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Assessment of Microbial Counts and -Enzyme Activities in Coastal Saline Soils of Eastern India

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An investigation was carried out to study the effect of salinity on microbes and enzyme activities of the salt affected soils in five districts of Odisha, India adjacent to Bay of Bengal in relation to physico-chemical properties to suggest suitable strategies for sustainable crop production. The soils are strongly acidic to slightly alkaline, and having a salinity of 2.28 to 8.11 dS m^{-1}, low in organic C, available N and moderate amounts of available phosphorus and potassium. The microbial population was relatively lower in these saline soils and in which bacteria was dominant over fungi and actinomycetes. Soil biological activity in terms of dehydrogenase and fluorescein diacetate activities in the saline soils varied from 0.89 - 2.11 **μg TPF hr^{-1} g^{-1} soil and 0.91 to 2.31 μg g^{-1} hr^{-1}, respectively. Acid phosphatase activity was relatively higher (27.8 - 64.2 μg p-nitrophenol g^{-1} soil h^{-1}) than alkaline phosphatase activity (17.8 - 55.9 μg p-nitrophenol g^{-1} soil h^{-1}) thereby influencing the P transformations. Among the various soil groups, Vertisols had higher status of available nutrients and enzyme activities followed by Inceptisols, Alfisols and Entisols. Salinity had negative relationship with all the microbial variables and chemical properties of the soil, indicating that the increase in soluble salt content affects severely the bio-chemical transformations that regulate** inherent soil fertility**. Since majority of soil biochemical transformations are dependent on presence of microbes and microbial activities, the present investigation emphasized the intervention of suitable strategies for maintenance of soil quality to realize higher crop productivity in the coastal regions.**

***(Key words**: Correlations, Enzyme activities, Microbes, Physico-chemical properties, Salt affected soils)*

Coastal soils are generally salt-affected due to certain hydrologic and geographical reasons, and the salinity in coastal areas is the main factor for poor crop yields (Kaur *et al*., 1998). The state of Odisha has a long coastline of 480 km with Bay of Bengal and saline soils occupy 2.54 lakh ha, out of which 1.93 lakh ha is under agriculture with low crop productivity. Monoculture of rice is predominant during the monsoon season in these areas with poor yields (Lenka, 1996).

Salinity stress negatively impacts agricultural production throughout the world. It affects crop germination and density, reduces the growth rate resulting in smaller leaves, shorter stature, limiting nutrient absorption and reducing the quality of available water. Excess salts interfere with plant nutrition by affecting nutrient availability, uptake, or their physiological role within the plant. The initial and primary effect of salinity is due to its osmotic effects, reduced root length and root biomass, delayed maturity rate, low hydraulic conductivity and aggregate instability (Freire *et al.*, 2009). The severity of salinity response is also mediated by environmental interactions such as relative humidity, temperature, radiation and air pollution (Shannon *et al*., 1996). Usually there is a shift in the onset of monsoon rains, occurrence of prolonged dry spells, possibly due to current global warming. It is inevitable to reduce the doses of inorganic nutrients to enhance the crop production for feeding millions of people.

Soil enzymes play an important role in the processes of organic matter decomposition which regulate ecosystem functioning by catalyzing many reactions necessary for the life processing of microorganisms in the soil. Dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soil and both of acid and alkaline phosphomonoesterases are associated in the mineralization of organic phosphorus compounds like inositol phosphate, nucleic acid, phospholipids and other simple ester to inorganic phosphate. Fluorescein diacetate hydrolyzing activity (FDHA) can be measured as sensitive indicator of ecosystem development and disturbance. These enzyme activities could be used as more sensitive indicators of soil microbial response to land use, soil management, and environmental variables.

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A plethora of information is available on the effects of salinity on physical and chemical properties of soil (Sardinha *et al*., 2003), however, soil microbial aspects of natural saline environments are scantily studied (Zahran, 1997). Soil microbial communities and their activity are greatly influenced by salinity (Rietz and Haynes, 2003), which is a concern because microbial processes in soils control ecological function and transformation of nutrients, which regulates soil quality. In addition, abiotic and biotic environmental variables can affect microbial parameters. There is a need to understand the effect of salinity in the coastal regions with respect to quality parameters of the coastal saline soils for making suitable strategies for its better management, sustainable crop production and to maintain ecological balance. The present investigation was planned to study the microbial population and the activities of microbial variables as influenced by salinity stress and its relationship with physico-chemical properties, in order to enhance the soil productivity for sustainable crop production in the coastal saline soils of Odisha, India.

