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Climate Change and Management Options for Sustainable Soil Health and Crop Production: Eastern Coast of India as an Example.

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Abstract

The Indian coastline with a length of around 7,517 km distributed along nine coastal states, two groups of islands and two union territories covering an area of 10.78 m ha, in which 3.094 million hectare is salt affected. This ecosystem is distinctly divided into two geomorphic situations viz. the West coast and the East Coast. The East Coast is more prone to natural calamities as compared to the West Coast. Farming becomes challenging due to soil and water salinity buildup and shortage of good quality irrigation water during dry season, and waterlogged situation in wet season due to heavy rainfall. Increasing stress on agriculture due to climate change would further affect the livelihoods of the farmers. This review focuses on current management practices for sustainable soil health and crop production in eastern coast of India. Some prominent cases of achievements are described in this article.

Key words: Acid saline soils, climate change, salinity, submergence, zero tillage.

Coastal Ecosystem and Climate Change

Coastal ecosystem includes estuaries, coastal waters, mudflats, sandy beaches, rocky cliff and lands located at the lower end of river systems, and influenced by sea and tidal waters. It also includes saline, brackish and fresh waters, as well as coastlines and the transition of lands from terrestrial to marine influences and vice versa. Coastal areas are mostly saline in nature with the exceptions of the hilly coasts. The salinity problem in coastal soils is developed during the process of their formation under marine influence and subsequently due to periodical inundation with tidal water. In case of coastal low lands the salinity occurs due to the proximity to sea, and also owing to high water table laden with high concentration of salts. On an average the marine influence with typical coastal flora and fauna exist approximately up to 50 km inshore.

Coastal ecosystems are some of the richest storehouses of biodiversity and natural resources. Besides a number of soil and water related factors limiting productivity of food grain crops, the entire shoreline is extremely fragile in nature and severely threatened by anthropogenic activities. The Indian coastline with a length of around 7517 km (SAC 2012) distributed along nine coastal states, two groups of islands and two union territories covering an area of 10.78 m ha, in which 3.094 m ha is salt affected (Yadav *et al.* 1983, Velayutham *et al.* 1998, Bandyopadhyay *et al.* 2003). This ecosystem is distinctly divided into two geomorphic situations viz. the West coastand the East coast. The West Coast is generally exposed with heavy surf and rocky shores and headlands along the relatively calm Arabian Sea. The Western coastline is marked by backwaters, hillocks and mud flats. The East Coast covering West Bengal, Odisha, Andhra Pradesh and Tamil Nadu states (Figure 1) is generally shelving with beaches, lagoons, deltas and marshes, relatively low lying with extensive alluvial plains and deltas along the virulent/ active wave actions of Bay of Bengal (Pramanik *et al.* 2015).

East Coast

The East Coast is more prone to natural calamities as compared to the West Coast. The major portions of land in East Coast are flat lands of deltas of major rivers having considerable area (1430 km^2) under mangrove vegetation.Owing to the peculiar climatic, edaphic and geomorphologic conditions the entire ecosystem is highly fragile and prone to degradation. The high intensity rainfall received during a short period coupled with impeded drainage causes prolonged water logging in several areas. The flash floods and water submergence

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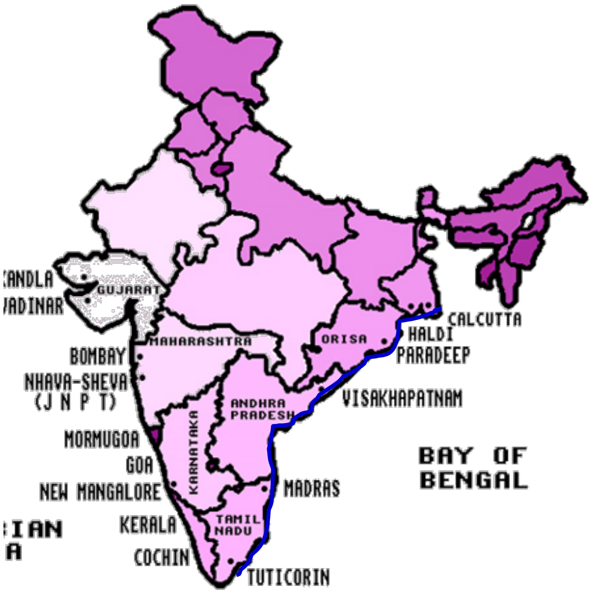

Fig. 1. The East Coast covering West Bengal, Odisha, Andhra Pradesh and Tamil Nadu shown by the blue dots (Pramanik *et al.* 2015).

reduce the input use efficiency, lower the crop yield and affect the human health. The coastal area along the shoreline is generally flat with slope towards the sea and is interspersed by innumerable river, deltas, channels, creeks, marshes, lagoons and other features. Though many places are protected from the tidal inundation by the embankments along the rivers and creeks, yet frequent breaches lead to seawater intrusion, causing heavy damage. Large scale human settlements, recreational activities and industrial development along the shoreline have been detrimental to the ecology of coastal tracts. The sediment movement resulting from the catchment erosion, addition of heavy metals and toxins through daily discharge of millions of litres of untreated effluents, and thermal pollutants affect the water quality and marine life. Thus, the coastal areas are more vulnerable to the environmental effects with continued expansion of urbanization, industrialization, tourism and other activities.

