Agroforestry to Rehabilitate the Indian Coastal Saline Areas

J.C. Dagar and P.S. Minhas

Abstract

About 35 % of Indians live within 100 km of the Indian coastline measuring 7517 km consisting of parts of the mainland India, Andaman-Nicobar Islands and Lakshadweep Islands. The coastal and island ecosystems have a vide variability in climate and topographical and edaphic conditions. These support diverse cultivated crops as well as natural vegetation ranging from tropical rainforests to coastal mangroves. The area is environmentally disadvantaged both on anthropogenic activities and weather adversities. Paddy is the predominant crop except the plantation trees mainly in homesteads. The soil salinity and waterlogging problems arise with intrusion of seawater, and these are expected to become severe with rise in sea level due to global warming. However, these ecosystems offer immense scopes and opportunities of increasing productivity through integration of agroforestry with livestock and aquaculture particularly in mangrove areas. Some of the possible strategies for their reclamation and management through sustainable agroforestry systems are discussed. These systems should further improve the livelihood security of the coastal population.

Introduction

Agricultural prosperity in India is evidenced by almost fivefold increase in food production from 50.8 in 1950–1951 to 247.6 million tons in 2012–2013 (ICAR 2014). This needs to be enhanced further to cope up with the increasing demand of population and that too in the wake of challenges like climate change, degradation of land and water resources, shrinking of land and scarcity of water available for agriculture. Already about 121 Mha land in India is suffering with various

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kinds of degradation (NAAS 2010). Agroforestry is probably the only means for getting the desired tree cover and is not only a technique for rehabilitation of degraded lands but is also a source of renewable energy resource and a means of reducing the risk of environmental degradation and climate change. The livelihood security through agroforestry and its potential in meeting basic needs (food, fuel, fodder, timber and employment generation) are well known. The importance of agroforestry is more relevant in coastal areas which are ecologically more disadvantaged and at a greater risk due to the anthropogenic activities and weather adversities. Trees have to play crucial role in conserving and protecting vast coast line particularly by mangroves and associate halophytes. About 35 % of Indians live within 100 km of the Indian coastline measuring 7517 km consisting of parts of nine states on mainland, Andaman-Nicobar Islands and Lakshadweep Islands (India 2013). The coastal and island ecosystems have a wide variability in climate, topographical and edaphic conditions, and they support diverse cultivated crops as well as natural vegetation ranging from tropical rainforests to coastal mangroves. The coastal ecology offers immense opportunities of commercial use not only for wide varieties of fish and fruit and vegetable crops but also plantation crops, spices and medicinal and aromatic plants, which may be blended in multistorey plantation-based farming systems and home gardens. The extent of land degradation due to waterlogging and salinity and rehabilitation of these areas through farming systems and agroforestry approach are discussed in this chapter.

Extent of Waterlogging and Salinity

Broadly the entire agroclimatic zones of the coastal region of India come under four agro-ecological regions and are spread across nine states and three union territories. The west coast covers parts of five states, namely, Gujarat (13 districts), Maharashtra (5 districts), Goa (2 districts), Karnataka (3 districts) and Kerala (14 districts), and union territories (Pondicherry, Daman and Diu and Dadar and Nagar Haveli); and east coast covers parts of four states, namely, Tamil Nadu (13 districts), Andhra Pradesh (9 districts), Orissa (11 districts) and West Bengal (3 districts). Two groups of islands—Andaman-Nicobar and Lakshadweep islands—are situated in the Bay of Bengal and the Arabian Sea, respectively. Entire coastal region of India except north Gujarat receives a normal annual rainfall of more than 1000 mm; in the west coast it is as high as 2500 mm. However, more than 80 % of the annual rainfall is received during June–September except coastal Tamil Nadu, which receives maximum rainfall during October and November. The major source of water in coastal regions is rainfall and groundwater. Inefficient rainwater management and over-exploitation of groundwater for irrigation in the west and south coastline have caused acute shortage of water. On the other hand, the major part of the east coast suffers from severe waterlogging problems due to flat topography and low hydraulic conductivity. All along the coastline, groundwater quality is being threatened due to the surface or subsurface seawater intrusion. In coastal regions, the areas affected by salinity and waterlogging are about 3 and 7 Mha, respectively (Table 1). The total area of groundwater within 3 m has been reported to be 7016 thousand ha, out of which 1.4 % is most critical (<1 m), 24.4 % critical (1–2 m) and 74.2 % less critical (2–3 m) for post-monsoon session during the year 2003–2005. However, during post-monsoon, this area increased to 2.25 times (15.76 Mha), out of which 8.5 % to be most critical, 39.9 % critical and 51.7 % less critical (RRSSC & CWC 2009).

Under the threat of climate change, increased levels of salinity arising from sea level rise and coastal flooding will pose a serious problem to the rural inhabitants of the coastal area. The predicted negative impacts of climate change are likely to bring new challenges in addition to magnifying existing problems, particularly in the areas like Sundarbans, where rural community already has limited capacity to adapt to these changes (Sujana-Dhar 2011). In coastal areas, the excess of water is stagnated during rainy season, and draining is very slow leading to waterlogging.

Table 1 Extent of coastline, mangrove areas, saline and waterlogged soils of maritime states and union territories of India

State/union territory	Coastal length (km)[a]	Mangrove area (000 ha)[b]	Saline area (000 ha)[c]	Waterlogged area (000 ha)[d]
West coast region				
Gujarat	1214.7	105.8	714	2602.3
Maharashtra	652.6	18.6	64	931.2
Karnataka	280.0	0.3	86	369.9
Kerala	569.7	0.6	26	116.4
Goa, Daman and Diu	160.5	2.4	18	5.3
Pondicherry	30.6	0.1	1	
East coast regions				
West Bengal	157.5	215.5	820	151.7
Orissa	476.4	22.2	400	754.7
Andhra Pradesh	973.7	35.2	276	1379.6
Tamil Nadu	906.9	3.9	100	704.7
Island regions				
Andaman-Nicobar	1962.0	61.7	15	NA
Lakshadweep	132.0	NA	Na	NA
Total	7516.6 (say 7517)	466.3	2520 + 466 = 2986	7015.8

Source:
[a]India (2013)
[b]FSI (2011)
[c]Yadav et al. (1983)
[d]RRSSC & CWC (2009)

Further, during summer season, the low rainfall leads to exploitation of groundwater for agriculture. Over a period of time, the groundwater table has decreased resulting in intrusion of seawater into the groundwater. Subsequently, the salinized groundwater used for irrigation has led to the accumulation of salt on the surface of the soil. The intrusion of seawater towards mainland/inland may vary from depth of water table, amount and distribution of rainfall. The distance may not be uniform throughout the coast line and vary due to climatic factors, topography, amount and distribution of rainfall, depth of water table, cropping intensity with use of groundwater etc. In Kerala, the lands are mostly waterlogged due to the lagoons, estuaries and wetlands. The intrusion of seawater is more frequent along east coast. However, certain areas where the estuaries and other forms of land with negative mean sea level (MSL) are the possible reasons for seawater intrusion in western coast.

Natural Vegetation and Cropping Systems

The coastal regions are very rich in biodiversity both of flora and fauna. The natural vegetation is composed of evergreen forests, semi-evergreen forests, deciduous elements and littoral species including mangroves. Tree species which are commonly seen include *Acacia auriculiformis*, *Acacia planiformis*, *Achras zapota*, *Ailanthus triphysa*, *Albizia amara*, *Anacardium occidentale*, *Annona ramosa*, *A. squamosa*, *Artocarpus chaplasha*, *Bombax ceiba*, *Borassus flabellifer*, *Clerodendron inerme*, *Cocos nucifera*, *Dalbergia latifolia*, *Elaeis guineensis*, *Emblica officinalis*, *Erythrina indica*, *Eucalyptus tereticornis*, *Gliricidia sepium*, *Hernandia peltata*, *Hibiscus tiliaceus*, *Jatropha curcas*, *Leucaena leucocephala*, *Mangifera indica*, *Morinda citrifolia*, *Moringa oleifera*, *Musa paradisiaca*, *Pandanus leram/fascicularis*, *Pongamia pinnata*, *Psidium* *guajava*, *Punica granatum*, *Ricinus communis*, *Salvadora persica*, *Samanea saman*, *Sesbania grandiflora*, *Tamarindus indica*, *Thespesia populnea*, *Vitex negundo*, *V. trifoliata*, etc. Quite good numbers of trees are fruit bearing.

Among mangroves *Acanthus ilicifolius*, *A. volubilis*, *A. ebracteatus*, *Aegialitis rotundifolia*, *Aegiceras corniculatum*, *Avicennia marina*, *A. officinalis*, *Bruguiera gymnorrhiza*, *B. parviflora*, *B. cylindrica*, *B. sexangula*, *Ceriops tagal*, *C. decandra*, *Cynometra ramiflora*, *C. iripa*, *Excoecaria agallocha*, *Heritiera fomes*, *H. littoralis*, *Kandelia candel*, *Lumnitzera racemosa* (*L. littorea* in Andamans), *Nypa fruticans*, *Phoenix paludosa*, *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *R. lamarckii* (only in Andamans), *Scyphiphora hydrophyllacea*, *Sonneratia alba*, *S. apetala*, *S. caseolaris*, *S. ovata*, *Xylocarpus gangeticus*, *X. granatum* and *X. moluccensis* and associated species such as *Acrostichum aureum*, *Barringtonia asiatica*, *B. racemosa*, *Caesalpinia bonduc*, *C. crista*, *Calophyllum inophyllum*, *Casuarina equisetifolia*, *Cerbera floribunda*, *Cordia subcordata*, *Cycas rumphii* (only in Andaman-Nicobar Islands), *Dalbergia monosperma*, *Derris scandens*, *Dolichandrone spathacea*, *Erythrina indica*, *E. variegata*, *Guettarda speciosa*, *Hernandia peltata*, *Hibiscus tiliaceus*, *Intsia bijuga*, *Licuala spinosa*, *Manilkara littoralis*, *Mimusops elengi*, *Morinda citrifolia*, *Ochrosia oppositifolia*, *Pandanus* spp., *Pongamia pinnata*, *Scaevola taccada*, *Premna corymbosa*, *Syzygium samarangense*, *Tabernaemontana crispa*, *Terminalia catappa*, *Thespesia populnea*, *Tournefortia ovata* and *Vitex negundo* are common. Many climbers and epiphytes such as *Asplenium nidus*, *Canavalia maritima*, *Clitorea ternatea*, *Dischidia bengalensis*, *D. nummularia*, *Finlaysonia maritima*, *Hoya parasitica*, *Hydnophytum formicarum* and many orchids are conspicuous throughout mangrove stands. *Ipomoea pes-caprae*, *Launaea sarmentosa*, *Wedelia biflora*, *Mapania cuspidata*, *Scirpus littoralis*, *Triumfetta repens* (only seen in Nicobars), *Canavalia maritima*, *Clitorea ternatea* and *Vigna marina* (wild pulse) are quite frequent on sandy beaches. *I. pes-caprae* shows its allegiance due to its evergreen shining leaves and violet flowers and found trailing over sandy beaches throughout coastal areas.