MATERIALS AND METHODS

A total of 30 surface soil samples (0.30 m depth) have been collected from arable lands adjacent to the Bay of Bengal representing five coastal districts (Balasore, Kendrapada, Puri, Khurda and Jagatsinghpur) of Odisha, India. The collected soil samples were processed and used for estimation of physico-chemical and chemical properties by using standard procedures (Jackson, 1973). Particle size analysis for sand, silt, and clay was carried out by following Bouyoucos hydrometer method (Piper, 1966). Another set of fresh soil samples were collected from all the locations, removed gravels and other waste materials, sieved with 0.5 mm sieve, stored for up to 3 weeks at 4° C and used for enumeration of microbes and estimation of enzyme activities. The media used for isolation of bacteria was nutrient agar (NA), for fungi it was potato dextrose agar (PDA) and for actinomycetes starch casein agar (SCA). Soil dilution plates were prepared from fresh soil on the day of sampling. Hence, by enumerating these colonies which develop on a specific growth medium, the number of viable cells of a particular group of organisms present in soil can be ascertained. After the serial dilution, 1.0 ml of required dilution (10^{-4} for fungi and actinomycetes and 10^{-5} for bacteria) was inoculated into the respective petri-plates. The sample was spread over the media via a flame sterilized bent glass rod and all plates were incubated in the dark at 20°C. Before the incubation the moisture was allowed to be absorbed into the agar. After microbial colonies were readily visible (2 to 7 days for bacteria & fungi and 7 to 14 days for actinomycetes), the number of colonies on each plate were counted and calculated. The number of cfu g^{-1} dry soil was estimated by taking the soil dilution factor and soil moisture content into account.

Soil biological activity was determined by the method as described by Casida *et al*. (1964). One g of fresh soil was taken in a test tube (15 ml capacity) and 0.2 ml of 2, 3, 5-triphenyl tetrazolium chloride (TTC) solution (3%), and 1.0 ml of 1.0 % glucose solution were added to each of the tubes and the bottom was gently tapped to drive out all trapped oxygen. The test tubes were cotton plugged and incubated at 28± 1°C for 48 hours. After incubation 10 ml methanol was added to each tube and mixed vigorously. It was then allowed to stand for 6 hours for color development. The clear pink/red coloured supernatant was withdrawn and readings were taken with spectrophotometer at a wave length of 485 nm and the results were expressed as μg TPF h^{-1} g^{-1}.

The fluorescein diacetate hydrolysis assay was determined by taking 1 g of fresh soil sample in a test tube, to which was added 5 ml of 60 mM of potassium phosphate buffer (pH 7.6), 10 μl fluorescein diacetate solution and incubated at 37° C for 2 h followed by addition of 0.2 ml of acetone, and filtered through Whatman No. 1 filter paper. The intensity of yellow colour developed was measured at 490 nm and the results were expressed as μg of fluorescein released g^{-1} soil h^{-1} (Green *et al*., 2006).

Phosphatase activity was determined by the method described by Tabatabai and Bremner (1969). One g fresh soil sample was taken in two sets in 50 ml conical flasks. Out of these two sets, one was used as control. 0.2 ml toluene and 4 ml of modified universal buffer (pH 6.5 or 11) were added to all the flasks followed by 1.0 ml of p-nitrophenyl phosphate solution to only one set of samples and flasks of both the sets were swirled for few seconds to mix the contents. These flasks were then stoppered and placed in an incubator at 37° C for one hour. After incubation, the stopper was removed, 1.0 ml of 0.5 M $CaCl_2$ and 4.0 ml of 0.5 M NaOH were added and the flasks were swirled for few seconds. 1.0 ml of p-nitrophenyl phosphate was added to the remaining set (control) of samples. All the suspensions were quickly filtered through Whatman No. 2 filter paper and the

yellow colour intensity of the filtrate was measured at 440 nm by using spectrophotometer and the phosphatase activity was expressed as µg p- nitrophenol released g^{-1} soil h^{-1}. Correlation coefficients were derived between enzyme activities with soil microbial counts and physico-chemical properties.

