lowest daily mean minimum air temperature recorded was 15.6 °C, while the highest maximum was 40.6 °C. The rainy season is normally observed during June to September (3101 mm during 2013). The behavior of rainfall in this region is unimodal. Weather parameters given here are collected from Indian Council of Agricultural Research Central Coastal Agricultural Research Institute Meteorological Observatory, Old Goa, India.

2.2 Soil sampling and chemical analysis

Soil samples (0–20 cm) were collected from twelve different locations from the coastal region of Goa. The detailed description of the sampling locations has been given in the Table 2. There were twelve site selected and from each of the site three replicated samples were collected. Furthermore, each of the replicate sample was made a composite sample of three subsample (distance between soil samples nearly 10 m). The sampling was done in this way to ensure the homogeneity and uniformity of the site so that the sample becomes a true representative sample of that location. At a given site, the distance between the replicated soil samples was about approximately 200–300 m. The selected sites were categorized into four salinity levels (three sites in each group) based on the electrical conductivity (EC) as (1) non-saline ($0.08 \pm 0.06\,\mathrm{dS\,m^{-1}}$), (2) weakly saline ($2.04 \pm 0.06\,\mathrm{dS\,m^{-1}}$), (3) moderately saline ($3.50 \pm 0.57\,\mathrm{dS\,m^{-1}}$) and (4) strongly saline ($5.49 \pm 0.49\,\mathrm{dS\,m^{-1}}$). These categories are based on the EC in the rainy season as it was lowest among three different seasons at all the sites. The EC of samples collected during rainy season was considered because rice cultivation is normally done in this season, however it remains fallow during post and pre-monsoon season due to high soil salinity. It would also allow to design the intervention for managing these soils for crop production. Consideration to EC of rainy season is also due

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to practice of rice cultivation in the rainy season. Each salinity level has three replicate locations. One representative composite sample per location was prepared from the three samples.

2.3 Soil analysis

2.3.1 Chemical properties and bulk density

Soil pH and electrical conductivity (EC) was measured in 1 : 2.5 soil to water solution using pH and EC meter (Jackson, 1973). Soil organic carbon (SOC) was determined by Walkley and Black's (1934) wet oxidation method. Soil bulk density (BD) was measured using soil core method (0–20 cm). Exchangeable cations i.e. sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg) were determined by Neutral *N* ammonium acetate extraction method.

Exchangeable sodium percentage (ESP) (Eq. 1) was calculated as,

$$\mathrm{ESP} = \frac{\text{Exchangeable Na}}{\text{Exchangeable (Na + K + Ca + Mg)}} \times 100 \quad (1)$$

The ESP was expressed in percentage terms.

2.3.2 Microbial activity

Field moist soil samples were gently sieved through 2 mm sieve and it was used for determining soil biological parameters. One of the basic soil microbial properties i.e. BSR was determined using incubation and titration method (Anderson, 1982). Sieved field moist soil (10 g) was weighed and placed in an air tight 1 L capacity conical flask. A vial containing 20 mL of 1 M NaOH was kept hanging and conical flask was air tightened. The soil was allowed to incubate at 28 ± 2 °C for 10 days. The amount of CO_2–C evolved and trapped in alkali was estimated by adding phenolphthalein and titrating with 0.5 M HCl. Before titration saturated $BaCl_2$ solution was added to precipitate the carbonates and bicarbonates as Barium carbonate.

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The MBC in moist soil was determined immediately after sampling by fumigation extraction method (Vance et al., 1987). Chloroform fumigated and unfumigated soils (20 g) were extracted with 100 mL of 0.5 M K_2SO_4. The MBC in the extract was estimated after oxidation with 0.2 N $K_2Cr_2O_7$ at 100 °C for half an hour. The MBC (Eq. 2) was calculated using formula,

$$MBC = (C_f - C_{uf})K_{ex}^{-1} \quad (2)$$

Where, MBC is soil microbial biomass carbon in $\mu g\,g^{-1}$ soil, C_f and C_{uf} are 0.5 M extractable organic carbon in fumigated and unfumigated soils, respectively, K_{ex} is efficiency of extraction, a value of 0.45 has been considered for calculation. Moisture content of the same soil samples was determined simultaneously for calculating MBC.