Frequency analysis of cyclones on the East and West Coasts of India during 1891-2000 shows that nearly 308 cyclones (out of which 103 were severe) affected the East Coast. During the same period 48 tropical cyclones crossed the West Coast, of which 24 were severe cyclonic storms. The west coast of India experiences high wave activity during the South-West monsoon with relatively calm sea conditions prevailing during rest of the year. On the East Coast, wave activity is significant both during South-West and North-East monsoons. The Bay of Bengal is more turbulent and epicentre of frequent devastating Bay cyclones, and sea surges because of the special nature of the coastline, shallow coastal ocean bottom topography and characteristics of tide. Their coastal impact in this region is very large because of the low, flat coastal terrain, high density of population, low awareness of community, inadequate response and preparedness and absence of hedging mechanism. People can remember the devastation of cyclone *Aila* in West Bengal during 2009, super-cyclone in Odisha during 1999 as well as *Tsunami* in eastern coast during 2004 when thousands of hectares of fertile agricultural land and adjoining mangrove forests were turned into a vast wasteland due to ingress of saline sea water.

A recent study of global deltas showed that the entire Bengal delta is sinking at a perilous rate due to sediment compaction from the removal of oil, gas and water from the inland delta's underlying sediments, the trapping of sediment in upstream reservoirs, flood plain engineering, and rising sea level (Syvitski *et al.* 2009). Global sea level data-based modelling (Eriscson *et al.* 2006) estimated that the sea level rise of the Bay of Bengal is the highest in the world at >10 mm year^{-1}. Other studies have confirmed this trend, but with rates ranging from 4.0 mm year^{-1} in the Western zone to 7.8 mm year^{-1} in the Eastern zone (Han *et al.* 2010, Unnikrishnan and Shankar 2007). The report of 2007 by UNESCO "Case Studies on Climate Change and World Heritage" has predicted 45 cm rise in sea level likely by the end of the 21st century. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report presented similar observational evidence of climate change in the coastal regions indicated the evidence of increased ocean temperature, changes in precipitation, corresponding upstream river discharge and rising sea level. This will generally lead to higher coastal flooding and increased salinity (Parry 2007) (Table 1).

Agriculture faces a host of difficult problems related to sea water, saline air, poor quality water as well as its inadequate supply, and severe competition for land. The cyclones, gales, heavy rains followed by floods are annual features in the coast. Farming becomes challenging due to soil and water salinity build up and shortage of good quality irrigation water during dry season, and waterlogged situation in wet season. Increasing stress on agriculture due to climate change would further affect the livelihoods of the farmers.

Table 1. Principal conclusions of the IPCC Fourth Assessment Report.

Climate change impact and direction of trend	Probability of Trend[a]	
	Recent decades	Future
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain
Frequency of warm spells/ heat waves increases over most land areas	Likely	Very likely
Frequency of heavy precipitation events increases over most land areas	Likely	Very likely
Areas affected by drought increases in many regions	Likely	Likely
Intense tropical cyclone activity increases in some regions	Likely	Very likely

[a]Probability classes: likely > 66% probability of occurrence; very likely > 90% probability of occurrence; virtually certain >9 9% probability of occurrence. Source: IPCC (2007).

It is essential to address these complex issues in relation to the holistic development of coastal ecosystem and to formulate relevant strategies with a long term perspective to improve the quality of life of the coastal people. Therefore, there is an urgent need for identifying management options for sustainable soil health and crop production particularly in eastern coast of India under the present climatic aberrations.

Soil resources

The areas along the coast in India are endowed with a variety of soils. Soils of east coast are generally deep to very deep having coarse sandy to fine loamy texture, non-calcareous to calcareous, poor to rich in organic carbon, slightly to moderately saline, and highly acidic to alkaline. In many coastal areas uncontrolled extraction of ground water has resulted in intrusion of seawater and development of high salinity. Important physical and chemical properties of soils of eastern coast of India are given in Table 2.

The salinity of soils varies widely from (electrical conductivity) EC 0.5 dSm^{-1} in monsoon to 50 dSm^{-1} in summer. Among the soluble salts NaCl is the most dominant followed by Na_2SO_4salt and the abundance of soluble cations follows the order, Na>Mg>Ca>K with chloride as the predominant anion, and bicarbonate in traces. The soils are, in general, free of sodicity problem except in a few pockets in the south (IPCC 2007).

Presence of acid sulphate soils has been reported in the low lying coastal areas of Sundarbans, West Bengal and in parts of Kerala (Subba Rao *et al.* 2011, Bandyopadhyay and Maji 1995, Maji *et al.* 2004) (Table 3). The generic term acid sulphate soil (ASS) generally refers to both actual (soils or sediments containing highly acidic soil horizons or layers affected by the oxidation of pyrite-iron sulphides) and potential ASS (containing iron sulphides or other sulfidic materials that has not been exposed to air and oxidised). Acidification of these soils is caused by a combination of abiotic and microbial oxidation of pyrites (FeS_2). Acid sulphate soils contain sulfides (mainly pyrites), which become very acid when sulfides are oxidized to sulphate on drying; and usually have a pH < 4 in water due to generation of sulphuric acid. There is generation of associated toxic metal ions (iron and aluminium) coupled with deficiency of nutrients especially available phosphorus, which cause very poor yield of agricultural crops (Ebimol *et al.* 2017). Further, poor root growth in the subsurface as a result of toxic levels of aluminium can reduce nutrient uptake and contribute salinity. For soils in islands of Andaman (Mongia *et al.* 1989), application of lime and phosphorus was beneficial for lowland rice, however, the soils should be leached of excess salts in case of high salinity before using these amendments. Application of lime reduced the concentrations of Al, Mn and Fe in the soil in coastal acid saline soil of Sundarbans (Maji and Bandyopadhyay 1996) (Table 4). Indira and Covilakom (2013) recorded that in acid sulphate soils of Kerala, exchangeable Al^{3+} was greater than exchangeable H^+ in surface soils. The exchangeable Al^{3+} was the highest for Thuravur series (3.91 cmol kg^{-1}) and the lowest value was noticed for Amabalapuzha series. In subsurface soils, the exchangeable Al^{3+} content varied from 0.67 cmol kg^{-1} to 6.64 cmol kg^{-1}. (Adhikari *et al.*1987) reported SiO_2/ Al_2O_3 ratios varied from 2.8-3.1 and mobile Fe and Al varied from 0.86-4.65 % and 0.92-4.5 %, respectively in Sundarbans soils. Areas affected by acid sulphate soils are generally mono cropped with rice during the rainy *(kharif)* season.