RESULTS AND DISCUSSION

General characteristics of coastal saline soils

The texture of the soils varied from sandy clay loam to clay loam (Table 1) and belongs to Alfisols (8), Inceptisols (10), Vertisols (8) and Entisols (4). The number of soils falling under each textural group were found to be loam - 1, sandy loam - 4, sandy clay loam - 16, clay loam - 9. The clay content in these saline soils ranged from 21.2 - 42.5 per cent, while, the silt and sand contents varied from 15.2 - 23.8 and 37.2 - 60.3 per cent, respectively. The mean clay content was highest in the Vertisols and ranged from 34.6 - 37.6 per cent with a mean of 36.1 per cent followed by Inceptisols (27.1 - 33.9 %, mean of 29.3 %). However, the silt and sand fractions in these saline soils varied from 15.9 - 23.8 and 37.2 - 64.4 per cent, respectively.

The pH of the soils varied from 4.24 to 7.95 (Table 1). Among the soils, 5 soils (17 %) had almost neutral pH and 10 soils had a pH of < 5.0 and the rest had a pH of 5.0 - 6.5. The soluble salt content (ECe) of the soils varied from 2.28 - 8.11 dS m^{-1}. Majority of the soils in the study had electrical conductivity of > 4.0 dS m^{-1} and the sequence of the soils with respect to mean salinity (dS m^{-1}) was in the order of Vertisols (4.66) > Entisols (4.58) > Inceptisols (4.20) > Alfisols (4.09). Organic carbon content in the soils of the present study varied from 0.35 to 0.70 % with a mean of 0.47 %. Of all the soils, 22 were deficient in organic C, 8 soils had medium and only one soil has recorded higher status of organic C. The mean organic carbon content was highest in Vertisols (0.599 %) followed by Inceptisols (0.456 %), Entisols (0.410 %) and Alfisols (0.399 %). Thus, the results emphasized that there is an urgent need to improve the organic matter status to enhance the productivity of various crops in the coastal saline soils of Odisha. Total nitrogen content in these soils ranged from 0.0728 - 0.2816 % and it was found highest in Vertisols (0.205%) followed by Inceptisols (0.182%) and Alfisols (0.141%). Though most of the soils contain lower organic matter, the total N content is relatively higher in these coastal saline soils.

The available N content of the soils varied from 133 - 345 kg ha^{-1} (mean 196 kg ha^{-1}). Majority of the soils (87%) are deficient in available N status, so they respond well to N fertilization (Mahajan *et al*., 1991). The available P content in the soils ranged from 11.88 - 55.74 kg ha^{-1} (mean 28.31 kg ha^{-1}). Of all the locations, 17 soils had higher and the rest had medium status of available P. The available K content widely varied from 107 - 756 kg ha^{-1} (mean 320 kg ha^{-1}), in which 16, 10, and 4 soils had higher, medium and deficient in available K, respectively. The results indicated that the coastal saline soils contain low available N and moderate amounts of available P and K.

Microbial population in coastal saline soils

Total fungal and actinomycetes population in these saline soils varied from 36-98 x 10^4 cells g^{-1} soil and 21-38 x 10^4 cells g^{-1} soil, respectively, whereas the total bacterial population ranged from 12-29 x 10^5 cells g^{-1} soil (Table 2). Highest fungal counts were observed in Entisols, while total bacterial and actinomycetes were highest in Alfisols. Incorporation of organic sources for paddy cultivation during *Kharif* season had profound influence on microbes since organic matter being the chief source of energy and food for most of the soil organisms and acts as store house for various essential nutrients, as well as, it provides congenial environment for growth and multiplication of various microbial communities in the soil. Application of lime and paper mill sludge by the farmers prior to paddy transplanting has shown greater impact on microbes in the soil as pH and salinity had a definite influence/effect on quantitative and qualitative composition of soil microbes. Most of the soil bacteria prefer neutral or slightly alkaline reaction between pH 4.5 - 8.0 and fungi grow in acidic reaction between pH 4.5 - 6.5, while actinomycetes prefer slightly alkaline soil reaction. Incorporation of organic sources in combination with inorganic fertilizers had significant impact on various soil microbes, which may be useful for nutrient transformations for enhancing the crop productivity (Tripathi *et al*., 2007).

