

Utilization of Degraded Saline Habitats and Poor-quality Waters for Livelihood Security



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Received: 📅 June 14, 2018; Published: 📅 June 25, 2018

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Abstract

The world population is estimated to cross 7.6 billion and to develop agricultural strategies to feed all people represents as one of the biggest challenges of this century. We have limited land and water resources; therefore need to develop all these resources carefully. Nearly one billion hectares of arid and semiarid areas of the world are salt-affected and remain barren. These soils are universally low in fertility and not suitable for conventional agricultural use. Irrigation without adequate drainage is leading to waterlogging and secondary salinization. Further, in most of these regions, the groundwater aquifers are saline. Usually cultivation of conventional arable crops with saline irrigation has not been sustainable. To bring these wastelands under sustainable productive system and use poor-quality waters judiciously in agriculture, we need to evolve innovative technologies and domesticate stress tolerant halophytes of high economic value. Further, saline agroforestry needs to be given preference as salt-tolerant forest and fruit trees, forage grasses, medicinal and aromatic and other non-conventional crops can be equally remunerative. In coastal areas, mangrove-based aquaculture needs to be developed. The littoral vegetation not only protects the shores and provides wood for fuel, fodder, thatching material, and honey for coastal population but also creates substratum, which provides shelter to a variety of animals. The ecosystem also helps in fish production and plays a key role in food web. Such uses have additional environmental benefits including carbon sequestration, biodiversity conservation, and biological reclamation. In this write up, some of these aspects have been discussed in brief.

Keywords: Salt-affected soils; Biosaline agriculture; Non-conventional; Halophytes; Mangroves; Saline irrigation; Carbon sequestration

Introduction

The world population is estimated to have reached 7.6 billion as of December 2017 and the United Nations predicted a population increase to 9.1 billion by 2050 and 11.8 billion by the year 2100 (<https://en.wikipedia.org>), putting huge pressure on food availability. By the year 2050, another 1 billion Mg of cereals and 200 million Mg of extra livestock products need to be produced every year. The imperative for such agricultural growth is strongest in developing countries, where the challenge is not just produce food but to ensure that the people have access that will bring them food and nutritional security. So, agriculture strategies for feeding all people represent one of the biggest challenges in this century. Therefore, there is to be enormous demographic and economic pressure on all nations to meet ever-increasing demands of people. Besides ever increasing population pressure, some other facts are aggravating this demand [1], which include:

- a) The increase of land occupation for biofuel supply deviating arable soils from food crops,
- b) Soil fatigues posed by post green revolution,
- c) Rise of soil degradation due to salinity, and
- d) Challenges posed by episodes of extreme environmental conditions, generally called "climate change events".

Recent trend in climate variability poses a serious threat to sustainability of agriculture, hence food security across the globe especially in developing countries. Land degradation due to salinity and waterlogging, land fragmentation, labour problems and over exploitation of natural resources, further accentuates situation in these countries. Nearly 1 billion hectares of arid and semiarid areas of the world are salt-affected and remain barren due to salinity

or water scarcity. Salinity, emerging as a major land degradation factor due to inefficient irrigation methods in most of the canal commands. Nearly 60 million ha of land area is already severely waterlogged in canal command areas. The problem is more severe in areas underlain with poor quality groundwater. In most of arid and semiarid regions, the groundwater aquifers are saline. Usually cultivation of conventional arable crops with saline irrigation has not been sustainable.

The waterlogging and inundation in landscapes are expected to increase with impending climate changes. Aberrations in rainfall, melting of glaciers and more frequent chances of severe tropical storms with rise of temperature are also likely to increase inundations in whole south Asia, and particularly in the Ganges, Brahmaputra and Meghna basins. Possible rise in sea level, high tides, storm surges and even increased subsoil seawater intrusion will alter hydrological cycle, increase soil and groundwater salinity and also risk of inundation in coastal areas of tropical regions. Though poor-quality groundwater available in dry land aquifers and urban sewage provides an opportunity for irrigation to sustain agriculture development and meet the increasing demands of food, forage, fuel wood and timber; but also poses risk of salinity build up adopting these means.