Mangrove forests bear net of aerial prop roots and thick stand (if undisturbed) along coast (Fig. 1) protecting the coastal areas from cyclonic tidal waves. These also provide an important habitat for young stages of commercially important fish and shrimps, breeding grounds for fish, shellfish, turtles and home for variety of wild life (Dagar et al. 1991; Dagar 1995b, 1996, 2003; Dam Roy 2003, 2015; Goutham-Bharathi et al. 2014).

The major cropping/agroforestry systems in these areas are coconut (*Cocos nucifera*) and *Casuarina*-based and homestead gardens. In the Bay Islands areca nut (*Areca catechu*, *A. triandra*), banana (*Musa* spp.) and *Artocarpus* spp. are also common. Screw pine (*Pandanus* spp.) and cashew nut (*Anacardium occidentale*) are quite frequent in Andamans and along Orissa coast. The rice during rainy season and vegetables and pulses during post-monsoon season are major crops. Fish cultivation along rice is common practice. Farming systems involving livestock, aquaculture, poultry, plantations, vegetables and rice cultivation are now frequently adopted. Despite of sufficient rainfall, the post-monsoon season faces scarcity of water due to non-harvesting of water during rainy season. Modern technologies (discussed later) of *in situ* and *ex situ* water harvesting are being developed.

Afforestation/Agroforestry Systems

Agroforestry systems provide alternatives for restoring soil health and amelioration of salt-affected coastal soils for their productive use. Location-specific multipurpose tree species (MPTs) can be grown mixed or separately planted for various purposes such as fruits, vegetables, wood, fodder, soil protection and soil amelioration. Amelioration of waterlogged salt-affected coastal soils with the domesticated agroforestry trees will reduce the pressure on the productive lands to fulfil the food needs of the growing population and environmental concerns. Agroforestry is the only alternative to meet the country's target

Fig. 1 Mangroves protecting shores from natural disasters like cyclones

of increasing forest cover besides improving the livelihood of rural people. A detailed account of many tree and shrub species suitable for planting in soils of different degrees of salinity is given in chapter "Global Perspectives on Agroforestry for Management of Salt-affected Soils" (Dagar and Minhas) of this publication. Mounding is essential on sites prone to waterlogging for establishing seedlings of trees and shrubs, with mounds positioned over the rip lines. In Western Australia, the seedlings planted in a 0.5–0.9 m wide trough between mound ridges and with a mound height of between 0.5 and 1 m had the highest survival rates. This mound design is preferable to a single ridged or flat-top mound. A single-ridge mound tends to shed rainfall and wet up from the water table or the furrows beside the mound, causing salt to accumulate in the mound. In contrast, the trough of a double-ridge mound tends to collect rainfall, favouring percolation and leaching of salts from the seedling root zone (Ritson and Pettit 1992). In areas underlain by palaeochannel, irrigated tree plantations are unlikely to have a significant effect on the local water table but may help to reduce subsurface drainage from the palaeochannel system if the leaching fraction beneath the trees is less than for other crop types. An additional advantage may be gained if the trees can derive a portion of their water requirement directly from the water table (Ayars et al. 2005). Groundwater pumping tests by Smith et al. (2005) further confirm the water table drawdowns beneath trees, planted over the palaeochannel system.

The drainage problems of coastal areas are related essentially to monsoon, caused by high rainfall and inadequate field tertiary and main drainage. Discharge from inland catchment also adds to the problem. Waterlogging and flooding conditions in most of the coastal lowlands are such that essentially only rice is grown during the wet (*kharif*) season. Trees can also influence groundwater tables by consuming groundwater 'directly'. This can occur in two ways: (a) extraction of water from the capillary fringe and (b) extraction of water from within the saturated zone. The capillary fringe is the area immediately above the water table in which groundwater is drawn up by capillary forces. The capillary fringe may be saturated close to the water table, but its water content decreases with increasing distance from the water table and is consequently well aerated. As such, trees with roots penetrating to the capillary fringe can readily utilize this water. Transpiration of the capillary water leads to a continuous movement of groundwater into the capillary fringe. Groundwater extraction can take place by trees specifically adapted to transpiring water when their roots are in saturated soil. Greenwood (1986) cited experimental evidence of Van Hylckama (1974) which showed decreasing water uptake of the phreatophyte *Tamarix pentandra* with increasing depth. Reasons for groundwater uptake decreasing with depth include decreasing root density, increasing soil bulk density (affecting root penetration), decreased oxygen level and greater gravitational potential difference (i.e. more effort required to lift the water against gravity).

The presence of 'ultrafilter' in roots of mangrove species of family Rhizophoraceae enables only selective absorption of ions. They may retain a low internal salinity by means of salt-excluding mechanisms in the roots. In this type, sodium and chloride concentrations are higher in xylem sap and do not reach the metabolic cellular environment. Another mechanism of salt regulation in mangroves is salt excretion. In species of *Avicennia*, *Aegialitis* and *Acanthus*, NaCl concentration in the excreted solution exceeds that of seawater. The same holds true for the halophytic grass *Aeluropus lagopoides* and tree *Tamarix articulata*. The ionic excretion of salt glands is constituted mainly of sodium and chloride. Under high-temperature conditions (25–30 °C), excretion rate is usually accelerated and the excretion process is dependent on light. Tree plantations in Sundarbans of West Bengal can dramatically lower the water table through decreasing local groundwater replenishment and increasing transpiration. In areas where the aquifer has small transmissivity, tree plantations may be effective at lowering the local water table, but this advantage may not be sustainable in the long term due to salt accumulation in the root zone (Sujana-Dhar 2011). Depending upon the need and situation, the following methods of planting have been adopted:

Row planting: Usually shelterbelts having 50–100 rows of trees are planted to minimise the wind speed.

Line planting: Line planting in coastal islands helps in reducing the wind force and stabilising the sand dunes.

Cluster planting: The latest method which is becoming popular with the farmers is cluster planting. In this method 2–3 seedlings are planted at each spot at a wider spacing of 2 m or 3 m.

On the coastlines wherever sulphur-containing sediments accumulate in tidal marshes or swamps or highly degraded mangrove ecosystems, acid sulphate soil formation takes place. These formations are quite frequent in Peninsular India and Andaman-Nicobar Islands, and rice is a major crop in these areas with very low productivity. However, under such conditions, it also suffers from an excess of water-soluble iron and particularly of aluminium, and toxic effect of these is a consequence of the strongly acidic pH. The application of lime mitigates the adverse and harmful effects on plants, but it is a costly preposition as the requirement of lime is very high. Therefore, alternative land use systems (agroforestry systems) need to be evolved.

Plantations in the Areas Closer to the Sea

The areas lying closer to the sea are flooded regularly with seawater and, therefore, have high salinity. The tidal areas protected against high wind velocity and waves of high intensity (as in case of many creeks, lagoons and estuaries) form a suitable situation for cultivation of mangroves. For cultivation of mangroves, we need seedlings of appropriate size. Many mangrove genera such as *Rhizophora*, *Ceriops*, *Aegialitis*, *Aegiceras*, *Bruguiera*, *Kandelia* and *Camptostemon* are viviparous in nature, and seed germinates when the fruit is intact to branch. The radical falls when mature and develops roots when it touches the muddy substratum. These mature radicals can be collected from the mangrove stands and planted directly in mangrove habitats or along protected shores as nursery in polybags. When seedlings are of proper size, these may be planted directly in tidal zone. Earlier attempts at restoration, regeneration and afforestation have been undertaken with direct planting of mangrove propagules or seeds (Karim et al. 1984; Hamilton and Snedaker 1984; Kogo 1985; Kogo et al. 1986). Untawale (1993) attempted rehabilitation of denuded mangrove areas via raising mangrove nursery in tidal zone on slightly raised platforms and supporting these with split bamboos to prevent possible drifting of polybags. Better results were obtained in areas with freshwater influence. After observing critically the natural zonation pattern (Dagar 1982, 1996, 2003; Dagar et al. 1991, 1993; Dagar and Singh 1999), it was recommended that *Rhizophora* may be planted facing the sea followed by belts of *Bruguiera*, *Kandelia*, *Ceriops*, *Avicennia*, *Sonneratia* and *Excoecaria* in middle zone towards land and species of *Ceriops*, *Aegiceras*, *Aegialitis* and *Camptostemon*, grown towards border with associate mangroves such as *Thespesia populnea*, *Pongamia pinnata*, *Terminalia catappa* and *Calophyllum inophyllum*. Species such as *Rhizophora mucronata, R. apiculata*, *Avicennia marina*, *A. officinalis*, *Bruguiera gymnorrhiza* and *B. parviflora* can be grown in highly saline sandy-clay substratum; while species such as *R. stylosa*, *Ceriops tagal*, *Aegiceras corniculatum* and *Sonneratia alba* are found more predominantly on silty clay substratum. *Sonneratia caseolaris*, *Xylocarpus granatum* and *Excoecaria agallocha* prefer low salinity and silty substratum and found distributed towards land. *Avicennia marina* is most tolerant to biotic stress and may be planted widely in all kinds of mangrove habitats. *Nypa fruticans*, a mangrove palm, is more predominant in muddy substratum along creeks. This can be propagated from suckers. *Terminalia catappa* (coastal almond), *Pandanus* spp., *Calophyllum inophyllum*, *Salvadora persica* and *Pongamia pinnata* are useful oil-yielding trees and can be commercially explored in areas bordering mangroves, but their nursery cannot be raised in tidal zone. The natural zonation pattern of mangrove stands of the area gives perfect understanding where to plant a particular species. The natural zonation pattern of Andaman-Nicobar Islands studied by Dagar (1982), Dagar et al. (1991) and Dagar and Singh (1999) is given in Fig. 2.