Dehydrogenase activity

Dehydrogenase activity across all the soils varied from 0.89 - 2.11 μg TPF hr^{-1} g^{-1} soil with a mean of 1.37 μg TPF hr^{-1} g^{-1} soil (Table 2). Highest mean biological activity (μg TPF hr^{-1} g^{-1}) was found in Inceptisols (1.594) followed by Vertisols (1.571), Alfisols (1.209) and

Table 1. *Physico-chemical properties of coastal saline soils of Odisha*

Location/Village	District	Textural components (%)			Textural class	Soil order	pH (1:2.5)	EC_e (dS m^{-1})	Org. C (%)	Total N (%)	Available nutrient (kg ha^{-1})		
		Sand	Silt	Clay							N	P	K
1. Hirigai	Balasore	54.9	23.8	21.3	Scl	Alfisol	5.72	4.85	0.348	0.126	135.5	18.44	355.4
2. Gesua	Balasore	57.4	17.5	25.1	Scl	Alfisol	5.54	5.43	0.432	0.190	136.7	27.18	235.3
3. Ramnagar	Kendrapada	57.1	16.1	26.8	Scl	Alfisol	4.24	4.91	0.418	0.146	170.6	22.16	368.8
4. Baulokoni	Kendrapada	55.6	15.9	28.5	Scl	Alfisol	5.55	5.88	0.392	0.164	148.0	17.92	340.9
5. Gadaharishpur	Jagatsinghpur	57.5	19.3	23.2	Scl	Alfisol	4.97	2.91	0.356	0.111	134.2	13.44	199.7
6. Siali	Jagatsinghpur	53.6	20.5	25.9	Scl	Alfisol	4.82	2.99	0.382	0.143	139.2	24.8	118.9
7. Sunadia	Jagatsinghpur	57.8	16.9	25.3	Scl	Alfisol	4.62	2.53	0.390	0.118	170.6	20.68	119.7
8. Sahana	Puri	53.9	21.4	24.7	Scl	Alfisol	5.11	3.21	0.474	0.127	166.8	25.31	312.9
9. Nuanai	Balasore	47.4	18.7	33.9	cl	Inceptisol	5.33	3.35	0.494	0.282	316.0	49.28	510.9
10. Chakna	Balasore	56.1	16.8	27.1	Scl	Inceptisol	7.44	5.52	0.422	0.227	145.5	26.88	113.3
11. Srigundi	Balasore	52.8	18.2	29	Scl	Inceptisol	5.69	4.85	0.402	0.141	174.4	23.94	122.5
12. Padmapur	Jagatsinghpur	52.7	20.1	27.2	Scl	Inceptisol	5.02	3.46	0.432	0.179	154.2	30.60	125.0
13. Misimisia	Jagatsinghpur	54.3	18.2	27.5	Scl	Inceptisol	5.16	2.48	0.459	0.196	249.6	32.03	338.8
14. Kendumatha	Jagatsinghpur	55.4	16.8	27.8	Scl	Inceptisol	4.96	3.01	0.434	0.135	184.4	25.68	113.7
15. Ambilari	Puri	52.2	17.3	30.5	Scl	Inceptisol	7.95	5.62	0.459	0.176	164.3	26.40	327.8
16. Nayagada	Puri	51.7	19.9	28.4	Scl	Inceptisol	6.03	5.78	0.446	0.189	191.9	23.72	194.3
17. Siripur	Khurda	48.6	21.2	30.2	l	Inceptisol	5.40	3.25	0.516	0.152	181.9	31.36	420.9
18. Nathapur	Khurda	50.6	18.5	30.9	Scl	Inceptisol	5.25	4.63	0.495	0.143	191.9	25.09	417.0
19. Kharnasi	Kendrapada	44.6	20.5	34.9	cl	Vertisol	5.13	7.35	0.529	0.223	217.0	30.91	271.0
20. Sudhikeswar	Kendrapada	42.6	22.8	34.6	cl	Vertisol	6.21	4.12	0.780	0.193	301.1	45.02	696.3
21. Gandalaba	Puri	43.9	18.5	37.6	cl	Vertisol	7.63	2.58	0.638	0.225	345.0	53.90	465.4
22. Daulokoni	Puri	43.8	20.5	35.7	cl	Vertisol	5.96	4.85	0.501	0.208	179.4	28.90	406.7
23. Tangi	Khurda	42.5	20.3	37.2	cl	Vertisol	6.89	3.98	0.683	0.261	331.2	38.08	563.8
24. Kalupada	Khurda	44.4	19.7	35.9	cl	Vertisol	5.66	3.46	0.585	0.138	194.4	27.05	470.2
25. Kalupada	Khurda	40.9	22.4	36.7	cl	Vertisol	5.48	3.53	0.655	0.274	239.6	55.74	756.3
26. Papira	Puri	37.2	20.3	42.5	cl	Vertisol	5.73	7.38	0.418	0.117	170.6	22.86	228.7
27. Pimperkani	Jagatsinghpur	60.9	20.7	18.4	Sl	Entisol	4.33	2.63	0.428	0.167	249.6	23.69	502.9
28. Ambadia	Jagatsinghpur	61.3	19.5	19.2	Sl	Entisol	5.07	3.34	0.418	0.154	133.0	22.40	195.1
29. Chaulia	Jagatsinghpur	63.1	17.2	19.7	Sl	Entisol	4.60	4.24	0.446	0.101	219.5	23.95	210.6
30. Daulokoni	Puri	64.4	16.3	19.3	Sl	Entisol	5.35	8.11	0.348	0.073	156.8	11.88	107.4
Range		37.2-64.4	15.9-23.8	18.4-42.5	–	–	4.24-7.95	2.48-8.11	0.348-0.780	0.073-0.282	133-345	11.88-55.74	107.4-756.3
Mean		52.0	19.2	28.8	–	–	5.56	4.34	0.473	0.169	196.4	28.31	320.3