However, adopting saline irrigation depends on crop salt-tolerance, soil and water characteristics, climatic conditions, availability of fresh water, and management practices influencing soil water crop atmosphere continuum and the saline water irrigation economics [2-4]. All this suggests for timely development of suitable measures for adaptation and mitigation of adverse impacts of climate change on biosaline agriculture. Further, with the increasing demand for good-quality land and water for urbanization and development projects in the future, which are taking place at rapid pace, agriculture will be pushed more and more to the marginal lands, and use of poor quality waters for irrigation is inevitable. To bring the salt-affected wastelands under sustainable productive system and use poor-quality waters judiciously in agriculture, we need to evolve innovative technologies and domesticate stress-tolerant halophytes of high economic value.

In recent years, however, the attention is being paid worldwide to accommodate the salt-tolerant species of economic importance for highly saline degraded areas including coastal marshes and irrigating them with saline water. The scopes of many of these species of high economic value for saline and sodic habitats along with their management and utilization have been discussed in this paper. Potential of afforestation and agroforestry in carbon sequestration particularly in salt-affected soils has been worked out. Therefore, growing forest and fruit trees, grasses and non-conventional crops of high economic value including medicinal and aromatic plants on salt-affected soils or using saline water for irrigation is a sustainable option of utilizing these degraded

resources. Some of these opportunities have been discussed in this write up.

Potential Salt-tolerant Resources

Based on their genetic potential to counter the root zone salinity, the plants differ in their capacity to adapt to saline habitats. The capacity to lower the osmotic potential of cell sap, salt exclusion, salt secretion, and succulence are common but differently expressed attributes of salt-tolerant vegetation. Thus, the plants which are able to grow successfully with sufficient growth and complete life cycle on high saline habitats and possess special adaptive procedures are called halophytes. Many of these sustain saline irrigation and produce economic biomass and products. For halophytes succeed as irrigated crops, Glenn [5] mentioned four basic conditions essential, which include high yield potential; the irrigation needs must not exceed the conventional crops and be harmless to the soil; the products from halophyte crops must be able to replace the conventional crop products; and high salinity agriculture must be applicable to the existing agricultural infrastructure. During last four decades many studies have been undertaken to domesticate and popularize the halophytic crops in unfavourable conditions [2, 6-12] showing their potential in changed environment.

The potentiality of using halophytes in commercial exploitation, though still limited, is already being applied for some species. The search for potential halophytes have resulted in identification of many genera such as *Acacia*, *Anacardium*, *Arthrocnemum*, *Atriplex*, *Avicennia*, *Batis*, *Brachiaria*, *Bruguera*, *Calophyllum*, *Capparis*, *Carandas*, *Cassia*, *Casuarina*, *Ceriops*, *Chloris*, *Citrus*, *Coccoloba*, *Cressa*, *Crithmum*, *Distichlis*, *Eucalyptus*, *Glycyrrhiza*, *Grindelia*, *Juncus*, *Kochia*, *Kosteletzkya*, *Leptochloa*, *Leucaena*, *Limonium*, *Lumnitzera*, *Maireana*, *Matricaria*, *Nypa*, *Pandanus*, *Pongamia*, *Panicum*, *Plantago*, *Porterasia*, *Prosopis*, *Rhizophora*, *Salicornia*, *Salvadora*, *Simmondsia*, *Sonneratia*, *Spergularia*, *Sporobolus*, *Suaeda*, *Tamarix*, *Taxodium*, *Terminalia*, *Thinophyrum*, *Vetiveria*, *Xylocarpus*, *Ziziphus* and *Zostera*. There may exist as many as 250 potential staple halophytic crops [13]. However, adaptability of any potential halophyte to saline habitats and its economic use decides the acceptability of it in different regions. Also, the project "Greening Eritrea" from the Seawater Foundation (<http://www.seawaterfoundation.org>) represents an example of how to convert a decertified region into a useful soil. About 2600 halophytic species are known and only few are extensively studied for their potential in agriculture and as biological resources with economical potential as source of food, oils, flavours, gums, resins, pharmaceuticals, and fibres [8,14-16], or with environmental potential for protection and conservation of ecosystems [17-19]. While documenting biodiversity of halophytes, Dagar and Singh [11] reported 1140 salt-tolerant flowering species under 541 genera and 131 flowering families from Indian salt-affected and waterlogged habitats; out of which 988 having economic uses. Some of the potential halophytes are discussed as below:

