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Soil quality in mangrove ecosystem deteriorates due to rice cultivation

Rahul Tripathi[a,*], A.K. Shukla[b], Md. Shahid[a], D. Nayak[c], C. Puree[c], S. Mohanty[a], R. Raja[d], B. Lal[a], Priyanka Gautam[a], P. Bhattacharyya[d], B.B. Panda[d], Anjani Kumar[a], N.N. Jambhulkar[a], A.K. Nayak[e]

[a] Scientist, ICAR-National Rice Research Institute, Cuttack 753006 Odisha, India
[b] PC, Micronutrient, IISS, Bhopal 462038 Madhya Pradesh, India
[c] Senior Research Fellow, ICAR-National Rice Research Institute, Cuttack 753006 Odisha, India
[d] Senior Scientist, ICAR-National Rice Research Institute, Cuttack 753006 Odisha, India
[e] Principal Scientist and Head, Crop Production Division, ICAR-National Rice Research Institute, Cuttack 753006 Odisha, India

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ABSTRACT

In this paper an attempt has been made to quantify and test whether rice cultivation in adjoining areas of mangrove forest by cutting forest tress has brought about significant changes in physicochemical, microbial and enzymatic properties of soils of the mangrove ecosystem. We collected 48 soil samples (24 pairs). We collected paired soil samples from each location, i.e., one soil sample from mangrove forest and its paired soil sample from adjacent rice fields. Various soil physicochemical, microbial and enzymatic properties were analyzed. Total soil organic carbon (TOC), available potassium and Bray P were significantly higher in soils of mangrove forest than soils of cultivated rice fields. Soil pH was in the acidic range at all locations, but was moderated towards neutral in mangrove soils. DTPA extractable concentrations of soil micronutrients (Zn, Mn) were significantly higher under the soils of mangrove than soils under cultivated rice fields. Enzymatic activities (Dehydrogenase, Urease, FDA hydrolysis, Acid Phosphatase) in soils of mangrove forests exceeded than under cultivated rice fields except for acid phosphatase activity which had higher activity in soils of cultivated rice fields. Populations of ammonium oxidizer and nitrite oxidizer were higher in mangrove soils, whereas populations of aerobic hetreotrophs were higher in cultivated rice fields compared to mangrove soils. The study provides a soil quality index based on soil physico-chemical and microbiological properties. This index is a function of the eight soil parameters, which showed the greatest weight in the factorial analysis made with all the parameters analysed. The value of the soil quality index was higher in mangrove soils compared to soils of rice fields at all the four locations of sampling indicating the adverse effect of rice cultivation around the mangrove forests.

1. Introduction

Mangroves, a highly fragile and complex ecosystem, lie within the (deltaic and estuarine) transition zone between land and ocean, with the atmosphere as a medium for the exchange of matter and energy (Chauhan et al., 2008). Mangroves play a major role in biogeochemical cycles and act as reservoirs in the tertiary assimilation of wastes. A large microbial diversity thrives due to the organic matter and nutrient flow in the mangrove ecosystem. The stability of the mangrove is influenced by salinity, soil type and chemistry, nutrient content and dynamics, physiological tolerance, predation, competition and human intervention at local level (Smith et al., 2003).

The global distribution of mangroves indicates a tropical dominance with 9 orders, 20 families, 27 genera and roughly 70 species of mangroves occupying a total estimated area of 181 000 km^2. Indian mangroves occupy an area of 6740 km^2, 7% of the world's mangrove. Bhitarkanika, the second largest mangrove ecosystem of India, is located along eastern coast of India in Kendrapada district of Odisha. This ecosystem constitutes a serious-cross network of tidal estuary, mangrove forest, swampy lands and adjoining paddy field created due to

* Corresponding author. Tel.: +91 0671 2367757; Mobile: 919439282740.
E-mail addresses: rahulcrri@gmail.com, tripathirahul123@gmail.com (R. Tripathi), arvindshukla2k3@yahoo.co.in (A.K. Shukla), shahid.vns@gmail.com (Md. Shahid), debakanta9@gmail.com (D. Nayak), chandrika.puri@gmail.com (C. Puree), sangitamoha@gmail.com (S. Mohanty), rajatnau@gmail.com (R. Raja), blalsgnr@gmail.com (B. Lal), priyanakagautam@gmail.com (P. Gautam), pratap162001@yahoo.co.in (P. Bhattacharyya), bbpicar@gmail.com (B.B. Panda), anjaniias@gmail.com (A. Kumar), nitiprasad1@gmail.com (N.N. Jambhulkar), aknayak20@yahoo.com (A.K. Nayak).

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anthropogenic activities. However, agricultural development has led to the drainage, degradation and loss of vast areas of mangrove wetland (Tanner Chris et al., 2013). Williams et al. (2013) have used simulation models and field data to estimate the water, nitrogen and phosphorus inputs from an agricultural field to a mangrove wetland in Jobos Bay watershed, Puerto Rico.

Proper understanding of the soil physicochemical and biological variables are essential in order to assess the soil degradation or changes occurring between pristine mangrove forests and the adjoining cultivated lands created due to anthropogenic activities. Soil biological and biochemical properties provide rapid and accurate information on changes in soil quality due to their sensitivity to environmental stress, role in soil degradation and strong influence on microbially mediated processes like nutrient cycling, nutrient capacity and aggregate stability (Yakovchenko et al., 1996). In order to minimize soil degradation and to adopt management techniques that contribute to the maintenance or recovery of soil fertility, the soil quality should be ascertained in order to understand the limits that can be set to its use and treatment. In this paper an attempt has been made to quantify and test whether rice cultivation in adjoining areas of mangrove forest by cutting trees and clearing forest has brought about significant changes in physicochemical, microbial and enzymatic properties of soils of the mangrove ecosystem.