The alcohol yielding *Nypa fruticans* is more frequent in muddy creeks of Andamans and Sunderbans and may be cultivated as commercial crop. Several projects have later been implemented for rehabilitation of mangroves in Indian subcontinent, and quite sizeable area has been planted with mangroves particularly in Korangi-Phitti creek and Indus Delta in Pakistan and Goa and Pichavaram in Tamil Nadu. Some denuded areas have been rehabilitated with suitable mangrove species along Goa and Tamil Nadu coasts of India. The sandy beaches along Orissa coast have been planted successfully with *Casuarina glauca*, *C. equisetifolia*, *Pandanus*, cashew nut (*Anacardium occidentale*), coconut and *Acacia auriculiformis* (Dagar 2014). Due to *tsunami* land got elevated in North Andaman and in many uplifted mangrove areas due to nonavailability of tidal water mangroves have died and soils have turned acidic. Dam Roy and Krishnan (2005) reported critical analysis on effects of *tsunami* at different locations of Andamans. *Avicennia marina* and *Sonneratia alba* were least affected showing their adaptability to cyclones. To rehabilitate the uplifted areas for the choice of species, we need careful analysis of soil and natural succession of vegetation. Species bordering mangroves such as *Clerodendron inerme*, *Thespesia populnea*, *Terminalia catappa*, *Salvadora persica*, *Casuarina glauca*, *Pandanus* spp. and *Pongamia pinnata* may find a place.

Brackish Water Aquaculture in Mangrove Areas or behind Mangroves

The seawater near mangroves is resource for a wide variety of species of pelagic, demersal and oceanic fish. The pelagic resources include anchovies, sardines, mackerels, carangids, ribbon, seer, neritic tunas and barracuda; the demersal resources constitute perches, silver bellies,

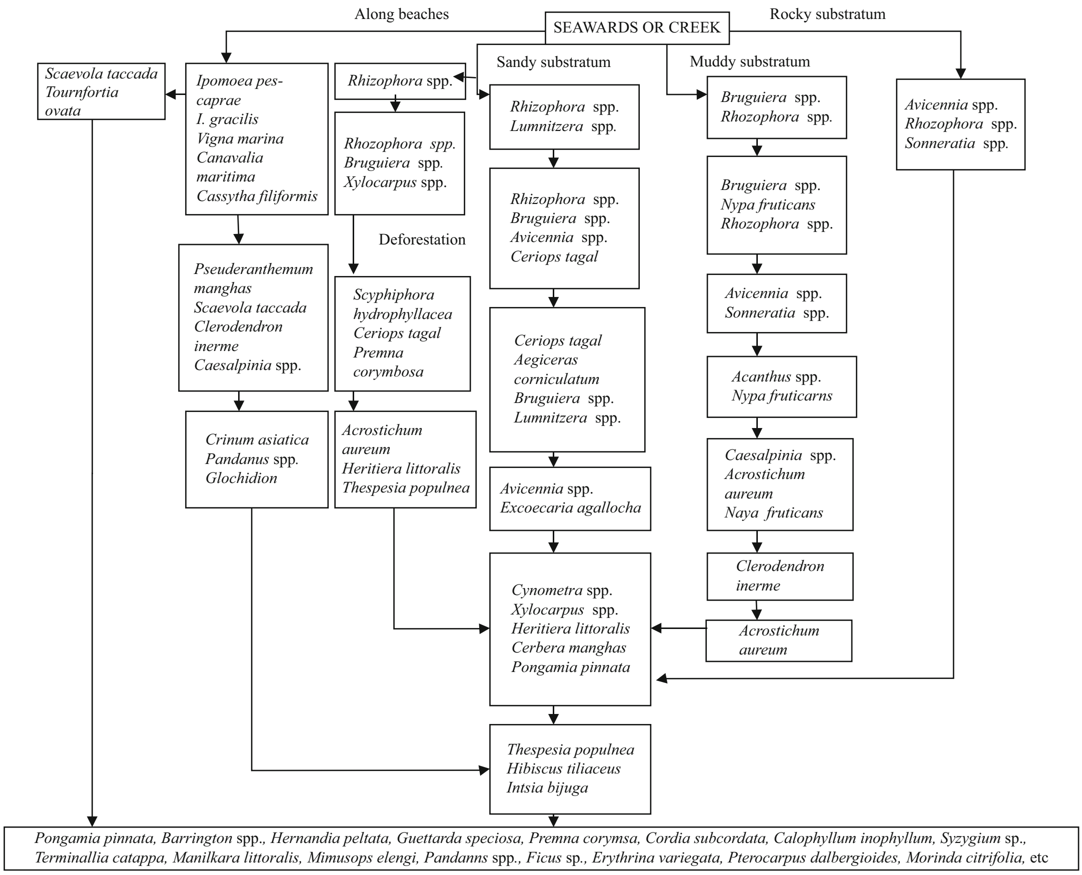

Fig. 2 Zonation pattern of mangrove forests in Andaman-Nicobar Islands

pomfrets, scads, sciaenids, nemipterids, shrimps and lobsters; and the oceanic resources are skipjack, tuna, sail, marlin and sword fish, and pelagic shark (Dam Roy et al. 2015). High-value crabs, prawns and lobsters are in plenty. These resources are dwindling as mangrove stands are facing tremendous anthropogenic pressure. Reclamation of backwater areas for aquaculture acid sulphate soils is constrained due to acidification of exposed mud with drying process. Any dyke construction from this mud thus results in acid leaching with rainwater to reduce pH resulting in stress or even death to the cultured stock. The iron carried into pond water is oxidized and later precipitated out as insoluble ferric hydroxide that clogs the gill filaments of aquatic organisms (fish) leading to asphyxiation (Dam Roy et al. 2005). The iron in pond interferes with smooth osmotic exchange of gases between organisms and water resulting in poor excretion. The carbonates and bicarbonates in pond water deplete as they react with acid resulting in soft shelling and poor moulting response of shell fish. These chemical reactions also negatively affect composition of bacteria-plankton–meiobenthos-microphytes affecting the pond food chains. The reclamation of saline acid sulphate soils for brackish water aquaculture can be achieved only through a model, which nullifies or reduces the abovementioned problems. Shrimp or fish farming is one of the viable commercial alternatives to agriculture in these areas. The development of brackish water aquaculture especially shrimp farming has been one, and it has been found to have substantial economic gains.

Aquaculture keeping mangroves intact is most feasible and sustainable option for promotion of aquaculture in inundated areas. In a preliminary study, mullet, prawn tilapia and fish culture could be made feasible and by connecting these ponds with brackish water behind mangroves particularly in association with *Avicennia* communities. The shrimp fry (*Penacus* and *Metapenaeus*) could be produced with rice. *Nypa fruticans*, a mangrove palm (frequent in Sunderbans and Andaman-Nicobar Islands), is cultivated in the Philippines and Bangladesh as a commercial crop and can have potential for Indian conditions also. Vannucci (1989) reported 15,000 l ha^{-1} $year^{-1}$ alcohol production by this palm. As it is a predominant palm in Sunderbans, the feasibility of its commercial cultivation must be explored which will generate employment in poor coastal population. Thus, fish/prawn culture, keeping mangroves intact, is very viable and useful system particularly in areas where freshwater streams merge with seawater. Bee humps are natural in Sunderbans; hence, beekeeping and duck-based poultry can be blended with fish culture associated with mangroves particularly along creeks. In the post-*tsunami* scenario, in South Andaman alone, due to the subduction of the land by about 1.25 m, the level of submergence due to tidal influence has also increased. Approximately 4000 ha areas of agricultural farmlands was submerged, out of which 630 ha suited for coastal aquaculture. On dykes of ponds, coconut and areca nut can successfully be cultivated for extra income.

Central Island Agricultural Research Institute (CIARI) took an initiative in collaboration with the Forest Department to look into the mangrove ecosystem as a livelihood source for the coastal fisherman, and a mangrove-based agro-aqua farming system was developed and demonstration adjacent to the creek within the brackish water farm complex of the institute in Sippighat, Port Blair (Dam Roy 2015). It demonstrates sustainable aquaculture where stocking and harvesting will be done round the year without supplementary feed, and the same is advocated for the areas adjacent to the mangroves in Andaman. Mangroves contribute about 3.7 Mg of litter ha^{-1} $year^{-1}$ (Dam Roy 2015), which decompose into detritus and made available as nutrients by microorganisms to marine animals. In protected stands, the litter quantity may exceed this amount as Dagar and Sharma (1991, 1993) reported 8.4 to 11.0 $Mgha^{-1}$ $year^{-1}$ litter fall in some protected mangrove stands of Andamans. Further, Dam Roy (2015) reported that mangroves contribute 18–42 Mg C $ha^{-1}year^{-1}$, approximating the distribution of the tropical rainforests and 10 times higher than primary production in the open ocean. Dagar and Singh (1999) gave details of structure, standing biomass, productivity of mangrove water and nutrient component of leaves of different mangrove species of Andamans. Ghoshal et al. (2006) reported 426 and 397 μg g^{-1} microbial biomass carbon in surface and subsurface soil at relatively undisturbed mangrove site in Andamans showing richness of microbial activities in the substratum. Besides other animals, mangrove waters are very rich in fish fauna. Rajan and Dam Roy (2003) reported 239 species of fish from mangrove ecosystem of Bay Islands, 68 % being of commercial importance while the rest of other types. This shows the potential of fish culture keeping mangroves intact.

Agroforestry in Inundated Areas Due to Seawater Flooding

The 2004 Indian Ocean *tsunami* severely damaged the coastal ecosystems of India. Velmurugan et al. (2015) conducted experiments to assess the impact of bunding and broad bed and furrow (BBF) systems in restoring the productivity of inundated areas of South Andaman (Fig. 3). They found that bunding of agricultural land leached out the salts by impounding of rainwater with significant reduction in electrical conductivity (ECe), sodium absorption ration (SAR) and exchangeable ions (Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}). The BBF system installed in low-lying waterlogged areas improved the drainage of the beds, harvested the rainwater (4476 m^3ha^{-1}), prevented entry of tidal and runoff water into the furrow and reduced the overall salinity. In addition microbial biomass C was significantly improved (193–210 mg kg^{-1} soil) and the soil under BBF systems adequately drained. The

Fig. 3 Broad bed furrow system in Andamans (Source: CIARI, Port Blair)

depth of submergence (R^2 = 0.798) and soil salinity (R^2 = -0.787) were found correlated with rainfall amount. Consequently BBF systems enabled a higher cropping intensity (218 %), increased fish productivity (INR 47.36 m^{-3}) and enhanced employment generation (213 man-days). These results can easily be upscaled elsewhere at least in Southeastern Asia.