Halophytes as Food Crops

(Bio) saline agriculture can provide food in many ways, especially in areas where traditional agriculture cannot be profitable. Appropriate species can be domesticated and their seeds, fruits, roots, tubers or foliage can be used directly or indirectly as food. Aronson [8] reported that at least 50 species of seed bearing halophytes are potential sources of grains and oil. Since long, many species are used in variety of dietary ingredients but their scientific exploration developed only in the latter half of the 20th century [21,22]. Species such as *Distichlis palmeri*, *Zostera marina*, *Chenopodium quinoa*, *C. album*, *Salicornia bigelovii*, *Diptotaxis tenuifolia*, and many others have been established as food crops. These can be explored commercially using sea water for irrigation.

The Eelgrass (*Zostera marina*) grows in the Gulf of California; seed contains 50% starch, 13% protein and 1% fat; is comparable with wheat. The Palmer salt grass (*Distichlis palmeri*) used as food by natives (contains protein contents 8.7% and fibre higher than wheat) has been used to develop grain crop by NyPa, Inc. having well balanced amino acid composition. Alkali Sacaton (*Sporobolus airoides*), is another candidate for domestication. Pearl millet (*Pennisetum typhoides*) grows well on sand dunes and tolerates EC of 27-37dS m⁻¹ of saline water used for irrigation, can be grown as a food crop with seed yield up to 1.6 Mg ha⁻¹ and straw as fodder up to 6.5 Mg ha⁻¹. *Aster tripolium* (also known as Sea Aster or Sea Spinach) grows in temperate regions, close to the coast mainly in the salt meadows and estuaries, is a very productive and can be cut several times with a regrowth of young shoots every 3-4 weeks, has now become a delicacy in the Netherlands. Some interesting research has been carried out concerning the response of *Aster tripolium* and *Puccinellia maritima* to atmospheric carbon dioxide enrichment and their interactions with flooding and salinity [22].

The perennial Seashore mallow (*Kosteletzkya virginica*) can produce 1.5 Mg ha⁻¹ grain of high protein (32%) and oil (22%) content making it an excellent candidate as a grain or oil crop [15]. Many *Acacia* species (*A. aneura*, *A. coriacea*, *A. cowleana*, *A. dictyophleba*) produce seed that are rich in nutrients with higher energy, protein and fat contents than wheat or rice. *A. aneura* is a potential oil crop (37% fat), whereas *A. dictyophleba* is a potential grain crop with high protein (26.8%) content [15]. The use of *Suaeda maritima*, *Salicornia brachiata* and *Salsola baryosma* in *sajji*/pappar industry in Rajasthan and Gujarat is well known. *Salicornia bigelovii* (having CAM metabolism), is a very well studied species, cultivated for its oil seed (both for human and animal use) and straw. The seed yield is ~2 Mg ha⁻¹, similar in quality to soybean, contain 28% oil rich in polyunsaturated fatty acids (linoleic acid 74% of total) and 31% protein [4] and a biomass of 18 Mg ha⁻¹, over a 200 days cycle. The residual seed meal is very rich in protein (~33% crude protein). *Salicornia* species including those native to the Arabian Gulf Region (e.g. *S. herbacea*), produce an edible, safflower like seed oil and plant material about 20 Mg ha⁻¹ when irrigated with sea water, used as fodder for sheep and goats.