Coastal sand dunes are deficient in plant nutrients due

Table 2. Physical and chemical properties of soils of east coast of India.

States	AESR No.*	pH (1:2.5)	EC (dSm^{-1})	O.C. (%)	CEC {cmol(p+) kg^{-1}}	B.S. (%)
West Bengal	15.1	6.3-7.4	1.5-9.8	0.15-0.52	19.4-22.7	70-80
	18.5	6.5-7.6	4.1-35.0	0.3-0.78	6.6-10.6	74-82
Odisha	18.4	6.7-7.4	--	0.10-0.22	12.8-13.4	75-85
	18.5	4.5-6.3	--	Tr.-0.20	33.8-55.5	49-69
Andhra Pradesh	18.3	8.0-8.4	4.6-27.0	0.9-1.1	2-6	-
Tamil Nadu	18.1	5.1-6.1	--	0.06-0.09	4.0-6.6	89-100

*Agro Ecological Sub Region, Velayutham *et al.* (1998)

Table 3. Physical and chemical characteristics of typical coastal saline soils of West Bengal, Odisha and Kerala

Physicochemical characteristics	Saline soils		Acid sulphate soils	
	West Bengal (Kamalpur) Typic Endoaquepts	Odisha (Balimunda) Vertic Fluvaquents	West Bengal (Nirdeshkhali)	Kerala (Arikalm, Calicut)
pH (1:2)	6.5 – 8.0	6.1 – 7.9	4.0 – 5.9	3.5 – 4.8
EC_e (dSm^{-1})	7.0 – 10.5	9.3 – 19.7	2.1 – 5.8	8.4 – 43.6
OC (%)	0.26 – 0.78	0.65 – 0.92	0.6 – 2.2	2.4 – 4.8
CEC [cmol (p^+ kg^{-1}]	19.7 – 21.6	25.7 – 28.9	19.4 – 23.4	14.7 – 69.2
ESP	10.9 – 15.2	4.7 – 19.2	11.6 – 20.6	5.8 – 20.5
SAR	10.5 – 12.1	12.9 – 31.7	3.9 – 5.4	-

Maji *et al.* (2004)

Table 4. Effect of lime on soil acidity and nutrient availability in acid saline soil of Sundarbans

Lime rate ($t\ ha^{-1}$)	pH (1:2)	Available ($kg\ ha^{-1}$)		Exchangeable [cmol (p^+) kg^{-1}]			Available (ppm)	
		P	K	Ca	H	Al	Mn	Fe
0	4.9	7.8	831	5.6	0.68	0.83	28.7	66.8
1.7	6.3	10.1	833	7.4	0.31	0.04	19.8	49.4
3.4	6.5	11.7	829	8.0	0.18	0.02	15.5	32.1
6.8	6.8	9.5	831	8.8	0.09	0.01	12.6	17.4

Source: Maji and Bandyopadhyay (1996)

to extensive leaching. Dune fertilization is a useful management tool for improving the establishment and growth of new plants. If fertilization of sand dunes with urea is contemplated as a management tool, it may be prudent to apply a nitrification inhibitor such as N serve in order to minimize NO_3-N losses. On the other hand, such a combination might enhance NH_4-N volatilization, thereby necessitating the addition of urease as well as nitrification inhibitor.

Water resources

Coastal ecosystem occurs in the vicinity of creeks, rivers, deltas, lowlying lands, estuaries, and is characterized by high salinity of groundwater, besides paucity of good quality water in the post-monsoon season. It poses serious problems and challenges to cultivation. The entire area is almost monocropped, rice being the major crop. Though these areas receive good rainfall ranging from 1000 to 1800 mm during monsoon, there is virtually no source of irrigation to the crop except the rainwater. The paucity of good quality irrigation water, besides building up the salinity in soil and groundwater, is always a limitation for taking second post-monsoon crop. The nature and extent of the problems vary from region to region, but in most of the places the coastal ecosystem presents a unique problem of water management. With

Table 5. Impact of climate change on water resources in India.

Region/location	Impact
Indian subcontinent as a whole	Increase in monsoon and annual run-off in the central plains
	No substantial change in winter run-off
	Increase in evaporation and soil wetness during the monsoon and on annual basis
All India	Increase in potential evapotranspiration
	Increase in area of saline underground water and salinity of underground water
	Increase in waterlogged areas
Indian coastline	One-metre sea level rise will likely to affect 5763 km^2 and will put 7.1 million people at risk
	More area will come under waterlogging
	Sizeable area under good-quality water will turn to saline
Orissa and West Bengal	One-metre sea level rise will inundate 1700 km^2 of prime agricultural land and larger area will suffer with salinity and waterlogging; underground water will become saline
Southern India	Soil moisture will increase marginally by 15–20 % during monsoon season

Source: Dagar *et al*. (2016).

changing climate, there will be further impact on the water resources of India in general and coastal region in particular (Dagar *et al.* 2016) (Table 5). Excess rainfall can be harvested to create irrigation resources for dry seasons and for multiple cropping and reduce the soil and water salinity. Rain water harvested in farm can give a scope for agriculture- aquaculture farming system. Ample supply of brackish water is a potential but underutilized resource for enhancing productivity of the coastal lands.

An action plan is needed for coastal ecosystem separately keeping in view the objective of optimal and sustainable development and management of water resources. The strategy for research has to focus on augmentation of available water resources and their optimal utilization without sacrificing on its quality, with active participation of all the stakeholders. All available water resources (surface as well as ground) have to be managed in an integrated and synergic manner.