The metabolic quotient (qCO_2) was calculated as a ratio of BSR to MBC and expressed as mg CO_2–C mg^{-1} MBC day^{-1}. Whereas the fraction of the SOC as MBC was calculated as MBC divided by SOC and expressed as percentage (%).

2.3.3 Enzyme activities

Dehydrogenase activity of the soil was determined using method of Tabatabai (1982). Soil (1 g) was taken into screw type air tight test tube and 0.2 mL of triphenyltetrazolium chloride and 0.5 mL of 1 % glucose solution was added. The tubes were then incubated at 27 °C for 6 h. The clear pink colored supernatant was withdrawn and absorbance was recorded at 485 nm wavelength. The dehydrogenase activity was expressed as µg Triphenylformazon (TPF) formed g^{-1} day^{-1}.

Acid phosphatase activity of the soil was estimated by method of Tabatabai (1982). Soil (1 g) was taken into erlenmeyer flask and 0.2 mL Toluene, Modified Universal Buffer (pH 6.5) and 1 mL p-Nitrophenol (PNP) were added sequentially. The flasks were swirled, stoppered and incubated at 37 °C for an hour. After 1 h incubation 1 mL 0.5 M $CaCl_2$ and 4 mL 0.5 N NaOH was added and flasks were swirled. The suspension was filtered and yellow color intensity was estimated at 440 nm wavelength. The acid

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phosphatase activity expressed as µg p-Nitrophenol released g^{-1} h^{-1}. All the soils had acidic soil reaction (pH < 7.0), therefore acid phosphatase activity was determined in all the soil samples.

Urease activity in soils was estimated as amount of urea hydrolyzed after incubation. Soil (5 g) was incubated with known amount of urea at 37 °C for 5 h. The suspension was filtered and 5 mL of filtrate was mixed with potassium chloride-phenyl mercuric acetate and coloring agent. The solution was heated for half an hour on hot water bath and allowed to cool down. The intensity of red color was determined at 527 nm wavelength. The urease activity was expressed as mg urea hydrolysed g^{-1} h^{-1}.

2.4 Statistical analysis

The soil salinity and season were considered as two different factors for the present study. The factor salinity had four levels i.e. non-saline, weakly saline, moderately saline and strongly saline and factor season had three levels i.e. monsoon, post-monsoon and pre-monsoon. The effects of salinity and the season on microbial and enzyme activity were tested using one way analysis of variance (ANOVA). For each one way ANOVA, Tukey's Honest Significant Difference (HSD) was followed to identify the extent of variation within the levels of each factor. The Pearson's correlation matrix plot was drawn using the PROC SGSCATTER to study the relationship between soil salinity, microbial and enzyme activities. Statistical analysis was done using SAS Version 9.3 (SAS Institute, 2012).

3 Results and discussion

3.1 Physico-chemical properties of soil

As already mentioned in the section materials and methods, the soils were categorized in four groups based on the EC in the rainy season. The EC of the soils col-

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lected ranged from 0.81 to 8.83 dS m^{-1}. The three levels of salinity exhibited significant ($p < 0.01$) variations in EC in all three seasons. During monsoon season, strongly saline soils had EC as high as 5.59 dS m^{-1} while non-saline soils had 0.81 dS m^{-1}. Salinity of 5.49 dS m^{-1} in the highest rainfall month (July, Fig. 1a and b) is a considerable level to limit the crop production. Similar sort of trend of EC was recorded during the post-monsoon and pre-monsoon season as well. The EC also varied significantly ($p < 0.01$) among monsoon, post-monsoon and pre-monsoon and had average values of 2.96, 4.90 and 6.31 dS m^{-1}. Very high rainfall and low evaporation rate causes washing of salts with rainwater and reduces the salinity level during monsoon season (Fig. 1a, b). Thus, rainfall and evaporation are two major factors besides salt water intrusion monitoring the soil salinity in these areas. The variations in soil pH with different salinity levels and seasons were non-significant. But, important to note is that, the soil pH was less than 6.11 (ranged from 4.66 to 6.11). The soil reaction exhibited by soils was acidic at all the sites during all the seasons. The soils originally are lateritic type and experience salt accumulation due to natural and anthropogenic activities. Thus, salinity in these soils exists under low pH unlike secondary soil salinity associated with high soil pH in arid and semi-arid parts of the country. Existence of salinity under low soil pH or acidic soil reaction is an interesting and rare situation. Little attention has been given on investigation on these soils and scanty literature is available. The pattern of the SOC at different salinity levels and among different seasons was interesting and significant ($p < 0.01$) (Table 2). In all the seasons, the highest SOC was recorded in non-saline soils (5.05–16.21 g kg^{-1}), whereas it was lowest in the strongly saline soils (2.85–5.62 g kg^{-1}). Highest average SOC was observed in the pre-monsoon (10.27 g kg^{-1}) followed by post-monsoon (7.20 g kg^{-1}) and it was lowest in monsoon (3.93 g kg^{-1}). In general, the soil organic carbon decreased with increasing levels of salinity within the same season. The higher soil organic carbon in post-monsoon season might be due to the decomposition and mineralization of the left out residues of rice crop. Decreased decomposition and mineralization of the crop residues due to submergence in monsoon could be a probable reason for the lowest