By adopting this technology, farmers of Andamans could earn INR 1,17,532 per ha by growing vegetables [okra (*Abelmoschus esculentus*) + *Amaranthus* sp. - okra)] in beds; brinjal (*Solanum melongena*) + *Moringa oleifera* + banana (*Musa paradisiaca*) in border areas; and rice + *Azolla* + fish in furrows (Dam Roy et al. 2015). Trees such as *Casuarina*, noni (*Morinda citrifolia*), *Moringa oleifera*, coconut (*Cocos nucifera*), banana (*Musa* spp.) and areca nut (*Areca catechu*, *A. triandra*) can successfully be grown on bunds, vegetables and pulses on broad beds and fish and rice in furrows. Farmers in Andamans have four types of land holdings—hilly, slopping hilly uplands, medium upland valley and low-lying valleys. Low-lying valleys may be cultivated following BBF system; medium upland valleys may be planted with banana, coconut, areca nut and spices like clove (*Syzygium aromaticum*) or cinnamon (*Cinnamomum zeylanicum*) and black pepper (*Piper nigrum*) as climber; slopping hilly uplands may be utilized growing fodder grasses and legumes, while hilly lands may be retained with forest trees and planted with multipurpose trees (Dagar 1995a).

Need-based integrated land improvement approach comprising of six different methods, viz. broad bed and furrow, rice-fish cultivation, three-tier farming, farm pond, paired bed and furrow and pond-nursery systems, was developed and implemented in degraded coastal areas, and more than 500 farmers were benefited, which led to the crop diversification and livelihood security in islands.

Different land-shaping techniques for improving drainage facility, rainwater harvesting, salinity reduction and cultivation of plantation and crops and fish (freshwater and brackish water fish) for livelihood and environmental security were tested on about 400 ha degraded and low-productive land in disadvantaged areas in Sundarbans region of Ganges delta (West Bengal) and *tsunami*-affected areas in Andaman-Nicobar Islands covering 32 villages in 4 districts (South 24 Parganas and North 24 Parganas districts in West Bengal and South Andaman and North and

Fig. 4 Land shaping for deep furrow and high-ridge cultivation in coastal saline areas of West Bengal (Source: CSSRI, Karnal)

Middle Andaman districts in Andaman-Nicobar Islands) during 2010–2014. The soil in the study area was affected by high level of soil salinity (ECe up to 18 dS m^{-1}) and water salinity (EC up to 22 dS m^{-1}) that limits the choice and options of growing crops in the area. The following land-shaping technologies were tried on farmers' fields in coastal and islands areas (Burman et al. 2013):

Land shaping for deep furrow and high-ridge cultivation: The 50 % of farm land was sloped into alternate furrows (3 m top width × 1.5 m bottom width × 1.0 m depth) and ridges (1.5 m top width × 3 m bottom width × 1 m height). The ridges remained relatively free from drainage congestion and low in soil salinity build-up. These could be successfully used for raising plantations (fruits) or vegetables during both *rabi* and *kharif* and furrows for rainwater harvesting (to be used as life-saving irrigation in *rabi* season) and cultivation of rice and fish along with remaining original field. During dry season, the remaining field was also used for cultivation of low-water-requiring crops.

Land shaping for shallow furrow and medium ridge cultivation: About 75 % of the farm land was shaped into furrows (2 m top width × 1 m bottom width × 0.75 m depth) and medium ridges (1 m top width × 2 m bottom width × 0.75 m height) with a gap of 3.5 m between two consecutive ridges and furrows (Fig. 4). In wet season, the furrows could be used for rice and fish culture with rest of the field and rainwater harvesting. In dry season these could be used for rice cultivation. The ridges are planted with fruit trees or cultivated with vegetables or pulses throughout the year. The remaining original land could be used for low-water-requiring crops.

Land shaping for farm ponds: The 20 % of farm land was converted into on-farm reservoir (OFR) for in situ conservation of excess rainwater used during dry season, supplemental irrigation in *kharif* and freshwater aquaculture. The dugout soil was used to raise land to be used for crop cultivation. The dykes of the pond may also be planted with fruit trees.

Land shaping for paddy-cum-fish culture: Trenches of about 3 m width × 1.5 m depth

Table 2 Average depth of standing water (ADSW) and soil properties under different land situations created through land-shaping techniques in Sunderbans and Andaman group of islands

Land situation	ADSW (cm) in *kharif*	ECe (dS m^{-1})	pH	Org-C (%)	MBC (μg g^{-1} dry soil)	Avail N (kg ha^{-1})	Avail P (kg ha^{-1})	Avail K (kg ha^{-1})
Low land (without LS)	40–50	15.5	7.2	0.61	187.7	195.8	15.4	673.8
Low land (LS)	30–40	13.2	7.5	0.80	244.0	234.0	17.1	628.4
Medium land (LS)	15–20	7.3	7.4	1.10	279.0	238.1	18.9	480.3
High land (LS)	0	6.6	7.3	1.20	280.5	251.7	22.4	430.5

Source: Burman et al. (2015)
LS land-shaping technique

were dug around the field with a ditch of 6 m × 6 m × 3 m (depth) at one corner. The excavated soil was used for making dykes of about 3 m width and 1.5 m height to protect the fish cultivated with paddy. During wet season paddy and fish were grown on original land and vegetables/fruits on dykes. During summer low-water-requiring crops and vegetables were grown on dykes (in case fruits are not grown), and low-water-requiring crops on original land and lifesaving irrigation were given from water harvested in furrows. The original land in some cases was used for brackish fish culture. In that case at the end of summer season, brackish water was drained out along with monsoon rains, and the land was again used for paddy-*cum*-fish culture. Due to the creation of different land situations and following cultivation of crops round the year organic C, available N, P and K and biological activities (microbial biomass C) in surface soil were increased under land-shaping techniques compared to land without land shaping (Table 2).

About 1950 water storage structures were created under different land-shaping techniques, and 13,05,000 m^3 rainwater was harvested annually in these structures in the study area, and with this harvested rainwater, about 260 ha areas which were earlier under monocropping with rice due to shortage of irrigation water were brought under irrigation for growing multiple crops round the year. The cropping intensity increased up to 240 % from a base level value of 100 % due to implementing the land-shaping techniques (Table 3). These land-shaping techniques are very popular among the farmers of both Sundarbans and Andaman-Nicobar Islands as these have increased the employment and income of the farm family by manifolds compared to baseline value. Average net income per ha of farm land has been increased from INR 22,000 to 1,23,000 in Sundarbans and INR 22,400 to Rs 1,90,000 in Andaman-Nicobar Islands.

Homestead-based Integrated Farming Systems

In Bay Islands before penal settlement, Nicobari tribes indulged in community farming under *tuhet* system, wherein they practised a sustainable type of coconut based farming in a traditional way, which is prevalent even these days. Coconut trees are allowed to grow and propagate as wild forming a coconut forest. No spacing is followed; fertilizers are never applied. The interspaces (if any) are utilized for growing tuber crops. *Amorphophallus paeoniifolius*, *Coleus* spp., *Colocasia esculenta*, *Dioscorea alata*, *D. glabra*, *D. pentaphylla*, *D. bulbifera*, *Ipomoea batatas*, *Manihot esculenta*, *Maranta arundinacea*, *Tacca leontopetaloides* and *Xanthosoma sagittifolium* are common tribal tuber food in islands, which have several wild varieties/cultivars. Bhargava (1981, 1983), Dagar (1989), Dagar and Dagar (1989, 1991, 1999) and Dagar and Singh (1999)

Table 3 Enhancement in cropping intensity, employment generation and net income under different land-shaping techniques in Sundarbans and Andaman and Nicobar Islands

Land-shaping technologies	Cropping intensity (%)		Employment generation (man-days hh^{-1*} $year^{-1}$)		Net return (000 INR ha^{-1} $year^{-1}$)	
	Before	After	Before	After	Before	After
Farm pond	114[a], 100[b]	193[a], 200[b]	87[a], 8[b]	227[a], 22[b]	22[a], 10[b]	140[a], 148[b]
Deep furrow and high ridge	114[a]	186	87	218	22[a]	102[a]
Paddy-*cum*-fish	114[a], 100[b]	166[a], 200[b]	87[a], 8[b]	223[a], 35[b]	22[a], 24[b]	127[a], 148[b]
Broad bed and furrow	100[b]	240[b]	9[b]	48[b]	24[b]	212[b]
Three tier	100[b]	220[b]	10[b]	42[b]	30[b]	221[b]
Paired bed	100[b]	240[b]	9[b]	54[b]	24[b]	216[b]
Brackish water aquaculture	0/100	–	25[a]	100[a]	–	146[a]

Source: Burman et al. (2015)
Note: Costs and returns at current price of 2012–2013
*hh^{-1}: per household
[a]av. holding was 0.35 ha in Sundarbans
[b]av. holding of implementation was 0.20 ha in Andaman and Nicobar Islands

have reported the uses of several plants as food, shelter, canoe-making and drugs in the life of aborigines of Andaman-Nicobar Islands.

The community with their wise wisdom go for a shifting cultivation, but they do not burn the vegetation. The Nicobarese are of the habit of rearing pig (Nicobari pig is endemic to Nicobar group of islands), poultry (the bird is also endemic to Nicobars) and of recent cattle and goat. Keeping in view the dietary habits, limitation of land and markets for perishable produce, CIARI has developed homestead-based farming system for them comprising home garden (400 m^2), backyard poultry (20 nos.) and goat farming (2 nos.), and composting was developed for improving productivity. Consumption of fruits, vegetables, eggs and meat increased significantly, and a total of 95 man-days were generated from the system (Swarnam et al. 2014).

In other parts of islands, coconut and areca nut plantations are raised in coastal areas, while spices like black pepper, cinnamon, clove, Bay leaf, nutmeg and turmeric are cultivated in interspaces. In some areas forage grasses are cultivated. In low-lying areas, salt-tolerant rice varieties such as CARI Dhan-4, CARI Dhan-5 and CSR-36 are cultivated. *Gliricidia sepium* and *Sesbania* are cultivated for green manuring. *G. sepium* is also used as support for black pepper in many localities. Now farmers have also gained knowledge of mushroom cultivation on agricultural wastes and by-products available. On saline lands fruit species such as *Khaariphal* (*Ardisia solanacea* and *A. andamanica*), *Phoenix paludosa*, pond apple (*Annona glabra*) and noni (*Morinda citrifolia*) are grown successfully (Dam Roy et al. 2015). Experiments on grafting cultivated nutmeg (*Myristica fragrans*) on related *Knema andamanica* of the same family have given positive results (Rema et al. 2006). Other related species include *Endocomia macrocoma* syn. *M. prainii*, *Horsfieldia glabra* syn. *M. glabra*, *H. irya* syn. *M. irya*, *H. macrocarpa* var. *canarioides* syn. *M. canarioides*, *Knema conferta* syn. *M. conferta*, *K. glaucescens* syn. *M. glaucescens* and *M. glauca*. Similarly there are numerous wild cultivars of banana under *Musa acuminata* and *M. textilis* and of mango under *Mangifera andamanica*, *M. indandamenasis*, *M. camptosperma*, *M. indica* and *M. sylvatica* species, which can be explored for developing disease-resistance cultivars. Different integrated farming system (IFS) models for different micro-farming situations in hilly upland (plantation + dairy + backyard poultry), medium upland (crop + cattle + fish + poultry + goat) and valley areas (rice + vegetables + fish) at farmers' fields could increase farm income up to INR 3, 90, 000 ha^{-1} $year^{-1}$ besides additional employment generation of 163 man-days ha^{-1} y^{-1} (CIARI 2014).