Entisols (1.168). Incorporation of organic sources and balanced doses of chemical fertilizers by the farmers had greater influence on dehydrogenase activity, which may be due to increased microbial population and enhanced biological activity. These results are in agreement with the findings of Casida *et al*. (1964) and Prasad and Mertia (2005).

Fluorescein diacetate hydrolysis assay

The fluorescein diacetate activity (FDA) in the coastal saline soils varied from 0.91 - 2.31 μg g^{-1} hr^{-1} with a mean value of 1.43 μg g^{-1} hr^{-1} (Table 2). The sequence of FDA (μg g^{-1} hr^{-1}) in the soils followed in the order of Vertisols (1.565) > Inceptisols (1.450) > Entisols (1.302) > Alfisols (1.10). The biological activity in terms of DHA and FDA were higher in the saline soils of Khurda district, which was also revealed that the nutrient status in these soils was higher than the other locations. Increased doses of inorganic chemical fertilizers for paddy in *Kharif* season showed an increasing trend of dehydrogenase and FDA in the soils. These results are in accordance to the findings of Zelles *et al*. (1987). FDA hydrolysis is often used as an indicator of microbial activity and is correlated with microbial respiration. As such it is a simple, non-specific, but sensitive technique that can be used to estimate relative levels of microbial activity in soils, and has been recommended as a useful parameter to assess the soil quality (Schnürer and Rosswall, 1982). The increased microbial activities (dehydrogenase, fluorescein diacetate, and phosphatase) due to residual effect of organic manures in combination with chemical fertilizers, may be ascribed to greater availability of substrates that support such activities, as well as the cofactors of several enzymes (Kremer and Li, 2003; Zablotowicz *et al*., 1998).

Phosphatase activity

The activities of acid and alkaline phosphomono-esterases in the saline soils ranged from 27.8 - 64.2 μg p-nitrophenol g^{-1} soil h^{-1} and 17.8 - 55.9 μg p-nitrophenol g^{-1} soil h^{-1}, respectively (Table 2). Among the various soil orders, Vertisols recorded highest mean acid phosphatase activity (45.0 μg PNP g^{-1} soil h^{-1}) followed by Inceptisols (44.7 μg PNP g^{-1} soil h^{-1}), Alfisols (34.1 μg PNP g^{-1} soil h^{-1}) and Entisols (33.4 μg PNP g^{-1} soil h^{-1}). However, the mean activity of alkaline phosphomonoesterase (μg PNP g^{-1} soil h^{-1}) was found highest in Inceptisols (36.5) followed by Vertisols (35.1) and Alfisols (26.2). The saline soils of Khurda district have recorded highest phosphatase activities followed by Balasore and Kendrapada.

Increased activities of both acid and alkaline phosphomonoesterases in these coastal saline soils would have enhanced the transformation of organic P compounds into inorganic forms which may readily available for P nutrition of the crop. Application of lime had positive effect on both acid phosphatase and alkaline phosphatase activities as it improves the soil pH, which can limit the enzyme-mediated reaction rates by affecting the maximum activities of enzymes, and the solubility of substrates and cofactors (Dick *et al*., 1996). The activities of both alkaline and acid phosphatase are closely related to soil pH, with acid phosphatase dominating in acid soils, and alkaline phosphatase in alkaline soils, and the results of the present study are in concurrent with the findings of Eivazi and Tabatabai (1977).