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soil organic carbon in monsoon season. Reduced crop growth, C input, gradual dispersion of the soil aggregates leaving organic matter unprotected and susceptible to degradation could be the apt reasons for low SOC at high salinity levels (Egamberdieva et al., 2010). Under salt affected soil conditions the available soil organic matter is dispersed and not protected physically and undergoes higher biological mineralization (Abiven et al., 2009; Wiesmier et al., 2012) and moreover higher accessibility of the free organic matter to microbial decay further reduces the fertility and physical stability of the soils (Neson and Oades, 1998; Wong et al., 2010; Fterich et al., 2014). This way the availability of the organic matter and metabolic energy for microbial assimilation further reduces and results in to poor microbial activity (Singh, 2015).

3.2 Cationic composition of soils

The cationic composition of the soil depended significantly ($p < 0.01$) on the salinity levels and seasons (Table 3). In general, the concentration of exchangeable Na was next to Ca and it was higher than that of exchangeable K and Mg. Concentrations of all the cations studied were highest during pre-monsoon season followed by post-monsoon and lowest in monsoon. High concentration of Na in the coastal saline soils of India causes poor physical and chemical properties, impeded water infiltration and water availability (Dhanushkodi and Subrahamaniyan, 2012). This causes due to swelling, slaking, dispersion of clays and degraded soil structure (Biovin et al., 2004; Tejada and Gonzalez, 2005; Iwai et al., 2012). Thus, excess of Na in the soils prevailing in all the seasons is a matter of concern for crop production in these soils.

3.3 Microbial activity

The microbial activity in soils can be determined from the soil organic matter decomposition (Reitz and Haynes, 2003), carbon dioxide emission, soil microbial biomass and MBC/SOC (Wong et al., 2010; Balota et al., 2013) and nutrient release or mineralization (Nelson et al., 1998). These are important parameters to explain various

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stresses on the microbial activities (Singh, 2015). The data on the effect of salinity levels and microbial activity is presented in Table 4. The MBC, MBC/SOC, BSR and qCO_2 depended significantly ($p < 0.01$) on the salinity levels and seasons (Table 5). The MBC, MBC/SOC and BSR reduced significantly with increasing salinity level in all the seasons, whereas qCO_2 showed an increasing trend. The lowest MBC (21.1 mg kg^{-1}) was recorded in strongly saline soils during pre–monsoon season, whereas highest was recorded in non-saline soils during monsoon (112.7 mg kg^{-1}) and post-monsoon (112.8 mg kg^{-1}). In the present study, the MBC of weakly, moderately and strongly saline soils were higher in monsoon, followed by post-monsoon and it was lowest in pre-monsoon season. Low organic matter and high salinity (e.g. strongly saline soils group in the present study) creates undesirable environment for the microbial community. Besides the physical properties of the soil, the biological properties serves as a better indicator of soil quality and one such biological properties is MBC (Mahajan et al., 2015). Inverse relationship of the salinity with MBC, during all the seasons, is in line with those reported by Tripathi et al. (2006), Iwai et al. (2012), and Mahajan et al. (2015). The range of the MBC in the present investigation is 21.1 to 112.8 mg kg^{-1}. The MBC reported in by researchers in non-saline soils is 100 to 600 mg kg^{-1} soil (Powlson et al., 1987; Anderson et al., 2003; Shah and Shah, 2011) and in saline soils it was as low as 125 mg kg^{-1} soil (Tripathi et al., 2006), 47.3 mg kg^{-1} soil (Yuan et al., 2007), 40.5 mg kg^{-1} soil (Iwai et al., 2012), 158 mg kg^{-1} (Sardinha et al., 2003), 147 mg kg^{-1} (Shah and Shah, 2003), etc. Singh et al. (2012), in the field experiments, observed reduction in the MBC and BSR in sodic soils with 95 % ESP whereas the substantial reclamation using afforestation improved the MBC and BSR. The toxic effect of the salinity on C might be due depressive effect of Na on the microorganisms (Reitz and Haynes, 2003; Egamberdieva et al., 2010; Ndour et al., 2008). It is not only the degraded environments like salinity but also mine and forest fires affected areas and land use changes affect the soil microbial activity significantly. The forest fires has found to slowdown the recovery of the soil organic matter related properties, nutrient availability and soil enzyme activities (Guenon et al., 2013). Under such en-