Afforestation of Land Impregnated with High Salinity

Most of the area in Rann of Kutchh along Gujarat and Pakistan coast comes under this category. Because of low rainfall and high evapotranspiration, and saline shallow underground water, the problem becomes more severe. In many areas, natural salt is prepared in evaporation saltpans. MPTs such as *Prosopis juliflora*, *Salvadora persica*, *Tamarix articulata*, *T. troupii*, *Arthrocnemum indicum* and many halophytes are found growing naturally in these areas with stunted growth. Gururaja-Rao et al. (2004, 2013) advocated that *Salvadora persica* can be cultivated on highly saline soils (ECe > 55 dS m^{-1}). Even nursery of this plant could be raised using saline water of ECiw 15 dS m^{-1}. Plant started bearing seeds during second year producing about 725 kg seeds per ha. During the fourth and fifth years, it could produce 1580 and 1838 kg seeds per ha, respectively. Fruit trees such as ber (*Ziziphus mauritiana*), pomegranate (*Punica granatum*), sapota (*Achras zapota*) and banana (*Musa paradisiaca*) can successfully be cultivated in saline black soil as well as coastal sandy saline soils of Gujarat. Many seed spices such as cumin, fennel, coriander, dill and fenugreek in isolation or with forest and fruit trees are suitable for saline black Vertic Haplustepts soils (Dagar and Tomar 1998; Gururaja-Rao et al. 2000, 2004, 2013; Gururaja-Rao 2004). These may be irrigated with saline water.

A viable and productive silvopastoral system can be developed incorporating forage trees with suitable salt-tolerant forages such as species of *Atriplex*, *Kochia indica*, *Aeluropus lagopoides*, *Chloris gayana*, *C. barbata*, *Dichanthium annulatum*, *Leptochloa fusca*, *Echinochloa colonum* and *Sporobolus helvolus*. Oil-yielding species such as *Salvadora persica*, *Salicornia bigelovii*, *Pongamia pinnata* and *Terminalia catappa* and firewood trees like *P. juliflora*, *Acacia nilotica* and *Casuarina glauca* can be raised in furrows and abovementioned grasses in interspaces. In coastal sandy areas particularly along beaches of Orissa, *Casuarina equisetifolia* is successfully grown. At many places, plantations of *Eucalyptus*, cashew nut (*Anacardium occidentalis*), soapnut (*Sapindus trifoliatus*), *Acacia leucophloea*, *A. auriculiformis* and *Tamarindus indica* are found raised successfully. More species to be grown with saline water have been discussed in detail in chapter "Saline Irrigation for Productive Agroforestry Systems".

The silvopastoral system usually refers to land use system in which pasture (grazing land) and livestock production are integrated with woody perennials on the same land management unit and grazing is major component but a more productive and efficient concept covers broadly 'cut-and-carry' fodder production practices also. These land use systems are generally characterized by higher productivity on account of the vertical stratification of the shoot and root systems of different components. The trees in managed species have a great potential for efficient cycling of plant nutrients. Growing of nitrogen fixing trees has additional advantage as these help in fixing the atmospheric nitrogen into the soil which in turn is utilized by the associated field crops.

Mathew et al. (1992) in Kerala revealed that growth and yield of fodder species are significantly influenced by tree components only after tree canopy formation. The fodder species such as *Pennisetum purpureum*, *Panicum maximum*, *Brachiaria ruziziensis* and *Euchlaena mexicana* grown in association with *Casuarina equisetifolia* and *Ailanthus malabarica* recorded comparatively higher forage yield even after canopy formation. However, forage yield in association with *Acacia auriculiformis* and *Leucaena leucocephala* was relatively lower. The forage grasses are cultivated in the order of *P. purpureum* > *P. maximum* > *B. ruziziensis* > *E. mexicana* producing mean biomass of 74.5, 59.0, 42.5 and 23.9 Mg ha^{-1}, respectively. Among other shade trees *Acacia auriculiformis*, *Ailanthus triphysa*, *Casuarina equisetifolia* and *Leucaena leucocephala* can successfully be utilized along with grasses. Overall *Casuarina* among abovementioned trees and hybrid napier (*Pennisetum purpureum*) and guinea (*Panicum maximum*) among forage crops (other forage crops were congo-signal (*B. ruziziensis*) and teosinte (*Zea mexicana*) performed better than others. Opportunities exist for growing salt-tolerant fodder trees along banks of wetlands in coastal areas of West Bengal. Forage grasses such as *Coix lacryma-jobi*, *Brachiaria mutica* and *Echinochloa* spp. could be successfully cultivated and produced 41.3, 31.1 and 24.4 Mg ha^{-1}, respectively, forage biomass from five cuts during *kharif* season (Biswas 1994). Further 100 kg N ha^{-1} was sufficient for optimal yields of these forages.

In canal command areas of Karnataka, *Acacia nilotica* and *Casuarina equisetifolia* are found effective in controlling seepage along canals. The grasses in between complimented the effects. The water table receded significantly underneath the plantation while increased significantly outside plantation area. Two to four rows of *A. nilotica* with a spacing of 4 m × 2 m parallel to canal (5 m away from canal) helped in controlling canal seepage in Tug Bhadra irrigation command area (Vishwanath et al. 2013). Among other trees *Acacia auriculiformis*, *A. ferruginea*, *Albizia lebbeck*, *Gliricidia sepium* and *C. equisetifolia* performed well under saline (ECe 10–12 dS m^{-1}) and high water table conditions. All these species also helped in ameliorating the soil in terms of organic matter and nutrient pool. Among fruit trees pomegranate (*Punica granatum*) and *ber* (*Ziziphus mauritiana*) maintained steady growth in low salinity and shallow water table, while wood apple (*Feronia limonia*) was promising under relatively high salinity but deep water table conditions. Jamun (*Syzygium cuminii*) and sapota (*Achras zapota*) were better performers under shallow water table conditions.

Along the 880 km long coastal area of Pakistan, the soils are light-textured grazing lands and inhabited by *Prosopis juliflora* vegetation. There are a few well-known halophytes that are grazed, the most outstanding being *Arthrocnemum indicum*, *Salsola drummondii*, *Bienertia cycloptera* and *Zygophyllum simplex* (Qureshi et al. 1993). These are highly palatable to camels. Taxa such as *Tamarix articulata*, *T. indica*, *T. stricta*, *Salvadora persica* and *S. oleoides* are other valuable fodder sources for desert livestock and may be cultivated with saline water. Other potential species identified for this region include *Leucaena leucocephala*, *Prosopis cineraria*, *Acacia nilotica* and *Sesbania sesban* among woody species; species of *Atriplex* and *Maireana* among shrubs; and *Leptochloa fusca*, *Echinochloa crus-galli*, *Cenchrus ciliaris* and *Dactyloctenium sindicum* among grasses.

Subsurface Freshwater Skimming System (Improved Doruvu Technology) in Coastal Areas with Sandy Soil along Sea Coast

Out of the total 82 thousand ha of sandy soils along the sea coast of Andhra Pradesh, 18 thousand ha have shallow water table (0.5–3.0 m). These soils occur in 10 km wide and 972 km long strip along the coast extending from Ichapuram in Srikakulam district in the north to Tada in Nellore district in the south. Although the area receives 855 mm annual rainfall, irrigation water at critical growth stages of crops is the major impediment for obtaining optimal crop yield. With very high permeability of coastal sands, almost all the rainwater percolates in to the soil, and this water having lesser density floats over the subsurface saline water, which itself is underlain by impervious soil layer. Traditionally farmers dug a conical pit known as *doruvu* in local language and draw good-quality water manually and irrigate limited crops using pitchers. To overcome the drawbacks of traditional method, a subsurface freshwater skimming system (SSFWSS) was evolved by Raghu Babu et al. (1999) known as 'Improved Doruvu technology', which works on the principal of rapid phreatic flow in sandy soils under the influence of vertical recharge. The lateral flow is collected in a sump constructed on an impermeable layer. One or two parallel collector lines are imbedded for the collection of lateral flow by digging a horizontal trench and connecting these to the sump. Experiences show that each SSFWSS can supply sufficient good-quality water to raise plantations in 4–5 ha area using drip irrigation. Plantations such as red oil palm (*Elaeis guineensis*), coconut, banana, guava and pomegranate can successfully be grown in wider spaces. In the interspaces groundnut, pulses and vegetables can be grown successfully.

Agroforestry on Waterlogged Soils Intruded with Seawater

Cramer et al. (1999) showed that *Eucalyptus camaldulensis* intercepted deep groundwater, while *Casuarina glauca* relied on shallower unsaturated zone. Keeping this fact into consideration, Roy Chowdhury et al. (2011) conducted experiments in coastal deltaic Orissa where problem of waterlogging was both due to seawater intrusion and due to topographical depression. *Casuarina* was more efficient in discharging saline groundwater than *Eucalyptus.* The deltaic Orissa on an average experiences annual rainfall more than 1400 mm, during monsoon. As a result, for about 10–12-week period, the plantations experience above-ground waterlogged condition and remain so till the end of monsoon. Therefore, in present scenario, the scope for assessment of efficacy of biodrainage plantation has been limited to only in post-monsoon season. The effect of planted tree species on underlain water table was monitored by them through observation wells monitoring systems. The lowest water level at Patna (Orissa) was 1.02 m below ground which declined to 1.18 m in 3 years. Similarly decline from 1.27 to 1.52 m and from 1.69 to 1.85 m at other sites was observed. Thus, it is evident that at phreatic surface, there has been a clear drawdown in level of water table underneath tree plantations.