Interrelationship between soil physico-chemical properties

Sand fraction of the soil was negatively and significantly related with organic C, total N, available N, P and K available nutrient status and the 'r' values were found to be -0.71^{**}, -0.54^{**}, -0.49^{**}, -0.65^{**} and -0.58^{**}, respectively (Table 3). However, clay fraction of the soil had positive and significant relationship with organic C, total N, available N, P, and K and the 'r' values were found to be 0.66^{**}, 0.54^{**}, 0.49^{**}, 0.62^{**}, 0.49^{**}, respectively. Soil salinity had negative relationship with available nutrients of the soil, emphasizing that increased salt concentration affects the nutrient transformations led to low availability of soil nutrients for uptake by the plants. These results are in accordance with the findings of Goyal *et al*. (2003).

Organic carbon content of these saline soils had significantly negative relationship with sand ($r = -0.71^{**}$), positively significant relationship with clay fraction of the soil ($r = 0.66^{**}$), as well as available N, P and K, which may be ascribed to the fact that the available nutrients in soils originates from organic matter through mineralization process. Thus, organic matter is the store house for all essential nutrients and regulates the availability of various essential nutrients for uptake by the plant system. Total N showed significant relationship with clay ($r = 0.54^{**}$), org. C ($r = 0.60^{**}$) and available N ($r = 0.61^{**}$). Since total N is the main pool for different N fractions, the low status of total N responds more to N fertilization.

***Table 2**. Microbial population and enzyme activities in coastal saline soils of Odisha*

Location	District	Soil order	Fungi ($1x10^4$cells g^{-1})	Bacteria ($1x10^5$ cells g^{-1})	Actinomycetes ($1x10^4$cells g^{-1})	Dehydrogenase (μg TPF hr^{-1} g^{-1})	FDA (μg g^{-1} hr^{-1})	Acid Phosphatase (μg PNP g^{-1} h^{-1})	Alk. Phosphatase (μg PNP g^{-1} h^{-1})
1. Hirigai	Balasore	Alfisol	65	23	29	0.989	0.888	38.6	33.8
2. Gesua	Balasore	Alfisol	36	17	33	1.125	1.108	39.7	41.0
3. Ramnagar	Kendrapada	Alfisol	75	24	29	1.115	1.142	32.8	28.7
4. Baulokoni	Kendrapada	Alfisol	84	21	38	1.444	1.225	33.6	24.3
5. Gadaharishpur	Jagatsinghpur	Alfisol	80	26	38	0.912	0.979	29.9	19.8
6. Siali	Jagatsinghpur	Alfisol	83	21	35	1.798	1.229	38.4	23.7
7. Sunadia	Jagatsinghpur	Alfisol	79	25	29	1.302	1.009	28.1	17.8
8. Sahana	Puri	Alfisol	79	26	31	0.983	1.218	31.6	20.8
9. Nuanai	Balasore	Inceptisol	87	16	22	1.780	1.651	52.4	45.7
10. Chakna	Balasore	Inceptisol	83	19	25	1.320	1.112	41.2	37.7
11. Srigundi	Balasore	Inceptisol	51	15	24	1.454	1.335	43.5	41.2
12. Padmapur	Jagatsinghpur	Inceptisol	88	19	31	1.828	1.325	42.0	25.8
13. Misimisia	Jagatsinghpur	Inceptisol	87	13	22	2.312	2.082	43.2	26.3
14. Kendumatha	Jagatsinghpur	Inceptisol	80	12	33	1.421	1.511	59.7	55.9
15. Ambilari	Puri	Inceptisol	65	19	24	1.485	1.384	41.0	27.5
16. Nayagada	Puri	Inceptisol	76	28	31	1.315	1.451	37.3	25.3
17. Siripur	Khurda	Inceptisol	60	29	28	1.484	1.204	45.4	41.4
18. Nathapur	Khurda	Inceptisol	65	15	32	1.543	1.442	41.5	38.6
19. Kharnasi	Kendrapada	Vertisol	79	15	33	1.325	1.354	46.7	27.7
20. Sudhikeswar	Kendrapada	Vertisol	65	18	31	1.821	1.493	64.2	44.8
21. Gandalaba	Puri	Vertisol	78	17	35	1.785	1.669	44.0	34.9
22. Daulokoni	Puri	Vertisol	70	20	29	1.338	1.512	39.6	37.1
23. Tangi	Khurda	Vertisol	71	16	24	1.818	2.114	40.8	34.2
24. Kalupada	Khurda	Vertisol	43	16	29	1.722	1.672	43.3	40.9
25. Kalupada	Khurda	Vertisol	87	20	25	1.776	1.577	53.6	38.1
26. Papira	Puri	Vertisol	98	16	33	0.983	1.132	27.8	23.2
27. Pimperkani	Jagatsinghpur	Entisol	79	21	27	0.928	1.488	34.1	19.2
28. Ambadia	Jagatsinghpur	Entisol	90	15	25	0.999	1.119	29.3	21.0
29. Chaulia	Jagatsinghpur	Entisol	81	18	21	1.080	1.422	41.6	40.1
30. Daulokoni	Puri	Entisol	81	15	33	1.664	1.177	28.6	19.4
Mean	–	–	74.8	19.2	29.3	1.43	1.367	40.5	31.9
Sd (±)	–	–	13.8	4.5	4.6	0.351	0.288	8.88	9.97