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vironments, the vegetation recovery normalizes the post fire soil microbial processes (Hedo et al., 2015). Vegetation with the fast growing trees improves the soil microbial community composition through the improvement in the soil organic carbon (Wu et al., 2013). Wu et al. (2013) recommended that the soil microbial community composition should always be considered for the large scale management of the degraded lands. The soil microbial variables proved to be strong indicators of soil sustainability (Tejada and Benitez, 2014) when addition of organic matter (crushed corn straw and waste) was tested to affect soil microbial activity. Besides the salinity, other degraded environment also have recorded poor soil microbial activity in low organic matter content soils. Lower C substrate availability, desiccation due to dry weather (Van Gestel et al., 1992) and high salinity also attributes to the reduction in MBC.

In all the seasons, a significant ($p < 0.01$) negative relation between salinity levels and MBC/SOC was observed. The order of the mean MBC/SOC in different salinity groups was as: strongly saline (0.59 %) > moderately saline (0.91 %) > weakly saline (1.02 %) > non-saline (1.35 %) soils. The mean MBC/SOC of non-saline soil was 2.28 times higher than that of strongly saline soils. The order of MBC/SOC was observed as post-monsoon (1.25 %) > monsoon (0.87 %) > during pre-monsoon (0.79 %) season. The results clearly indicated the detrimental effect of the salinity on microbial activities. The significant reduction of MBC/SOC due to high salinity also recorded by Egamberdieva et al. (2010) and Mahajan et al. (2015), may be related to microbial stress by higher organic consumption per unit MBC to maintain the cell integrity and release the Na^+. These both processes consume and require metabolic energy (Utsugi et al., 1998). The values of MBC/SOC in the strongly saline soils (0.59 %) are close and in line with those reported by Sardinha et al. (2003) under strong saline soils (0.50 %). The adverse effect of the soluble salts and osmotic stress could have caused inhibition of the C assimilation by microorganisms (Mahajan et al., 2015).

On the contrary to the MBC and MBC/SOC, the qCO_2 increased significantly ($p < 0.05$) with the increasing levels of salinity. The qCO_2 index establishes that MBC becomes more efficient in utilizing the resource available (Garcia-Orenes

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et al., 2010). The order of season for qCO_2 was observed as: pre-monsoon (0.43 mg CO_2–C day^{-1} g^{-1} MBC) > post-monsoon (0.43 mg CO_2–C day^{-1} g^{-1} MBC) > monsoon (0.43 mg CO_2–C day^{-1} g^{-1} MBC). The qCO_2 of strongly saline soils was 2.4 times higher than that of non-saline soils. The occurrence of higher qCO_2 with high salinity levels has been reported in literature by researcher (Mahajan et al., 2015; Iwai et al., 2012; Tripathi et al., 2007) and our observations are in line with them. Chowdhury et al. (2011) and Setia et al. (2011) reported the decrease in BSR with increasing levels of salinity and this trend was similar even after addition of organic matter. This explains the magnitude of the salinity effect on microbial activity. The qCO_2 is an indicator of the environmental stress on the microbial community (Reitz and Haynes, 2003; Rasul et al., 2006; Iwai et al., 2012; Mahajan et al., 2015). The reduced qCO_2 in high salinity levels indicates the lower microbial functioning efficiency (Anderson and Domsch, 1989) and it also implies that relatively high C has to be allocated by the microorganisms for maintenance than growth. The native microbial population could be less able to incorporate the soil C for their proliferation (Garcia-Orenes et al., 2010). Physiologically more active population of the microorganisms that used substrate less efficiently was observed by Wichern et al. (2006) under high osmotic stress situation. The higher energy requirement of the unit microbial cell for selective Na exclusion might also reflect the high qCO_2 in the present study (Wichern et al., 2006). Fterich et al. (2014) reported the high carbon use efficiency in terms of qCO_2 values in different textured soils cultivated with *Acacia tortilis*. Vegetating the degraded lands with appropriate crops could be one of the possible solutions to manage them.