This accelerated drainage has helped the farmer to advance *rabi* cultivation by a period of 15–20 days. There was an advantage of growing watermelon (*Citrullus vulgaris*) with *Casuarina*, as the latter caused 21–34 % reduction in incident of photosynthetically active radiations over watermelon crop in comparison to control, and there was 34 and 39 % increase in yield in cultivars Mokassa and Arka Manik, respectively, in association with *Casuarina* as compared to control (Roy Chowdhury et al. 2012). Through this process, the cultivation of watermelon as intercrop inside *Casuarina* vegetation could get additional benefit of about INR 15,000 per ha for the farmer due to better market price of the crop as well as avoiding the market glut. In *kharif* season, rice was taken as intercrop inside *Casuarina* vegetation at one site. The final average yield of the paddy obtained during 4 years was 1.8 Mg ha^{-1}. The yield under *Eucalyptus* ranged from 2.3 to 3.5 Mg ha^{-1} (average 2.6 Mg ha^{-1}) during the same period. At another site, the net return of watermelon under *Casuarina* plantation in *rabi* season was INR 30,000 with B/C ratio of 2.14. Similarly under *Eucalyptus* from groundnut, net return was INR 21,000 with a B/C ratio 2.10, and from watermelon, net return was INR 62,500 and with B/C ratio of 3.67. Many other crops were also tried and showed promise as intercrops with these plantations. Aquaculture intervention in the biodrainage field was also initiated during the first week of June 2007 using a dugout pond of 400 m^2 of water surface area with *Casuarina* plantation. After carrying out standard pond preparation protocol, air-breathing fish like magur (*Clarias batrachus*) and koi (*Anabas testudineus*) were cultivated. A yield of 1.25 Mg ha^{-1} composite yield of fish was obtained within 10 months with a B/C ratio of 2.5. *Eucalyptus* clones 'JK Super' developed by JK Paper Ltd., Rayagada, Orissa, were planted and found effective. A stretch of a canal of 0.63 km length and 3.0 m width was under observation with growing of *Eucalyptus tereticornis* and banana varieties, viz. Poovan, Karpuravalli, Rastali and Monthan. Half of the canal length was planted with *Eucalyptus tereticornis* and the remaining length was planted with banana varieties. The survival *of Eucalyptus tereticornis* was much higher (Masilamani et al. 2003). The average transpiration rate (measured by sap flow) of groundwater by *Eucalyptus* plantations ranged from (L d^{-1} tree^{-1}) 44.5–56.3 in May to 14.8–16.2 in January. The annual transpiration rate was 268 mm (Roy Chowdhury et al. 2011). Optimizing micro-water resource design and integrated farming system approach for enhancing productivity of waterlogged area, Jena et al. (2006, 2011) modified the land by excavating ponds for storing excess water and created soil platforms for raising high transpiration trees such as *Acacia mangium* and *Casuarina equisetifolia*. This land was highly acidic, low in organic carbon and available nutrients and high in iron contents. The growth of trees was far superior and remunerative in modified land configuration and helped in lowering down the water table for growing intercrops. Similarly Mohanty et al. (2006) found feasibility of growing cowpea (*Vigna unguiculata*) and turmeric (*Curcuma domestica*) intercrops with drip irrigated banana plantation in waterlogged situation where there were additional benefits from the turmeric irrigated by microtubes, and extension tubes were Rs 24,700 and INR 24,200 ha^{-1} per season, respectively. This benefit with cowpea irrigating with microtubes and in-line drippers was lesser INR 11,000 and 7200 ha^{-1} $year^{-1}$, respectively.

Storage of rainwater in ponds for developing aquaculture-based integrated farming systems involving fish, poultry and halophytic crops gave net return of INR 69 thousand ha^{-1} $year^{-1}$ on 15 year basis in Orissa (Mohanty et al. 2004). The horticultural plants included banana, papaya, pineapple, mango and areca nut. From another enterprise involving poultry, fish and plantation on dykes, they could get net returns of more than INR 200 thousand per ha. The water productivity also of integrated farming system was far superior to paddy-based or sugarcane-based and vegetable-based systems. Therefore, in coastal waterlogged areas integrated farming, system approach is most profitable and feasible approach. A multi-enterprise model based on an integrated farming system and multiple water-use approach involving components of crops, fisheries, dairying, horticulture, vegetables, beekeeping, poultry, duck-based poultry, cow-dung-based plant, solar heating system etc. was developed on 2 ha reclaimed sodic land, to provide regular income, employment and livelihood to small farmers. The preliminary results indicated that the field crops (rice and wheat) gave a net income of about INR 52 thousands, berseem INR about 46 thousands and bottle gourd (*Lagenaria siceraria*) INR about 62 thousands ha^{-1}. Fish worth about INR 13 thousands was sold during the year from 0.2 ha fish pond (DARE/ICAR 2008–2009). Behera and Mahapatra (1999) reported that with the following integrated farming system approach in coastal areas of Orissa, a farmer with holding of 1.25 ha could get net return of INR 58,360 and generate 573 man-days in a year. Recently, Gangwar and Ravisankar (2014) reported that with the following farming system approach, the per-day profit of marginal and small households can be increased by 69 % through low-cost interventions such as using improved varieties, balanced recommended nutrient application, integrated pest management, good-quality fodder supply to cattle and the following farming system approach.

In Tamil Nadu, the coastal wetlands are highly saline. Since agriculture is not sustainable, silviculture is practised in river beds, on river and canal banks and in farm holdings and homesteads. Trees such as teak (*Tectona grandis*), *Prosopis juliflora*, *Eucalyptus* and bamboos (*Bambusa* spp.) are grown in small woodlots on patches of land in the wetlands for domestic use, but comparatively dry lands are preferred for raising commercial plantations of *Casuarina*. *C. equisetifolia*, *Thespesia populnea*, *Calophyllum inophyllum*, *Madhuca indica*, *Azadirachta indica*, *Pongamia pinnata*, *Borassus flabellifer*, *Lannea coromandelica* and *Bambusa bambos* are commonly grown on field boundaries and also on small landscapes. There is quite change in attitudes of tree growers from past to present seeing their sustainability and commercial use particularly in industry (Harikrishnan 1993). *Casuarina junghuhniana*, *C. equisetifolia*, *C. glauca*, *Eucalyptus*, *Melia dubia*, *Leucaena leucocephala*, *Prosopis juliflora* and bamboos are viable source of feedstock for combustible-type biomass power plants. Some major companies established their units in Ramanathapuram, Pudukottai, Sivaganga, Virudhunagar, Tirunelveli and Tuticorin districts of Tamil Nadu with the intention of using *Prosopis juliflora* which is seen almost everywhere in Tamil Nadu, as their main biomass material is feeling the pinch now with the high cost and non-availability of feedstock. However, the rural people utilize this wood for the production of charcoal by traditional methods to sustain their livelihood.

Shelterbelts and Shore Protection

In coastal areas high winds also carry salt with them and damage crops. Besides mangroves and other littoral species mentioned earlier, many trees and shrubs such as *Casuarina equisetifolia*, *Acacia auriculiformis* and *Gliricidia sepium* may play very important role in reducing the speed of the winds and protect the crops from injury. These also help in soil amelioration. Most of the coastal areas are prone to damage caused by cyclones and even *tsunamis*. Hence attempts should be made to conserve and restore the mangrove-degraded areas by planting suitable species. Besides mangroves, littoral species such as *Pandanus* spp., *Thespesia populnea*, *Scaevola taccada*, *Tournefortia ovata*, *Hibiscus tiliaceus* and *Salvadora persica* may also play important role in protecting the shores and beaches. MPTs such as *Calophyllum inophyllum*, *Pongamia pinnata*, *Heritiera littoralis*, *Terminalia catappa* and *Manilkara littoralis*, which are found growing luxuriously along beaches of Andamans (Fig. 5), can also be raised on degraded low-lying areas. These belts protect the shores/beaches, provide valuable forest products and also give shelter to wild life.

Domestication of Halophytes

Halophytes are naturally evolved salt-tolerant plants that represent at most 2 % of terrestrial plant species (Flowers and Colmer 2008). They have the ability to complete their life cycle in salt-rich environment where almost 99 % of salt-sensitive species die because of NaCl toxicity and thus may be regarded as a source of potential new crops (Glenn et al. 1991; Jaradat 2003; Dagar 2003) particularly for coastal areas where if necessary these may be irrigated with seawater. While halophytes since long have been in the diet of the people and are utilized in variety of ways in routine life, their scientific exploration as crops developed only in the latter half of the twentieth century (reviewed by Rozema et al. 2003 and Panta et al. 2014). Many halophytes have been evaluated for their potential use as crop plants (Miyamoto et al. 1996; Barrett-Lennard 2003; Reddy et al. 2008; Ruan et al. 2008; Qadir et al. 2008; Flowers et al. 2010; Tomar et al. 2010; Rozema et al. 2003; Dagar et al. 2013, 2014; Zhang 2014). Species such as *Distichlis palmeri*, *Chenopodium quinoa*, *C. album*, *Pennisetum typhoides*, *Salicornia bigelovii*, *Diplotaxis tenuifolia* and many others

Fig. 5 Littoral forest protecting the natural beach of Havelock, South Andaman

have been established as food crops, are being explored commercially and can be cultivated using seawater for irrigation. Similarly species of *Atriplex* and *Maireana*; grasses *Leptochloa fusca*, *Chloris gayana*, *Aeluropus lagopoides*, *Brachiaria mutica* and *Paspalum conjugatum*; and many other are constituents of silvopastoral systems developed on waterlogged salt lands in different agroclimatic regions of the world. At least 50 species of seed-bearing halophytes are potential sources of edible oil and proteins. *Salicornia bigelovii*, *Terminalia catappa*, *Suaeda moquinii*, *Kosteletzkya virginica*, *Batis maritima*, *Chenopodium glaucum*, *Crithmum maritimum* and *Zygophyllum album* are a few examples. A number of species including the halophytes *Tamarix chinensis*, *Phragmites australis*, *Spartina alterniflora* and species of *Miscanthus* have been evaluated as biofuel crops for ethanol production in the coastal zone of China (Liu et al. 2012), while many species such as *Halopyrum mucronatum*, *Desmostachya bipinnata*, *Phragmites karka*, *Typha domingensis* and *Panicum turgidum* are grown in coastal regions of Pakistan as source of bioethanol (Abideen et al. 2011). In addition, sugar beet (*Beta vulgaris*), mangrove palm (*Nypa fruticans*) and *kallar* grass (*Leptochloa fusca*) are identified as a source of liquid and gaseous fuel (Jaradat 2003). Screw pine (*Pandanus fascicularis*), quite predominant along Indian coast, is rich in methyl ether of beta-phenylethyl alcohol and is used as a perfume and flavouring ingredient (Dutta et al. 1987). Many woody and succulent halophytes are used for turf production for golf and landscape development, paper industry, medicinal use and other commercial purposes. As stated earlier mangroves are unique resources for tidal zone, which must be protected and multiplied in degraded areas. Therefore, more efforts are needed to domesticate these useful resources, particularly in coastal areas in agroforestry mode. For more details also see chapter "Saline Irrigation for Productive Agroforestry Systems".