Soil and Water management

Adequate drainage for removal of excess water needs necessary attention along with appropriate flood control measures in the coastal low lying areas during the *kharif* season. The agricultural land should be protected from tidal inundation through protective embankments having 3:1 slope at the river side, and 2:1 slope in the land sidewith 1m free board above the high tide level. Brick pitching of the earthen embankments and planting of mangrove trees as wind breaks are useful to protect from tidal inundation. Installation of one-way sluice gates on the river banks or any other suitable location to drain out excess water from the land to the river during low tides accelerates drainage of waterlogged land.

One of the important managements of coastal saline soils is leaching of soluble salts from crop root zone by good quality irrigation water during winter (*rabi)*/ summer season. Leaching requirement (LR) depends large lyon quality of irrigation water and method employed, soil texture, and the salinity tolerance limit of the crops grown. To leach 70 % of the salts from 0-30 cm soil layer, LR is 0.90 cm cm^{-1} of soil for sensitive crops and 0.60-0.75 cm cm^{-1} of soil depth for tolerant crops. Different agro-hydro salinity models, viz. SALTMOD, DRAINMOD-S or SAHYSMOD are developed to desalinize the saline soils by proper drainage under specified conditions. These models are developed based on sound principles of moisture and solute transport, for unconfined and semi-confined aquifer. However, these models were tested in the field mostly under arid or semi- arid conditions in order to predict the water distribution and salt balance in the soil profile following different practices of drainage and their response on crop function. SALTMOD model was also applied in coastal clay soils of Andhra Pradesh where subsurface drainage system was laid out at several drain spacing. The study suggested that the model could be used with confidence to evaluate various drain spacing of subsurface drainage system and facilitate reasonable predication of reclamation period.

For management of potential and actual acid sulphate soils following approaches have been suggested i) pyrite and soil acidity can be removed by leaching after drying/aeration and ii) pyrite oxidation can be limited or stopped and existing acidity inactivated by maintaining a high water table, with or without and iii) additional liming and fertilization with phosphorus, though liming may be often uneconomic in practical use. because of high lime requirement in most of the acid soils, short term effect of liming and transportation cost. The method cited above at ii) for maintaining a high water table to stop pyrite oxidation and to inactivate existing soil acidity have the advantage because its effects are much faster. Upon water logging, soil reduction caused by microbial decomposition of organic matter lowers acidity and may cause the pH to rise rapidly to near-neutral values. The method is particularly suitable with rice cultivation. The crucial factor is the availability of fresh water for irrigation. The less toxic and well developed and deep acid sulphate soils are moderately suitable for rice and can be improved by sound agronomic practises as discussed below.

In India, for the coastal acid sulphate soils of Sundarbans, application of lime, super phosphate and rock phosphateimproves soil properties and rice growth (Burman *et al.* 2010). Application of easily available Ca-rich oyster shell, containing calcium carbonates as an inexpensive alternative soil ameliorating agent was found beneficial if applied in powdered form.

For soils in Andaman Islands, application of lime and phosphorus is beneficial for lowland rice, but the excess salts in soils need to be leached in case of high salinity before using these amendments. In another study on mangroves (*Avecenia marina*) on muds of the Andaman Islands, it is reported that liming significantly reduced the concentrations of Al, Mn and Fe. Exchangeable Al content also decreased with lime application.

The depression of exchangeable Al may be due to precipitation of trivalent A1 and $A1(OH)_3$ in the presence of high concentration of OH^- ions (Marschner 1995) (Figure 2). Lime application, in general, also reduced the exchangeable and extractable Fe contents of the soil.

Integrated water management

In coastal region, fresh water aquifer available at deeper depths does not contribute to salt accumulation in the crop root zone. However, shallow water table rich in salts (generally not exceeding a depth of 2 m below the soil surface) is responsible for salinity development in soil. The net salt loading in the root zone will, however, depend upon the relative rate of recharge of salts by upward rise to rate of downward flux of salts by leaching. The relative salt accumulation will thus be treated generally as positive during dry season, and negative during wet season due to high rainfall, and the process will be repeated each year in a seasonally cyclic mode.

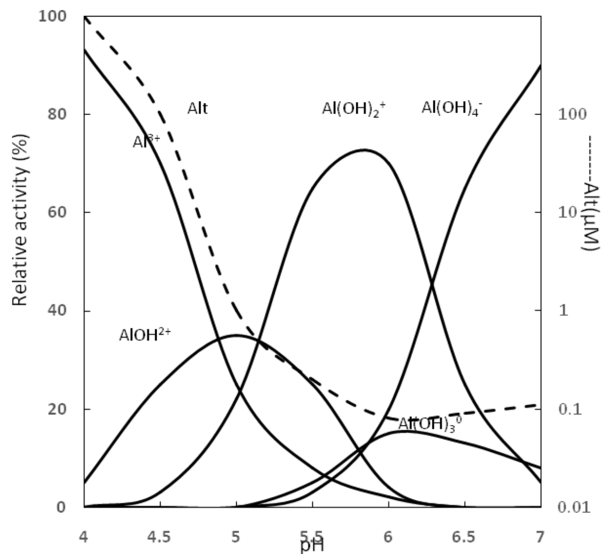

Fig. 2. Relative activity of mononuclear aluminium species and total concentration (Alt) of soluble aluminium as a function of pH (Marschner 1995).

Use of ground water for irrigation may be avoided in coastal areas in view of vulnerability of the coastal plains to seawater intrusion and its adverse impact on soil and plant growth. Therefore, irrigation source should be created by increasing the surface storage of rain water in dug out ponds, furrows, ditches, and community canals. Thus, water management in the coastal plains should principally revolve round creating more fresh surface water source and their proper management with little dependence on the subsurface source. Thus, rainwater harvesting with the objective to introduce multiple cropping in the otherwise predominantly mono-cropped areas is gaining momentum in the entire coastal region particularly in Sundarbans and Odisha.