***Table 3**. Interrelationship (r) between soil physico-chemical properties*

Soil property	Sand	Silt	Clay	pH	ECe	O.C.	Total N	Av. N	Av. P	Av. K
Sand	–	-0.503**	-0.958**	-0.420*	-0.058	-0.706**	-0.543**	-0.491**	-0.649**	-0.577**
Silt	-0.503**	–	0.235	0.007	-0.193	0.414*	0.215	0.191	0.333	0.492**
Clay	-0.958**	0.235	–	0.470	0.130	0.657**	0.539**	0.489**	0.619**	0.486**
pH	-0.232	-0.076	0.286	–	0.218	0.397*	0.433**	0.273	0.360*	0.196
Ece	0.162	-0.139	-0.129	0.218	–	-0.202	-0.129	-0.291	-0.367*	-0.236
O.C.	-0.897**	0.274	0.919**	0.397*	-0.202	–	0.602**	0.762**	0.806**	0.790**
Total N	-0.631**	0.180	0.652**	0.433**	-0.128	0.602**	–	0.612**	0.665**	0.561**
Available N	-0.666**	0.029	0.755**	0.273	-0.291	0.762**	0.612**	–	0.718**	0.676**
Available P	-0.784**	0.258	0.795**	0.360*	-0.332*	0.806**	0.804**	0.784**	–	0.696**
Available K	-0.777**	0.374	0.738**	0.196	-0.237	0.790**	0.561**	0.676**	0.696**	–

* and ** significant at 5 and 1.0 per cent level, respectively

***Table 4**. Correlation coefficients (r) between soil micro flora and enzyme activities*

Enzyme activity	Fungi	Bacteria	Actinomycetes	DHA	FDA	Acid phosphatase	Alkaline phosphatase
Fungi	–	0.351*	0.563**	0.061	0.228	0.141	-0.116
Bacteria	0.351*	–	0.521**	0.646**	0.425*	0.432**	0.303*
Actinomycetes	0.563**	0.521**	–	0.449**	0.384*	0.255	0.093
DHA	0.061	0.646**	0.449**	–	0.693**	0.481**	0.324*
FDA	0.228	0.425*	0.384*	0.693**	–	0.270	0.524**
Acid phosphatase	0.141	0.432**	0.255	0.481**	0.524**	–	0.816**
Alkaline phosphatase	-0.116	0.303*	0.093	0.324*	0.270	0.816**	–

* and ** significant at 5 and 1 per cent level, respectively

Interrelationship between soil microbes and enzyme activities

Perusal of the data in Table 4 revealed that total fungi in these saline soils had positively significant relationship with actinomycetes (r = 0.56**) rather than bacteria (r = 0.35*), however, total bacteria also had significantly positive relationship with actinomycetes (r = 0.52**), indicating that the conditions prevailing in the saline soils of the study area for multiplication of one group of microbes also favours the multiplication of other microbes. The microbial counts with respect to bacteria and actinomycetes had significant relationship with dehydrogenase activity (r = 0.65** and 0.45**, respectively) and fluorescein diacetate activity (0.43* and 0.38*, respectively), indicating that the biological activity of these saline soils was mostly influenced by bacteria and actinomycetes. Both the acid and alkaline phosphatase activities in the soils had significant relationship with bacteria (r = 0.43** and 0.30**, respectively) and non-significant relationship with fungi and actinomycetes, emphasizing that the transformation of P was influenced by bacteria rather than fungi and actinomycetes.