Conclusions

The coastal areas are usually struck by disasters like cyclone and other climate vagaries incurring heavy productivity losses and associated salinity and waterlogging problems. These fragile and resource poor areas also face several other socio-economic constraints and thus demand for a holistic approach to raise their agricultural productivity. Opportunities exist because of the rich biodiversity and high availability of rainwater (>1000 mm) and thus paving ways for agroforestry-based strategies. The site-specific farming systems can combine forest and fruit trees, plantation crops, spices, forages, vegetables and halophytic plants. Integrated farming systems involving fish, shrimps, all kinds of aquaculture, multistoreyed plantation-based cropping systems, duck- and chick-based poultry, high-value medicinal and aromatic plants and spices can be highly remunerative. In low-lying areas, land shaping has helped in utilizing salt-affected waterlogged areas for increasing farm productivity; hence, such programmes must be undertaken at larger scale with support of different agencies involved in agriculture.

Mangroves are unique ecosystems which are nursery ground of several aquatic species, which stand a scope of commercial exploration through all kinds of aquaculture keeping mangroves intact. These will not only act as life-support system but also will protect the shores from natural disasters and act as carbon sink. Thus, agroforestry land use system should be of great relevance to the coastal and island ecologies particularly in the scenario of climate change. Unfortunately natural mangrove stands are in most dwindled stage and need to have special attention under mission-mode approach. These habitats must be replanted and developed at all possible sites.

Research efforts are needed in developing and domestication of high-value halophytic woody and herbaceous species. In coastal saline areas, leguminous species such as *Vigna marina*, *Clitorea ternatia* and *Canavalea* spp. are found natural giving a room to develop stress-tolerant pulses by inculcating the potential genes. Many other wild relatives of fruit and spice trees and orchids may be utilized for developing disease-resistance high-value crops. Seaweeds and marine wealth can successfully be explored in food, cosmetic, fertilizer and drug industries. Many ornamental fish species can be explored for ecotourism. Thus, though vulnerable to climate change and other natural disasters, the coastal and island regions have tremendous opportunities for increasing agricultural and related productivity through integrated farming system mode involving agroforestry science.

References

Abideen Z, Ansari R, Khan MA (2011) Halophytes: potential source of ligno-cellulosic biomass for ethanol production. Biomass Bioenergy 35:1818–1822

Ayars JE, Christen EW, Soppe RWO, Hornbuckle JW, Schoneman RA (2005) In-situ crop water use from shallow ground water to reduce drainage and save irrigation water. In: Proceedings of the international salinity forum, managing saline soils and water, riverside, 25–27 Apr 2005, pp 25–28

Barrett-Lennard EG (2003) Saltland pastures in Australia-a practical guide (Second Edition). State of Western Australia and CRC for Plant-based management of dryland salinity, South Perth, Western Australia, p 176

Behera UK, Mahapatra IC (1999) Income and employment generation of small and marginal farmers through integrated farming systems. Indian J Agric Sci 44(3):431–439

Bhargava N (1981) Plant in folk life and folk lore in Andaman and Nicobar Islands. In: Jain SK (ed) Glimpses of Indian ethnobotany. Oxford/IBH Publishing Co Ltd, New Delhi, pp 329–344

Bhargava N (1983) Ethnobotanical studies of the tribes of Andaman and Nicobar Islands. I. Onge. Econ Bot 37:110–119

Biswas CR (1994) Studies on feasibility and yield of forage crops in coastal saline areas of Sundarbans (West Bengal). J Indian Soc Coastal Agric Res 12:91–94

Burman D, Bandyopadhay BK, Mandal S (2013) Land shaping-a unique technology for improving productivity of coastal land. Technical Bulletin 02/2013. CSSRI Regional Research Center, Canning Town, West Bengal, India

Burman D, Mandal S, Bandopadhyay BK, Maji B, Sharma DK, Mahanta KK, Sarangi SK, Mandal UK, Patra S, De S, Patra S, Mandal B, Maitra NJ, Ghoshal TK, Velmurugan A (2015) Unlocking production potential of degraded coastal land through innovative land management practices: a synthesis. J Soil Salinity Water Qual 7(1): (in press)

CIARI (2014) CIARI-the Journey and the Road Ahead. ICAR-Central Island agricultural Research Institute, Port Blair, p 24

Cramer VA, Thornburn PJ, Fraser DW (1999) Transpiration and ground water uptake from farm forest plots of *Casuarina glauca* and *Eucalyptus camaldulensis* in saline areas of south east Queensland, Australia. Agric Water Manage 39:187–204

Dagar JC (1982) Some ecological aspects of mangrove vegetation of Andaman and Nicobar Island. Sylvatrop Philippines. For Res J 7:177–216

Dagar HS (1989) Plant folk medicines among Nicobarese tribals of Car Nicobar Island, India. Econ Bot 43:215–224

Dagar JC (1995a) Agroforestry systems for Andaman and Nicobar Islands in India. Int Tree Crop J 8(2&3):107–128

Dagar JC (1995b) Ecology of halophytic vegetation in India: a review. Int J Ecol Env Sci 21:273–296

Dagar JC (1996) Rehabilation of Coastal saline lands by planting with suitable species. J Indian Soc Coastal Agric Res 14:185–191

Dagar JC (2003) Biodiversity of Indian saline habitats and management & utilization of high salinity tolerant plants with industrial application for rehabilitation of saline areas. In: Alsharhan AS, Wood WW, Goudie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets & Zeitlinger Publishers, Lisse, pp 151–172

Dagar JC (2014) Greening salty and waterlogged lands through agroforestry systems for livelihood security and better environment. In: Dagar JC, Singh AK, Arunachalam A (eds) Agroforestry systems in India: livelihood security & environmental services-advances in agroforestry, vol 10. Springer, New Delhi/Dordrecht/New York, pp 273–332 un, India, p 122

Dagar HS, Dagar JC (1989) Ethnobotanical observations among the Onge tribe of Little Andaman. Bull Medico Ethno Bot Res 10(1–2):1–10

Dagar HS, Dagar JC (1991) Plant folk medicines among the Nicobarese of Katchal Island, India. Econ Bot 45(1):114–119

Dagar JC, Dagar HS (1999) Ethnobotany of aborigines of Andaman-Nicobar Islands. Surya International Publications, Dehra Dun

Dagar JC, Sharma AK (1991) Litterfall beneath Rhizophora apiculata in mangrove forests of Andamans, India. Trop Ecol 32(2):231–235

Dagar JC, Sharma AK (1993) Litterfall beneath *Bruguiera gymnorrhiza* in mangrove forests of South Andamans, India. Indian J For 16(2):157–161

Dagar JC, Singh NT (1999) Plant resources of the Andaman & Nicobar Islands. Bishen Singh Mahendra Pal Singh, Dehra Dun, p 987

Dagar JC, Tomar OS (1998) Suitable agroforestry systems for coastal saline regions: case study. J Range Manage Agrofor 19:165–172

Dagar JC, Mongia AD, Bandyopadhyay AK (1991) Mangroves of Andaman and Nicobar Islands. Oxford/IBH Publishing Co Ltd, New Delhi

Dagar JC, Singh NT, Mongia AD (1993) Characteristics of mangrove soils and vegetation of Bay Islands in India. In: Lieth H, Al Masoom A (eds) Towards the rational use of high salinity tolerant plants, vol 1. Kluwer, Dordrecht, pp 59–80

Dagar JC, Tomar OS, Minhas PS, Mukesh K (2013) Lemongrass (*Cymbopogon flexuosus*) productivity as affected by salinity of irrigation water, planting method and fertilizer doses on degraded calcareous soil in a semi-arid region of northwest India. Indian J Agric Sci 83(7):734–738

Dagar JC, Pandey CB, Chaturvedi CS (2014) Agroforestry: a way forward for sustaining fragile coastal and island agro-ecosystems. In: Dagar JC, Singh AK, Arunachalam A (eds) Agroforestry systems in India: livelihood security & environmental services-advances in agroforestry, vol 10. Springer, New Delhi/Dordrecht/New York, pp 185–232

Dam Roy S (2003) A compendium on mangrove biodiversity of Andaman and Nicobar Islands. Central Agricultural Research Institute, Port Blair, p 196

Dam Roy S (2015) Mangroves ecosystem of the Islands: significance and management options. In: Dhyani SK, Newaj R, Alam B, Dev I (eds) Agroforestry: present status and way forward. Biotech Books, New Delhi, pp 395–401

Dam Roy S, Krishnan P (2005) Mangrove stands of Andamans vis-à-vis tsunami. Curr Sci 89(1):1800–1804

Dam Roy S, Soundararajan R, Krishnamoorthy V, Krishnan P (2005) Tsunami impact on fisheries sector, rehabilitation required and strategies to be followed in Andaman and Nicobar Islands. In: Paper in national symposium "The Seventh Indian Fisheries, Forum" 8–12 Nov 2005, Bangalore, India

Dam Roy S, Velmurugan A, Zamir-Ahmed SK, Nagesh-Ram K-S, Sankaran RM, Gautam RK, Swarnam TP, Singh S (2015) Island agriculture: perspective and strategies. In: Souvenir-national seminar on harmonizing biodiversity and climate change: challenges and opportunities. Andaman Science Association, Port Blair, pp 1–21

DARE/ICAR (2008–2009) Annual report 2008–2009. Department of Agricultural Research and Education, Indian Council of Agricultural Research, New Delhi, India

Dutta PK, Saxena HO, Brahman M (1987) Kewda perfume industry in India. Econ Bot 41:403–410

Flowers TJ, Colmer TD (2008) Salinity tolerance in halophytes. New Phytol 179:945–963

Flowers TJ, Galal HK, Bromham L (2010) Evaluation of halophytes: multiple origins of salt tolerance in land plants. Funct Plant Biol 37:604–612

FSI (2011) India State of Forest Report 2011. Forest Survey of India (FSI), Ministry of Environment & Forests, Govt. of India, Dehra Dun, p 286

Gangwar B, Ravisankar N (2014) Farming systems approach for managing soil, water and crops in coastal areas. J Indian Soc Coastal Agric res 32(1):1–6