Conservation of carry over soil moisture and its efficient utilization can be done by zero tillage (ZT) technology. During post rainy season, early sowing of potato can be done by zero tillage practices; as a result the crop needed significantly less irrigation water due to conservation of soil moisture in the soil profile. The tubers were covered immediately after sowing with dry compost and thereafter with thick layer (30-45 cm) of easily available paddy straw. The residual soil moisture helped in very good germination of tubers (Sarangi *et al.* 2018) (Figure 3). This practice is free from weed infestation, and helps in easy harvesting by just removing the paddy straw. In addition, it reduces the cost of cultivation and also protects the tubers from damage usually caused by sudden heavy rain. Tuber quality in zero tillage was better, and due to early harvest, it is possible to take another *rabi* crop like maize, green gram, onion in the same plot in the reserved soil moisture. Tuber yield varied from 7.5 to 26.9 tha^{-1} under conventional tillage while it is ZT produced 12.4 to 32.1 t ha^{-1} tuber under cultivation (Figure 3). Therefore, cropping intensity can be increased to 300% in rainfed low lands of Sundarbans.

Based on the hydrological process, a computer simulation model and a user-friendly software 'RAINSIM' was developed primarily for Sundarbans region for small holdings (Ambast and Sen 2009). It was tested for different agro-climatic regions in India. The software may be used for i) computation of soil water balance, (ii) optimal design of water storage in the on-farm reservoir (OFR) by converting 20 % of farm land, (iii) designing the surface drainage in deep and waterlogged areas to reduce water congestion in 75 % of the area, and (iv) designing a simple linear programme to propose optimal land allocation under various constraints of land and water to arrive at contingency plan for maximization of profit. Sen and Ambast (Sen and Ambast 2011) also reported the use of remote sensing and GIS in mapping lowlands, and their vegetation with crop yield estimation along with the performance assessment of irrigation/drainage systems.

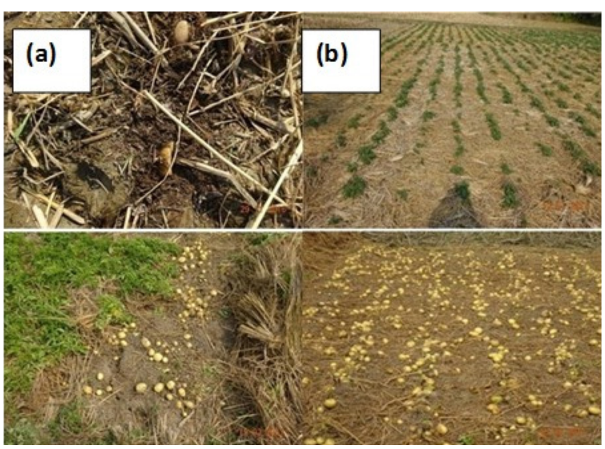

Fig. 3 Zero tillage potato cultivation in Sundarbans, West Bengal; a) Normal Cultivation, and b) zero tillage cultivation (ZT) (variety: Kufri Pokhraj) (Sarangi *et al.* 2018).

Integrated nutrient management (INM)

Long term field experiments in coastal saline soils in India showed that rice and wheat yield could be maintained even at 50 % NPK used in conjunction with FYM or green manure. It was also observed that in Sundarbans region, grain yield of crops in a rice-barley rotation increased significantly due to the application of nitrogen. A basal dose of 11 kg Pha^{-1} for rice and 5.5 kgP ha^{-1} for barley or similar other upland crops maintains the fertility status of the soil, whereas the K application may be omitted without any detrimental effect on soil fertility or crop growth as the availability of K content was high in these biotite and hence K-rich soils (Maji and Bandhyopadhyay 1995). Green manuring with *Dhaincha* as summer crop is well suited in entire coastal belt. Sources of biofertilizer viz. *Rhizobium* cultures for pulse or legume, and blue-green algae for waterlogged rice field may play a significant role in terms of integrated nutrient management for rice in coastal saline soils. Azolla, a free-floating freshwater fern, improves soil nutrients when incorporated into INM because of the additional N produced by the *Anabaena* species of blue-green algae present in the lobes of Azolla leaves. Farmers can produce their own Azolla inoculums in ponds and ditches common in coastal areas (Sarangi *et al.* 2014).

In saline condition, elevated Ca^{2+} ions protect the plants from salt (mostly NaCl) toxicity. On the other hand, an increase in the Cl^- concentration, in soil nutrient media, may lead to a reduction in the NO_3^- ions content of plants. In coastal areas for the flooded-saline soils', measures should be taken to reduce volatilization loss, either through i) placement of N-source (urea) at subsurface depth (through application of slow release source), and ii) through use of urea inhibitor, or by adjusting the time of application coinciding with the plant's active growth stage for higher N-uptake. Under flooded condition, soil organic matter contributes to Fe and Mn availability through the formation of metallo-organic complexes with organic substances. Increased Fe and Mn solubility in flooded soils benefits rice, which has a higher requirement for these elements (Yodkeaw and De Datta 1989). For sustainable soil health and improved soil quality in the coastal plains through higher soil organic carbon level, management protocols to enhance the C sequestration needs to be encouraged since low lying coastal soils may be a useful sink for higher organic carbon pool for the terrestrial system (Sahrawat *et al.* 2005, Bhattacharyya *et al.* 2018a, Bhattacharyya *et al.*

2018b, Bhattacharyya *et al.* 2000, Sahu *et al.* 2016). Direct seeded rice has a great scope for increasing soil carbon level as well as to overcome early flash flooding situation during July-August (Sarangi *et al.* 2017). Studies in Sundarbans region showed there was 15-20 % yield increase and higher tillering in direct seeded paddy than conventional planting method (Sarangi *et al.* 2017).