3.4 Soil enzyme activities

Soil enzymes are often considered as sensitive indicators of changes in soil due to different stresses (Schimdt et al., 2011; Nannipieri et al., 2012). Like MBC, soil enzyme activities significantly ($p < 0.01$) reduced with increasing levels of salinity (Table 5). In general, the soil enzyme activities–dehydrogenase and phosphatase decreased as

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monsoon > post-monsoon > pre-monsoon, whereas the urease activity was observed as post-monsoon > monsoon > pre-monsoon. The dehydrogenase enzyme activity was significantly highest in non-saline soils, but it varied non-significantly in rest three salinity levels in all the seasons. The mean dehydrogenase activity in non-saline soils (26.0 mg TPF kg^{-1} h^{-1}) was about 4.5 times that in strongly saline soils (5.73 mg TPF kg^{-1} h^{-1}). Almost similar sort of trend was observed for phosphatase enzyme activity. As mentioned above, the urease activity was higher in the post-monsoon season. This could be due to the higher availability of the decomposing substrate during the post-monsoon season. The urease enzyme activity in the monsoon and post-monsoon season was 2.34 and 2.84 times higher than that in the pre-monsoon season. The results of the present investigation revealed the inhibitory effect of salinity on soil enzyme activities (Table 5). The magnitude of the enzyme activity however was lower compared to the one observed in other soils (Dick et al., 1996; Tripathi et al., 2007). The dehydrogenase activity reported in the present investigation was found to be lower during the monsoon season (5.50–78.3 µg TPF g^{-1} day^{-1}) than those (213.6–312 µg TPF g^{-1} day^{-1}) reported by Tripathi et al. (2007) during similar season in coastal saline region of the Bay of Bengal, Sundarbans, India. But, the ranges for urease and phosphatase were found more or less similar. The better dehydrogenase activity in the normal (e.g. non-saline soils in the present study) could be attributed to higher organic substrates and MBC. Higher available organic substrate could have promoted the activity of the indigenous microorganisms and thereby the dehydrogenase enzyme (Hedo et al., 2015). The dehydrogenase activity is often considered as a sensitive indicator of the soil quality. Decreasing soil enzyme activities with increasing salinity might be due to increased osmotic stress on microorganisms (Frankenberger and Bingham, 1982). This shows lesser ability of the soils to mineralize essential nutrients and make them available to plants. Salinity in these soils limits microbial growth, soil organic matter decomposition and nutrient transformation. To overcome salinity barriers to restore microbial growth and their activities suitable ameliorative measure like organic matter addition needs to be developed in these soils (Tripathi et al., 2007). Increased avail-

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ability of substrate due to organic matter addition might counteract the adverse effect of salinity (Wichern et al., 2006; Mavi and Marschner, 2013). Cultivating degraded soils with right plants and addition of organic matter has proved to improve the soil quality indicators like enzyme activities (dehydrogenase, phophphatase, β-glucosidase, urease, etc.) (Flerich et al., 2014, Hedo et al., 2015). Hedo et al. (2015) attributed the better soil microbial activity in recovery of degraded land (fire affected lands) to higher organic matter concentrations, which can act as energy source to the microorganisms. Soil salinity affects the soil enzymes by their direct effect on enzyme production and by making structural changes in enzymes due to anionic movement and reduced availability of organic matter (Frankenberger and Bingham, 1982; Amato and Ladd, 1992; Yao et al., 2009; Singh, 2015). Although the soil enzymes have specific activity with respect to salinity, all three soil enzymes studied had depressive effect due to salinity.