Ghoshal CS, Raja R, Jayakumar V (2006) Biochemical and molecular characterization of the soils of mangrove forests of Andamans. Annual Report. CARI, Port Blair, pp 14–15

Glenn EP, O'Leary JW, Watson MC, Thompsom TL, Kuehl RO (1991) *Salicornia-bigelovii* Trr – an oilseed halophyte for seawater irrigation. Science 251:1065–1067

Goutham-Bharathi MP, Dam Roy S, Krishnan P, Kaliyamoorthy M, Immanuel T (2014) Species diversity and distribution of mangroves in Andaman and Nicobar Islands, India. Bot Mar 57(6):421–432

Greenwood EAN (1986) water use by trees and shrubs lowering saline groundwater. Reclam Reveg Res 5:319–341

Gururaja-Rao G (2004) Diversified cropping systems and socioeconomic prospects in coastal saline soils of Gujarat state. J Indian Soc Coastal Agric Res 22(1&2):178–184

Gururaja-Rao G, Nayak AK, Chinchmalatpure AR (2000) Dill (Anethum graveolens) a potential species for salt affected black soils. Technical Monograph No.1, Regional Research Station Anand of Central Soil Salinity Research Institute, p 10

Gururaja-Rao G, Nayak AK, Chinchmalatpure AR, Nath A, Babu VR (2004) Growth and yield of *Salvadora persica* a facultative halophyte grown on saline black soil (vertic haplustept). Arid Land Res Manage 18:51–61

Gururaja-Rao G, Chinchmalatpure AR, Sanjay-Arora, Khandelwal MK, Sharma DK (2013) Coastal saline soils of Gujarat: problems and their management-technical bulletin 01/2013. CSSRI Regional Station, Bharuch, Gujarat, India, p 60

Hamilton LS, Snedaker SC (1984) Handbook of mangrove area management. UNEP and East-West Centre, Environment and Policy Institute, Hanolulu

Harikrishnan M (1993) Sustainable management of coastal ecosystems. In: Swaminathan MS, Ramesh R (eds) Coastal agroforestry and its sustainable utilisation. Proceedings of the workshop held in Madras in October, 1991, pp 71–83

ICAR (2014) http://www.icar.org.in/en/node/7665

India (2013) India 2013-a reference manual. Publication Division, Ministry of Information & Broadcasting, Government of India, New Delhi, p 1206

Jaradat AA (2003) Halophytes for sustainable farming systems in the Middle East. In: Alsharhan AS, Wood WW, Goudie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets & Zeitlinger Publishers, Lisse, pp 187–204

Jena SK, Sahoo N, Roy Chowdhury S, Mohanty RK, Kundu DK, Mohanty M (2006) Optimizing microwater resource design and integrated farming system approach for enhancing productivity of waterlogged areas. J Indian Coastal Agric Res 24(1):184–187

Jena SK, Sahoo N, Roy Chowdhury S, Mohanty RK, Kundu DK, Behera MS, Kumar A (2011) Reclamation of coastal waterlogged wasteland through biodrainage. J Indian Coastal Agric Res 29:57–62

Karim A, Hossain Z, White KJ (1984) Study of the growth of mangrove plants in relation to edaphic factors in coastal afforestation plantation of Chittagong. In: Proceeding of thesymposium on Mangrove environment research & management, Kuala Lumpur, Malaysia

Kogo M (1985) Mangrove research & recommendations of afforestation in Pakistan. A report for UNDP/UNESCO Mangrove Project by Al Gurm Research Centre, Tokyo

Kogo M, Kaminura D, Miyagi T (1986) Research for rehabilitation of mangroves in Truck Islands. In: Mangroves of Asia & the Pacific-Status and monument. Technical Report. UNDP/4NESCO Regional Mangrove Project, New Delhi

Liu XZ, Wang CZ, Su Q, Lib CK (2012) The potential resource of halophytes for developing bio-energy in China coastal zone. Herald J Agric Food Sci Res 1:44–51

Masilamani P, Santhana Bosu S, Annadurai K (2003) Bio drainage for degraded drainage problem lands. Leisa India 5:19

Mathew T, Kumar BM, Suresh-BabuKV UK (1992) Comparative performance of some multipurpose trees and forage species in silvo-pastoral systems in the humid regions of southern India. Agrofor Syst 17:205–218

Miyamoto S, Glenn EP, Olsen MW (1996) Growth, water use and salt uptake for four halophytes irrigated with highly saline water. J Arid Environ 32:141–159

Mohanty RK, Sahoo N, Jena SK, Roy Chowdhury S, Verma HN (2004) Water productivity and economic evaluation of aquaculture-based integrated farming system approach in waterlogged ecosystem. J Indian Soc Coastal Agric Res 22:298–303

Mohanty S, Srivastava RC, Singandhupe RB (2006) Feasibility of intercrops in drip irrigated banana in coastal Orissa. J Indian Coastal Agric Res 24(1):184–187

NAAS (2010) Degraded and wastelands of India: status and spatial distribution. National Academy of Agricultural Sciences, New Delhi, p 158

Panta S, Flowers T, Lane P, Doyle R, Haros G (2014) Halophytes agriculture: success stories. Environ Exp Bot 107:71–83

Qadir M, Tubeileh A, Akhtar J, Larbi A, Minhas PS, Khan MA (2008) Productivity enhancement of salt-affected environments through crop-diversification. Land Degrad Develop 19:429–453

Qureshi RH, Aslam M and Rafiq M (1993) Expansion in the use of forage halophytes in Pakistan. Davidson N, Galloway R (eds) Productive use of saline land. ACIAR Proceedings No. 42, Australian Centre for International Agricultural Research, Canberra, Australia, pp 12-16

Raghu Babu M, Prasad PRK, Subbaiah GV, Mujeeb-Khan, Minhas PS (1999) Subsurface fresh water skimming system (Improved Doruvu Technique), Technical Bulletin 1/99 Central Soil Salinity Research Institute, Karnal, India, p 19

Rajan PT, Dam Roy S (2003) Mangrove fishes of Andaman and Nicobar Islands. In: Dam Roy S (ed) A compendium on mangrove biodiversity of Andaman and Nicobar Islands. CARI, Port Blair, pp 123–135

Reddy MP, Shah MT, Patolia JS (2008) *Salvadora persica*, a potential species for industrial oil production in semiarid saline and alkali soils. Ind Crop Prod 28:273–278

Rema J, Krishnamoorthy B, Mathew PA, Johnson George K (2006) Conservation of wild nutmegs of Andamans at IISR. Spice India, December, pp 21-22

Ritson P, Pettit N (1992) Research to improve reforestation techniques for saline groundwater discharge control in water resource catchments. Surface Water Branch, Water Authority of Western Australia, Rep. No. WS25, 44 pp

Roy Chowdhury S, Kumar A, Brahmanand PS, Ghosh S, Mohanty RK, Jena SK, Sahoo N, Panda GC (2011) Application of bio-drainage for reclamation of waterlogged situations in deltaic Orissa. Research Bulletin 53. Directorate of Water Management (ICAR), Bhubaneswar, p 32

Roy Chowdhury S, Brahmanand PS, Ghosh S, Jena SK, Mohanty RK, Kumar A (2012) Photosynthesis performance and yield of watermelon grown under biodrainage (*Casuarina equisetifolia*) vegetation. J Indian Coastal Agric Res 30(2):34–40

Rozema J, Muscolo A, Flowers T (2003) Sustainable cultivation and exploitation of halophyte crops in a salinising world. Environ Exp Bot 92:1–3

RRSSC & CWC (2009) Assessment of Waterlogging and Salt and/or Alkaline Affected soils in the commands of all major and medium irrigation projects in the country using satellite remote sensing. Regional Remote Sensing Service Centre, Indian Space Research Organization, Jodhpur; and Central Water Commission, New Delhi, p 165

Ruan CJ, Li H, Guo YQ, Qin P, Gallgher JL, Seliskar DM, Lutts S, Mahy G (2008) Kosteletzkya virginica, an agroecoengineering halophytic species for alternative agricultural production in China's east coast: ecological adaptation and benefits, seed yield, oil content, fatty acid and biodiesel properties. Ecol Eng 32:320–328

Smith AJ, Pollock DW, Salama RB, Palmer D (2005) Ivanhoe plain aquifer pumping trial, July 2003–April 2005: Stage 1 Ord River irrigation area, Kununurra, Western Australia, CSIRO land and water technical report, 24 May 2005

Sujana-Dhar (2011) Impact of climate change on the salinity situation of the Piyali River, Sundarbans, India. J Water Resour Protect 3:495–503

Swarnam TP, Velmurugan A, Zacharia-George RN, Sai TP, Dam Roy S (2014) Integrated farming system for sustainable livelihood in tribal areas of Nicobar Islands. J Andaman Sci Assoc 19(1):19–22

Tomar OS, Dagar JC, Minhas PS (2010) Evaluation of sowing methods, irrigation schedules, chemical fertilizer doses and varieties of *Plantago ovata* Forsk to rehabilitate degraded calcareous lands irrigated with saline water in dry regions of north western India. Arid Land Res Manage 24:133–151

Untawale AG (1993) Development of an intertidal mangrove nursery and afforestation techniques along the Indian Coast. In: Lieth H, Al Masoom A (eds) Towards the rational use of high salinity tolerant plants, vol 1. Kluwer, Dordrecht, pp 371–378

Van Hylckama TEA (1974) Water use by saltcedar as measured by the water budget method. Professional paper 49lE. United States Geological Survey, Washington, DC, 30 pp

Vannucci M (1989) The mangroves and us. A synthesis of insight. Indian Association of the Advancement of Science, New Delhi

Velmurugan A, Swarnam TP, Lal R (2015) Effect of land shaping on soil properties and crop yield in tsunami inundated coastal soils of Andaman Islands. Agric Ecosyst Environ 206:1–9

Vishwanath J, Hebbara M, Karegoudar AV, Rajkumar RH, Anand SR, Ambast SK, Gupta SK (2013) Groundwater quality and management of poor quality water for agriculture in Karnataka. Technical Bulletin 2013/1, AICRIP on management of salt-affected soils and use of saline water in agriculture, Gangavati, University of Agricultural Sciences, Raichur, Karnataka, India, p 47

Yadav JSP, Bandyopadhya AK, Bandyopadhya BK (1983) Extent of coastal saline soils in India. Indian Soc Coastal Agric Res 1(1):1–6

Zhang J (2014) Agroforestry systems of combating saline soils. In: Zhang J (ed) Coastal saline soil rehabilitation and utilization based on forestry approach in China. Springer, Berlin, pp 41–54