Crops and cropping systems

Rice is the predominant form of agricultural land use in many coastal and deltaic regions of the tropics. No crop other than rice can be grown under these adverse conditions of unstable water levels and highly saline locations. Mostly deep water and floating rice subjected to devastating floods and cyclone occupy the coastal rice. Because of prolonged waterlogging during the monsoon season, continuous monocropping of rice with long duration tall *Indica* varieties is practised in several coastal areas. India, as a whole has about 55 percent of the total rice area under lowlands, but the proportion is much higher in coastal tracts (Rai 2004). West Bengal, having the largest share of coastal area, has about 90 percent of the total area under 30-90cm depth of water (Table 6) and the yield level is comparatively low. However, in Andhra Pradesh and Tamil Nadu coast rice yield is one of the highest and it is mostly irrigated rice through cannel system. Salt-tolerant HYVs (high yielding varieties) of rice viz. Canning 7, CSR 4, CST 7-1, Luna Suvarna, Luna Sampad, Luna Barial and Luna Shankhi can tolerate soil salinity of 5.0–8.0 dSm^{-1} at the level of different maturity. Luna Suvarna and Luna Sampad, are the late maturing varieties (150 days) whereas Canning 7, CST 7-1 and Luna Shankhi, mature early (Sarangi and Maji 2017).

Though rice is the most adaptable crop in coastal ecosystem, the topographic settings and vicinity to the coast line render delta regions especially vulnerable to the consequences of natural hazards, namely (1) sea-level rise and (2) storm surge (Wassmann *et al.* 2009). Thus, any shortfall in rice production in this area through such hazards would affect the economy and food security of the farming communities of the country.

Before the Green Revolution, the Asian delta regions held a comparative advantage in rice production because of fairly productive—by contemporary standards—floating and deepwater rice systems. The early beneficiaries of the Green Revolution, however, were those areas where it was possible to irrigate two crops of rice with the construction of irrigation systems, as in Punjab. The deltaic regions initially were unable to take advantage of the new rice technologies, but have regained a comparative advantage over the past 15–20 years. Short duration cultivars facilitated an adjustment of cropping calendars to avoid excessive flooding; pumps are becoming increasingly popular to tap the shallow groundwater for irrigation during the dry season. However, rising sea level may deteriorate rice production in a sizable portion of the highly productive rice land in deltas. The "Aman" crop, is exposed to higher flood risk and experience severe cyclones over recent years causing enormous losses in rice production. With higher sea water levels and an increase in storm incidences, flooding and salinity stress for rice in delta areas are likely to increase and pose further challenges to agricultural scientists. The heavy rains together with poor or non-existent drainage create serious water logging and sometimes complete submergence, or prolonged stagnant floods. In these areas, a slight reduction in rainfall may not affect the water supply and agricultural production in general; however, a small increase in

Table 6. Rice cultivars for tolerance to different stresses

Land situation	Water depth (cm)	Salinity level (ECe:dSm^{-1})	Suitable rice varieties
Upland	0-20	6-8	Canning 7, CSR-4(Mohan), CSR-36, Bidhan-2, CST 7-1, WGL 20471, Bidhan2 and Luna Shankhi
Medium land	20-40	4-6	CSR 1 (Damodar), CSR 2 (Dasal), CSR 3 (Getu), CSR 6 (Nonasal selection), Utpala, Sumati, Bhutnath, Amal-Mana, Namita-Dipti (IET-17343), Bidhan-2, Patnai 23, Talmugur, Nona-Bokra, Luna Barial
Low land	40-60	4-6	Malabati, Kalamota, Sadamota (Selection), Tilak kachari, FR 13A, Asfal, Najani, Kumragour, CSRC(D)-7-0-4, CSRC (D)-12-8-12, Luna Suvarna, Luna Sampad, Luna Barial

Source: Sarangi *et al.* (2017)

Table 7. Rice varieties suitable to different land situation of east coast.

Stress	Cultivars
Waterlogging	AC 1125-A, AC 1781, AC 1996, AC 813, AC85, AC 39416A
Anaerobic germination	AC 34245, AC 34280, AC 40331-A, AC 40346, AC 416222-A,
	AC 41647, AC 41644-A, AC 41644-B, AC 39397, AC 394418, AC 39416-A
Complete submergence for 20 days better than Swarna-Sub1	AC 38575, AC, 37887. IC 258990
	IC 258830, AC 42087, AC 20431-B
Seedling stage salinity	Pokkali (AC 41485), Chettivivippu (AC 9389), AC 39394
Tolerant to both anaerobic germination and salinity	Kamini, Ravana, Talmunga, Paloi, Longmutha, Murisal, Rashpanjor, AC 39416 (A)
Tolerant to anaerobic germination, salinity and waterlogging	AC 39416 (A)

Source: Venkateswarlu *et al.* 2012.

rainfall may strongly affect farming because of the subsequent floods. Only a few low-yielding landraces in these areas are evolved to withstand such conditions. Modern rice varieties are not adapted to these conditions and their yield is severely reduced because of high mortality, suppressed tillering ability, reduced panicle size, and high sterility. These are probably the reasons why farmers in affected areas still rely on low-yielding local landraces. Efforts are needed to screen large sets of diverse rice germplasm with a reasonable level of flood and salinity tolerance high yielding rice genotype. Rice cultivars identified for tolerance to different stresses are furnished in Table 7 (Venkateswarlu *et al.* 2012).

Improved agronomic management practices for rice in coastal region recently developed have significant potential to increase yield in these fragile ecosystem. Use of balanced nutrients (organic and inorganic) and lower seeding rate (25 g m^{-2}) in nursery produced healthier and more vigorous seedlings that withstood floods and salinity better than traditional practice (Sarangi *et al.* 2015). Fertilizer dose of 50-20-10 kg N-P_2O_5-K_2O ha^{-1} + 5 t farm yard manure ha^{-1} and transplanting 2 seedlings $hill^{-1}$ at spacing of 15×15 cm combined with tolerant rice variety resulted in higher grain yield (4.51 t ha^{-1}) compared to 2.55 t ha^{-1} under farmer's practice (Sarangi *et al.* 2016).