Based on the results of the present study, the future areas of research or remediation strategies for management of these soils could be (1) use of the salinity tolerant microorganisms having plant growth promoting activities, (2) use of organic and chemical amendments to alleviate the salinity stress, (3) use of salinity resistant varieties of different crops, (4) use of integrated nutrient management system to promote plant growth, etc.

4 Conclusions

The soil salinity on the soil chemical properties, microbial and enzyme activities significantly. The exchangeable Na was the second most dominant cations among the four tested in the study. Significant reduction in the MBC, MBC/SOC, BSR and enzyme activity with increasing salinity in all the seasons indicates the adverse effect of salinity on the microbial activity. Unlike the microbial and enzyme activities, the qCO_2 was positively related to salinity levels and this reflects the environmental stress on the microorganisms. This might results in the reduced rate of the organic matter decomposition, mineralization of the key nutrient elements and their availability. The countermeasures

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which would alleviate the salinity stress and restore and improve the microbial activity could be used to manage these soils for crop production.

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Table 1. Detailed description of the study locations and soil texture.

Location number	Location name	Latitude	Longitude	Altitude (m)
1	Marcem Lolem (Cancona)*	14°57.435′ N	74°03.444′ E	15
2	Galgibagh (Cancona)	14°58.262′ N	74°02.811′ E	22
3	Palolem (Cancona)	15°00 884′ N	74°01.491′ E	8
4	Betul (Quepem)	15°09.535′ N	73°57.379′ E	9
5	Tuem (Pernem)	15°39.511′ N	73°48.653′ E	19
6	Uccarsim (Bardez)	15°35.103′ N	73°50.508′ E	9
7	Sangorda (Pilerne)	15°31.021′ N	73°48.429′ E	16
8	Betim (Tiswadi)	15°27.062′ N	73°53.057′ E	1
9	Chodan 1 (Tiswadi)	15°33.335′ N	73°53.899′ E	15
10	Rai Bandar (Tiswadi)	15°29.906′ N	73°51.462′ E	6
11	Merces (Tiswadi)	15°29.238′ N	73°51.428′ E	18
12	Dongri (Tiswadi)	15°27.804′ N	73°55.447′ E	29

* Name of Tahsil/Block.

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Table 2. Physico-chemical properties of the soils.

Salinity level	EC (dS m^{-1})				pH (1 : 2.5 soil:water)				BD (Mg m^{-3})				OC (g kg^{-1})			
	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean
Non-saline	0.81 ±0.06c	2.01 ±0.04c	3.47 ±0.36c	2.09	6.11 ±0.26a	5.35 ±0.23a	5.29 ±0.27a	5.58	1.53 ±0.14a	1.43 ±0.16a	1.39 ±0.14a	1.45	5.05 ±0.13a	6.21 ±0.11a	8.63 ±0.13a	6.63
Weakly saline	2.04 ±0.06bc	3.28 ±0.27c	5.76 ±0.16ab	3.69	5.82 ±0.6a	5.33 ±0.61a	4.90 ±0.84a	5.35	1.51 ±0.16a	1.36 ±0.16a	1.16 ±0.02a	1.34	4.16 ±0.12b	5.30 ±0.18b	7.50 ±0.14a	5.65
Moderately saline	3.50 ±0.57b	6.02 ±0.53b	7.16 ±0.23a	5.55	5.87 ±0.15a	5.33 ±0.25a	5.46 ±0.45a	5.55	1.59 ±0.04a	1.60 ±0.10a	1.31 ±0.09a	1.49	3.64 ±0.01bc	3.71 ±0.10c	7.07 ±0.13ab	4.80
Strongly saline	5.49 ±0.49a	8.29 ±0.015a	8.83 ±1.17b	7.53	5.26 ±0.03a	4.99 ±0.33a	4.66 ±0.2a	4.96	1.50 ±0.08a	1.40 ±0.10a	1.62 ±0.10a	1.51	2.85 ±0.35c	3.20 ±0.08c	5.62 ±0.68b	3.89
Mean	2.96	4.90	6.31		5.77	5.25	5.08		1.53	1.45	1.37		3.93	3.96	7.20	

EC, Electrical conductivity.
pH, Soil pH in 1 : 2.5 soil to water ratio.
BD, Soil bulk density.
OC, Soil organic carbon.
Mons, Monsoon season.
PostM, Post monsoon season.
PreM, Pre monsoon season.
Values in one column followed by similar letters indicates non-significance at 0.05 level.