Relationship between soil microbial variables and physico-chemical properties

The clay fraction of the soil had positively significant relationship with microbial variables (Table 5), whereas silt had non-significant relationship with micro-flora and enzyme activities. Soil pH had positive and significant relationship with total bacteria (r = 0.33*) and non-significant relationship with total actinomycetes (r = 0.28), indicating that increase in soil pH favorably influenced the multiplication of bacteria and other microbes which plays a significant role in enzyme activities and transformation of nutrients. The soil reaction had positive and significant relationship with FDA (r = 0.32*) and non-significant relationship with other enzyme activities. The changes in microbial biomass and microbial activity were related to the increase in pH, which induce the development of bacteria

Table 5. *Correlation coefficients (r) between soil physico-chemical properties with soil micro-flora and enzyme activities*

Microbes / Enzymes	Sand	Silt	Clay	pH	ECe	Org. C.	Total N	Av. N	Av. P	Av. K
Fungi	0.051	-0.037	-0.045	-0.187	-0.033	0.182	0.227	0.340*	0.313*	0.205
Bacteria	0.129	0.248	-0.228	-0.136	-0.161	-0.184	0.564**	0.647**	0.552**	0.587**
Actinomycetes	-0.035	-0.017	0.045	-0.100	0.197	-0.166	0.299	0.517**	0.347*	0.476**
Dehydrogenase	-0.365*	-0.010	0.414*	0.265	-0.206	0.484**	0.564**	0.777**	0.522**	0.516**
FDA	-0.427*	0.063	0.460**	0.244	-0.289	0.633**	0.448**	0.503**	0.558**	0.304
Acid phosphatase	-0.436**	0.246	0.409*	0.212	-0.215	0.644**	0.514**	0.520**	0.684**	0.465**
Alkaline phosphatase	-0.325*	0.026	0.357*	0.214	-0.119	0.444**	0.327*	0.329*	0.472**	0.306*

*and ** significant at 5 and 1.0 per cent level, respectively

to the detriment of fungi (Zelles *et al*., 1987). The available N, P, and K have influenced the multiplication of bacteria as revealed from the data rather than actinomycetes and fungi, which plays significant role in organic matter decomposition and nutrient transformations.

Positively significant relationship between dehydrogenase activity and chemical properties of the soil was observed and the 'r' values were found to be 0.48**, 0.56**, 0.78**, 0.52** and 0.52** in respect of organic C, total N, available N, P, and K (Table 5). Organic matter is the store house of various groups of microbes and hence improvement in organic matter had significant role in multiplication of micro-flora and various groups of enzymes involved in different bio-chemical processes in the soil. Fluorescein diacetate activity also had significant relationship with organic C (r = 0.63**), total N (0.45**), available N (r = 0.50**), and P (r = 0.56**). Soil phosphatase activity was closely related to soil organic matter content, supporting previous reports that elevated organic matter levels promote soil phosphatase activity (Frankenberger and Dick, 1983).

Increased concentration of soluble salts diminishes the multiplication of microbes and activity of various soil enzymes and the same had been revealed in the present study that the soil micro-flora and activities of enzymes showed negative relationship with salinity. Similar findings were reported earlier by Garcia and Hernandez (1996) and Chowdhury *et al*. (2011). Total N content of the soil had highly significant relationship with DHA (r = 0.56**), FDA (r = 0.45**), acid phosphatase (r = 0.51**) and alkaline phosphatase activity (r = 0.33*). Available P in the soil showed significant relationship with acid phosphates activity (r = 0.68**) followed by alkaline phosphatase activity (r = 0.47**), indicating that the P transformations were mostly influenced by acid phosphomonoesterase rather than alkaline phosphomonoesterase in these coastal saline soils.

In conclusion, the coastal saline soils had a salinity of 2.28 - 8.11 dS m^{-1} at the time of harvest of paddy and it rises up to 20 - 40 dS m^{-1} during summer months which causes lower multiplication of microbes and enzyme activities and in turn leads to lower rate of transformation of essential nutrients. These coastal saline soils contain lower organic C, lower status of available N and medium to high status of available P and K. The population of bacteria were relatively higher than the actinomycetes and fungi and soil bacteria plays major role in the transformation of various nutrients. Soil biological activity as referred by dehydrogenase and fluorescein diacetate, as well as phosphatase activities were highly influenced by salinity and were regulated by inherent soil fertility and addition of soil amendments, organic sources in combination with chemical fertilizers. Soil biochemical transformations were highly dependent on presence of various micro-flora and microbial activities. The present investigation emphasizes the intervention of suitable strategies for maintenance of soil quality in the salt affected areas to realize higher crop productivity in the coastal regions of eastern India.

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