Development of high yielding varieties of rice and other crops with greater tolerance to salinity, toxicity and excess as well as deficiency of water are the main issues (Tran 1997). Attempts are being made to improve the plant type with higher yield potential salinity tolerant native varieties. The use of genes conferring high level of tolerance in related genera would be worth considering. Development of varieties suitable to low light intensity limiting rice productivity in coastal areas needs special attention. Moreover, to overcome the osmotically stressed conditions induced by abiotic factors through biotechnological solution needs to be stressed. The coastal region where not more than 60 % of the realizable yield is being harvested from the existing high yielding varieties, disease-pest syndrome is the most important destabilizing factor accounting for 30-35 % yield loss. Characterization of the races/biotypes, identification of alternate/additional sources of resistance from primary and secondary gene pools, development and use of molecular marker-aided selection techniques and exploring the possibilities of using novel genes employing recombinant DNA technology can contribute substantially towards finding solutions to such disease pest problems (Wassmann *et al.* 2009).

Rice-being the most inefficient user of water and nutrients even under irrigated ecosystem, needs extensive diversification; it is more required in areas of mono cropping having limited water recourses. Diversification of agriculture has been acknowledged to give better returns to generate additional employment for rural masses and to conserve natural resources. Diversification to horticultural crops is the best option as these crops not only meet the above requirements but also are adapted to a wide range of climate, produce higher biomass than field crops per unit area, are more remunerative for replacing subsistence farming, and thus, alleviate poverty particularly in rainfed, coastal, dry land, hilly and arid ecosystem (Bhattacharyya *et al.* 2018a). The emphasis should be mainly on production, protection and post-harvest management of horticultural crops. India contributes 10-13 percent of the total world production of fruits and vegetables occupying second place in the world. The area under flower crops has also been increasing and protected cultivation of cut flower has been established (Chaddha 2004). Coastal ecosystem has wide scope and warrants special attention. Since the spices occupy a prominent place in the production system in the coastal tracts, intensified research to exploit the full potential of these crops in compatible diversified cropping in the coastal environment is needed. Integrated nutrient management in horticulture and plantation crops with inclusion of leguminous crops as cover cropping in perennial plantations, and incorporating them in the fields will help improve soil fertility, thereby supplementing the fertilizer needs; and reducing cost of production. Organic farming has immense potential and needs to be validated through intensive research.

There is a great scope of crop diversification of mono crop rice, based on soil salinity and water availability (Sarangi, Springer International Publishing AG, Cham) (Table 8). The scope to increase the cropping intensity and diversification in the coastal ecosystem depends largely on the soil salinity and irrigation water availability. With proper water management it is possible to incorporate pulses, oilseeds and vegetables in rice-based cropping system. Among the important winter/summer crops are barley, cotton, chilli, sunflower, and a number of vegetables. Tomato, chilli, brinjal, cabbage,

Table 8. Feasible crops for coastal areas.

Types of crops	Name of crops
Oilseed crops	Linseed, safflower, sunflower, groundnut
Pulses	Field bean (at lower salinity not exceeding 5-6 dSm^{-1}), Lathyrus
Fibre crops	Cotton (up to 13 dSm^{-1})
Vegetable crops	Tomato, brinjal, knol-khol, carrot, beet, lady's finger, chilli (up to 7 dSm^{-1}), spinach, cucurbits, amaranthus, ipomoea etc.
Root crops	Sweet potato, yam, colocasia
Spices	Fennel, black cumin, coriander
Aromatic	Lemon grass, aloevera, palmarosa, bhringaraj, mentha
Medicinal plants	Isabgul, sarpagandha
Fruit crops	Guava, sapota, banana
Fodder crops	Coix, paragrass (tolerant to both salinity and waterlogging)

Source: Sarangi *et al.* 2014.

cauliflower, melons, onion, peas, beans, ladies' finger (okra) and various leafy vegetables are produced in large quantities in coastal areas in the rice- based cropping system. Rice-potato-okra gave higher production and net returns in Odisha and West Bengal therefore are promising agricultural enterprise. For Andaman and Nicobar Islands rice-rice-pulse (cowpea) rotation is the most economic and feasible practice (https://icar.org.in/files/state-specific/chapter/128.htm).

The coastal ecosystem offers vast scope for commercial use not only for a wide variety of fruit and vegetables crops, but also plantation crops, spices and medicinal plants. Plantation crops, like coconut, arecanut, oil palm, cashew, coco, spices like ginger, and turmeric are high value commercial crops and coastal region have a great scope to cultivate commercially for all those crops. Both cashew and black pepper are good foreign exchange earners. India has emerged as the largest producer of coconut in the world, and coconut coir industry is a well-established business. Cashew is cultivated mostly in the coastal areas (Bhattacharyya *et al.* 2018a). Release of improved varieties in all these crops and improved production technology has brought significant improvements in the production of these crops.

Medicinal and aromatic plants play an important role in Indian traditional medicines. It is reported that over 2000 native plant species have curative properties, and another 1300 native coastal species are known for their aroma and flavour. Medicinal and aromatic plants, like isabgol (*Plantago ovate*Forsk) and opium poppy are produced on commercial scale. Vegetable seed production is also a potential area in this region. Oil palm (*Elaeis guineensis* Jacq.) is recognised as the highest edible oil yielding crop, producing 4-6 tonne of oil per tree in 25 years. Total potential area identified for growing oil palm is mainly along the coastal belt.