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Table 3. Effect of salinity levels on exchangeable cationic composition of soils.

Salinity level	ExNa (me L^{-1})				ExK (me L^{-1})				ExCa (me L^{-1})				ExMg (me L^{-1})			
	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean
Non-saline	2.38 ±0.30b	5.73 ±0.54c	10.84 ±0.49c	6.32	0.09 ±0.00a	0.36 ±0.05c	0.45 ±0.01a	0.3	3.31 ±0.16b	15.41 ±0.51c	45.71 ±5.7d	21.48	0.75 ±0.24c	0.30 ±0.12a	0.25 ±0.15c	0.43
Weakly saline	3.24 ±0.21b	11.99 ±0.22bc	14.49 ±0.92b	9.91	0.12 ±0.01a	0.62 ±0.09bc	0.58 ±0.05a	0.44	4.67 ±0.21ab	18.93 ±1.52bc	71.5 ±8.73c	31.7	1.19 ±0.49c	7.40 ±0.92a	11.44 ±1.02c	6.68
Moderately saline	4.74 ±0.37b	14.91 ±1.66ab	18.41 ±0.89a	12.69	0.24 ±0.04a	0.94 ±0.08b	1.22 ±0.07a	0.8	5.39 ±0.21ab	24.6 ±0.33ab	99.93 ±4.26b	43.3	24.45 ±3.56b	120.83 ±83.84a	83.07 ±9.07b	76.12
Strongly saline	9.61 ±1.32a	26.47 ±2.43a	21.86 ±0.82a	19.31	0.8 ±0.41a	1.48 ±0.18a	2.03 ±0.65a	1.44	7.16 ±1.25a	30.02 ±2.3a	169.9 ±18.93a	69.03	99.28 ±7.57a	118.57 ±7.63a	185.32 ±43.96a	134.39
Mean	4.99	14.77	16.39		0.31	0.85	1.07		5.13	22.24	96.76		31.42	61.78	70.02	

ExNa, Exchangeable sodium.
ExK, Exchangeable potassium.
ExCa, Exchangeable calcium.
ExMg, Exchangeable magnesium.
Mons, Monsoon season.
PostM, Post monsoon season.
PreM, Pre monsoon season.
Values in one column followed by similar letters indicates non-significance at 0.05 level.

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Table 4. Effect of soil salinity levels and season on basal soil respiration, microbial biomass carbon, fraction of organic carbon present as organic carbon and metabolic quotient.

Salinity level	BSR (mg CO_2–C evolved g^{-1} soil day^{-1})				MBC (mg kg^{-1} soil)				MBC/SOC (%)				qCO_2 (mg CO_2–C day^{-1} g^{-1} MBC)			
	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean
Non-saline	0.30 ±0.01a	0.31 ±0a	0.39 ±0.00a	0.33	112.75 ±0.82a	112.86 ±3.48a	43.2 ±2.41b	89.6	1.23 ±0.08a	1.63 ±0.12a	1.2 ±0.15a	1.35	0.07 ±0.01a	0.15 ±0b	0.23 ±0.02b	0.15
Weakly saline	0.28 ±0.00ab	0.3 ±0.01a	0.39 ±0.00a	0.32	101.11 ±1.19b	98.94 ±2.41ab	30.45 ±0.71c	76.83	0.86 ±0.01b	1.42 ±0.01ab	0.79 ±0.01b	1.02	0.11 ±0.01b	0.18 ±0.01b	0.41 ±0.03a	0.23
Moderately saline	0.25 ±0.01b	0.20 ±0.04a	0.38 ±0.00a	0.28	89.97 ±3.05c	82.2 ±1.98bc	24.98 ±0.53c	65.72	0.82 ±0b	1.18 ±0.03bc	0.74 ±0.02b	0.91	0.14 ±0.01b	0.22 ±0.01ab	0.49 ±0.02a	0.28
Strongly saline	0.20 ±0.01c	0.12 ±0.02b	0.33 ±0.00b	0.21	77.96 ±3.41d	67.56 ±9.27c	21.1 ±0.89a	55.54	0.56 ±0.03c	0.78 ±0.15c	0.43 ±0.11b	0.59	0.18 ±0.01c	0.3 ±0.04a	0.59 ±0.04b	0.36
Mean	0.25	0.23	0.37		95.45	90.39	29.93		0.87	1.25	0.79		0.13	0.21	0.43	