2. Materials and methods

2.1. Site details

Bhitarkanika wildlife sanctuary located between 20°35′ to 20°50′N and 86°45′ to 87°05′E, and is spread over an area of 672 km^2 in Kendrapara district of Odisha, formed by the rich alluvial deposits of Brahmani, Baitarani and Dhamra rivers. The climate of the area is tropical, characterized by three distinct seasons: summer (March to June), winter (November to February) and monsoons (July to October). The annual temperature variation is from 15 °C to 30 °C and the average rainfall is 1670 mm. It is a mangrove area of high tidal range (1–4 m) having strong bidirectional tidal fluxes. The delataic slopes of Bhitarkanika Sanctuary are extremely low lying and subject to regular tide inundation. The average elevation above mean tide level is between 1.5 and 2 m and extends up to 3.4 m (Dani and Kar, 1999). The sanctuary includes nearly 255 inhabited villages under the administrative jurisdiction of Rajnagar block in Kendrapada district of Odisha. The resident of the region depends mostly on fishery and coastal agriculture. However, due to lack of irrigation facilities and freshwater resources, mostly a mono-cropping pattern of rice cultivation is common in the region in the adjoining areas of the mangrove forests. Rice (Oryza sativa) is cultivated in rainfed lowland paddy fields. The land is plowed followed by puddling. This makes the soil suitable for transplanting and percolation losses of water are reduced considerably. Rice fields remain flooded up to 30 cm water depth throughout the growing season due to storage of rain water in bunded fields. Farmers do not apply balance fertilizer except 25–30 kg urea per hectare. Since salinity is also a problem in these areas, farmers grow local salt tolerant varieties (ex. Pokkali) and harvest only 1.5–2.5 t ha^{-1}.

2.2. Soil sampling and analyses

The Bhitarkanika contains 300 plant species belonging to 80 families of both mangroves and non-mangroves. Bhitarkanika supports one of the largest mangrove plant diversity in India and has more than 82 species of mangroves and its associates (Banerjee, 1984). Realizing the importance of mangroves the State Government of Orissa declared Bhitarkanika as Sanctuary in 1975 under the Wildlife (Protection) Act, 1972. After 1975, no further encroachment of forest land has been reported for mangrove forest of Bhitarkanika due to the restoration work of the mangrove forest division. But the lands encroached before 1975 are still used for rice cultivation for more than 40 years. Hence the soil sampling was done in order to quantify the changes due to rice cultivation on deforested mangrove lands compared to soils of mangrove forest.

Soil samples were collected from four locations on the basis of their proximity to forest, estuary, rivers and agricultural lands, details of which are presented in Fig. 1. Soil samples were collected in a way such that each sample collected from mangrove forests has a representative paired sample from the adjacent cultivated rice field (Fig. 1). Soil samples (0–15 cm) were collected after harvesting of rice in May 2012 before the onset of monsoon from 48 selected spots (24 pairs) using a soil core sampler (8 cm diameter, 15 cm length). Litters, organic debris were removed and the sample was divided into two subsamples. One set is stored in sealed plastic bags transferred to the laboratory and stored at 4 °C for analysis of biological properties. Other set samples were air dried in shade and passed through a 2 mm sieve and analyzed for physico-chemical properties.

2.3. Soil physicochemical properties and acidity

The soil pH was measured both in a soil-water suspension (1:2) and in KCl. The electrical conductivity (EC) was determined from the soil-water suspension (1:2). The total organic carbon (TOC) and total N of the samples were analyzed by a dry combustion method using an organic elemental analyzer (Thermo Scientific-Flash 2000) (Zsolnay, 2003). Phosphorus (Bray P, NH_4F + HCl), the method adopted by Bray and Kurtz (1945) and for potassium, NH_4OAc extraction method was used. Acidity due to variable charge component (pH dependent) was computed by different total potential acidity (extractable acidity, $BaCl_2$-TEA, pH 8.2) and exchangeable acidity ($H^+ + Al^{+3}$).

2.4. Estimation of microbial populations

Aerobic heterotrophic bacteria were enumerated by plating soil dilutions to agar media in petri dishes. The agar medium contained dilute (1:100 full strength) trypticase soy broth (Difco), 10% soil extract (prepared as described by Zuberer, 1994), and 1.5% agar (difco). Plates were incubated at 28 ± 2 °C for 72 h prior to enumeration. Ammonium oxidizers and dentrifiers were enumerated using the MPN techniques of Schmidt and Belser (1994)and Tiedje (1988), respectively.

2.5. Measurement of soil enzyme activities

Activities of alkaline and acid phosphatase were determined spectrophotometrically by measuring intensity of yellow colour due to formation of p-nitrophenol from p-nitrophenyl phosphate (Tabatabai, 1994); urease enzyme activity was measured by Douglas and Bremner (1971) method which involves spectrophotometric estimation of unhydrolyzed urea after an incubation period. Fluorescein diacetate (FDA) hydrolysis assay was conducted spectrophotometrically by measuring the formation of fluorescein (fluorescent yellow-green) to assess the overall enzyme activity of the total microbial population (Adam and Duncan, 2001).

2.6. Analysis of DTPA extractable soil micronutrients

Phytoavailable iron (Fe), Zinc (Zn), Copper (Cu) and Manganese (Mn) contents of soil was determined using a DTPA extraction technique (Lindsay and Norvell, 1978) followed by analysis using atomic absorption spectrophotometer (Varian SpectrAA55B).