Agroforestry including silvi-pastoral and horti-pastoral systems have promise in problem soils for sustained production of food, fodder and fuel (Singh *et al.* 2002). The role of forestry in maintaining the level of CO_2 and other toxic gases in the atmosphere is well established and caught the attention of all concerned worldwide. The present status of forest area in the East and West coastal belts constitutes only about 18.7 and 29 percent, respectively, of the total geographical area of the region. The forest coverage in the Andaman and Nicobar Group of (A and N) Islands, however, is as nearly 88 percent of its total land area. Mangroves growing under natural condition along the coastal shoreline occupy nearly 0.4 million hectare in the country. According to Government of India estimate, mangroves are estimated to cover about 0.6 million hectare located in the alluvial deltas of rivers, such as the Ganga, Mahanadi, Godavari, Krishna and Cauvery, in the Andaman and Nicobar Group of Islands, and in minor patches in Maharashtra and Gujarat, comprising about 7 percent of the world's Mangroves (Dagar *et al.* 2014).

Agro-forestry systems are more common in India and other developing countries than in the developed countries. It has good prospect for the coastal ecosystem. Based on the nature of the components the common agroforestry systems in India are broadly classified as agri-silviculture (crop+trees), agri–horticulture (crops+fruits trees), agri-horti-silviculture (crops+fruitstrees+multipurpose trees), silvipasture (trees+pasture+animals), homestead agroforestry (multiple combinations of various components) and others.

As sub-surface drainage is costly and disposal of effluents has inherited environmental problems, a viable alternative is bio drainage, which is 'pumping of excess soil water by deep-rooted plants using bioenergy'. The impact of block plantations of *Eucalyptus tereticornis* was tested and found effective. In another experiment it was observed that the ground water table underneath the strip plantations was 0.85m during a period of 3 years and it reached below 2m after 5 years. The average transpiration rate (measured by sap flow) of ground water by these plantations ranges from 44.5-56.3 in May to 14.8-16.2 litres day^{-1} tree^{-1} in January. The annual transpiration rate was equal to 268 mm per annum (Minhas *et al.* 2014).

Irrigation of forest species grown for the non-edible products like fuel and timber with wastewater is another approach, which can help overcoming health hazards associated with sewage farming. Developing green belts around the cities with forest trees under wastewater irrigation also helps revive the ecological balance and improves environment. These agro-forestry systems known as HRTS (high transpiration rate systems), promote the treatment of wastewater through renovating capability of living soil filter enabling recycling and reuse of waste water. Although very tall claims have been made for sewage disposal through plantations but the real estimates on the loading rates of such plantations without the contamination of ground water, show that the annual ET rates increased from 53-140 cm (increment of about 14 cm yr^{-1}) between 2 to 6 years and stabilized thereafter indicating little advantages of trees over crops (rice/maize/cotton-wheat) will occur only after about 5 years of plantations. The values improved considerably with density plantation (96-160 cm yr^{-1}) but for these to be effective, land requirements would be very high. Thus, there are not many differences in quantities by land disposal and that through forestry plantations but the latter would still result in economic returns in terms of fuel wood production and environmental services. Additional advantage of tree plantations would be harvest of large amount of toxic metals as tree are known to sequester, tolerate and accumulate higher levels of these toxic metals. Adoption of agro-forestry systems further reduce the farmer's direct contact with and exposure to sewage and carbon sequestration has an additional bonus (Yadav 2001).

For coastal areas the integrated farming system combining crop production with sericulture, apiculture, dairy, poultry, duckery, aquaculture, and agroforestry have a scope (Sarangi and Islam, Springer International Publishing AG, Cham). Vast potential exists for rice-based agro-silvicultural production systems in suitable coastal areas. Based on research, *Acacia auriculiformis*, *Casuarina equisetifolia*, *Acacia niloticaand Prosopis chilensis, Prosopis juliflora* are some of the promising tree species (Minhas *et al.* 2014). Fast growing *Casuarina* plantation as an excellent source of fuel wood and as stabilizer of sand dunes is popular even among the farmers of the coastal areas. *Coixlacrymajobi* has been identified as a suitable fodder species for the salt affected and waterlogged soils. *Stylosanthes hamata* is another protein rich leguminous fodder.

Rice-fish culture has assumed prominence in the recent years. The fresh water and brackish water aquaculture is one of the most important activities in the coastal areas for employment, income generation and supplementary food item. Promotion of prawn culture in brackish water has made tremendous change in the economy, especially in Andhra Pradesh, Odisha, and West Bengal in the recent years. Brackish water fish culture can be integrated with rice and coconut cultivation. Rice-fish inside the field and vegetables/fruits on the bunds or rice fields has shown great promise in coastal area of Odisha and Sundarbans region of West Bengal. Coconut-based system is popular in Andaman and Nicobar group of Islands and in several parts of west and east coasts on the mainland. Homestead farming comprising of coconut, arecanut, other trees and species (black pepper, clove and cardamom) in different tiers around the houses is in vogue in Kerala state. These complex integrated farming systems, however, need further improvement through most efficient and cost effective management of soil, water, nutrient and other inputs, but the location-specific packages, thus developed should be socially acceptable.

Conclusions

Holistic approach with micro level planning of available soil, water and crop resources are needed for higher and sustainable productivity in the coastal region in view of fragile nature of the coastal ecosystem. This is more so due the changing climate due to global warming. Mapping the coastal areas in a smaller scale with the help of modern tools like remote sensing and GIS should be taken up for characterization of the coastal soil resources for effective coastal ecosystem planning for improved irrigation and land drainage practices, nutrient management and other land use options. It also shall help in monitoring these invaluable natural resources. Improved management practices with tolerant crops, varieties, adaptation strategies are essential to cope with the natural hazards and increasing population. The productivity growth in the favourably endowed and irrigated areas has already shown signs of fatigue. But the sizable low productive coastal areas offer tremendous opportunities to be harnessed with adoption of proper strategies backed by well-focussed action plans, such that agriculture is more productive, profitable, sustainable, competitive and eco-friendly.

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