BSR, Basal soil respiration.
MBC, microbial biomass carbon.
MBC/SOC, fraction of organic carbon present as microbial biomass carbon.
qCO_2, metabolic quotient.
Mons, Monsoon season.
PostM, Post monsoon season.
PreM, Pre monsoon season.
Values in one column followed by similar letters indicates non-significance at 0.05 level.

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Table 5. Effect of soil salinity levels and season on the soil enzyme – dehydrogenase, phosphatase and urease activities of soil.

Salinity level	DHA (mg TPF kg^{-1} soil h^{-1})				Urease (mg urea hydrolyzed kg^{-1} soil h^{-1})				PHP (mg pnp kg^{-1} soil h^{-1})			
	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean	Mons	PostM	PreM	Mean
Non-saline	44.02 ±7.11a	19.04 ±1.97a	14.96 ±1.50a	26	257.51 ±2.06a	290.63 ±3.66a	135.2 ±10.50b	227.78	268.18 ±26.99ab	121.11 ±0.48b	112.66 ±2.23a	167.32
Weakly saline	21.33 ±4.09b	10.26 ±0.74b	7.29 ±0.39b	12.96	234.58 ±6.66b	280.54 ±0.57ab	96.43 ±2.86c	203.85	322.54 ±71.64a	127.31 ±0.81a	106.69 ±3.95a	185.51
Moderately saline	8.33 ±0.91b	8.30 ±0.21b	5.67 ±0.28b	7.43	217.12 ±0.51c	275.16 ±1.73bc	85.26 ±1.89c	192.52	138.10 ±7.96bc	119.67 ±1.29b	95.17 ±2.20a	117.65
Strongly saline	5.97 ±0.21b	6.45 ±0.34b	3.70 ±0.47b	5.37	209.65 ±2.56c	267.52 ±1.85c	74.56 ±3.77a	183.91	69.90 ±26.24c	114.09 ±1.31c	70.59 ±2.31a	84.86
Mean	19.91	11.01	7.91		229.71	278.46	97.87		199.68	120.55	96.28	

DHA, Dehydrogenase activity.
Urease, Urease activity.
PHP, phosphatase activity.
Mons, Monsoon season.
PostM, Post monsoon season.
PreM, Pre monsoon season.
Values in one column followed by similar letters indicates non-significance at 0.05 level.

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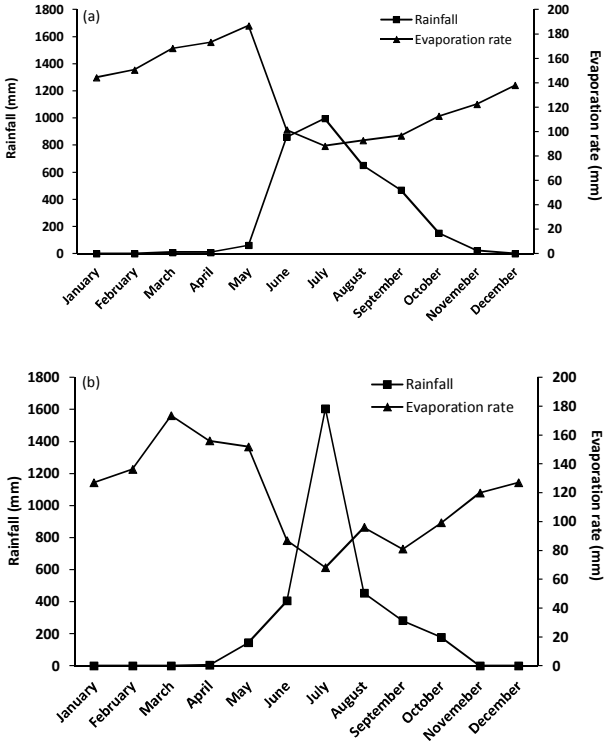

Figure 1. (a) Mean monthly pattern of the rainfall during 2013 and **(b)** mean monthly pattern of the rainfall during 2014.

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