At least 50 species of seed bearing halophytes are potential sources of edible oil and proteins. *Salicornia bigelovii*, *Terminalia catappa*, *Suaeda moquini*, *Kosteletzkya virginica*, *Batis maritima*, *Chenopodium glaucum*, *Crithmum maritimum* and *Zygophyllum album* are a few examples. Seeds of various halophytes, such as *Suaeda fruticosa*, *Arthrocnemum macrostachyum*, *Salicornia brachiata*, *Halogeton glomeratus*, *Kochia scoparia* and *Haloxyton stocksii* possess a sufficient quantity of high quality edible oil with unsaturation ranging from 70-80%. Seeds of *Salvadora persica* and *S. oleoides* contain 40-50% fat and are a good source of lauric acid, a potential substitute for coconut oil [1]. Seed oil (52%) from Indian almond nut (*Terminalia catappa*) has been found suitable for consumption. The physicochemical properties of the seed oil indicated that it is edible, drying and suggested its suitability for industrial purposes as well as the nutritional potentials of the nut, which could serve as an alternative food ingredient for unsaturated vegetable oil. The suitability of coconut (*Cocos nucifera*) oil for food consumption and hair oil is well established.

The annual herb Quinoa (*Chenopodium quinoa*), is one of the staple food of native South Americans, produces nutritious seeds (30% of dry weight of the plant or 2.5 Mg ha⁻¹) with higher protein contents and amino acid composition compared to wheat. *C. album*, is another nutrient rich herb commonly used as green vegetable during winter in Indian sub-continent. Seaside purslane (*Sesuvium portulacastrum*), Common purslane (*Portulaca oleracea*), sea fennel (*Crithmum maritima*), *Atriplex triangularis*, *A. hortensis*, *Suaeda maritima*, *Amaranthus spinose*, *A. viridis* and many other herbs are commonly used as green vegetables in India. Species such as *Cochlearia officinalis*, *Crambe maritima*, *Crithmum maritimum*, *Inula crithmoides*, *Mesembryanthemum crystallinum*, *Plantago coronopus*, and *Tetragonia tetragonoides* are used as fresh salad or cooked vegetables. Wild water chestnut (*Eleocharis dulcis*) tubers are cooked or pounded to meal. Similarly, the roots and stems of saltwort (*Batis maritima*) can be used for food; the plant produces up to 17 Mg ha⁻¹ of dry biomass using seawater for irrigation. *Diptotaxis tenuifolia*, also is a promising species for saline agriculture and has a potential for food (salad) and forages. Beet root (*Beta vulgaris*) is widely used as vegetable, salad and also a source of forage as well as sugar. Pods of salt-tolerant tree *Prosopis cineraria* are consumed as vegetable when raw and animal feed when ripe.

Though the fruit trees are among the most sensitive to salinity, researchers have been able to identify certain halophytic species that can be used either as rootstocks or as grafts to produce economic fruit yields using saline water for irrigation [12]. *Ziziphus nummularia*, a salt-tolerant species with small berries (edible) can be used as a rootstock for *Z. mauritiana* that can produce larger berries. Similarly, *Manilkara hexandra* can be used as a rootstock for grafting *M. zapota* that can produce large fruits. Some trees such as date palm (*Phoenix dactylifera*) yielding edible fruits, *Carissa carandas* (fruit pickled) and *Capparis decidua* (fruit pickled) are well-known for their salt tolerance. Fruits of coastal *Morinda*

citrifolia are consumed, pickled and used for extracting juice. Large fruits of *Pandanus* are staple food for coastal population of Andaman-Nicobar Islands. They also consume fruits of *Artocarpus heterophyllus* (as vegetable and fruits), *Annona squamosa*, *A. glabra*, local banana (varieties of *Musa acuminata*, *M. textilis*, *M. paradisiaca*), *Ardisia solanacea* and *A. andamanica*. The tuber roots of *Manihot esculentum* along with several *Dioscorea* roots are also consumed by them. Coconut (*Cocos nucifera*) is the life tree for the aborigines. Palmirah palm (*Borassus flabellifer*) is widely used along Andhra coast for toddy, jiggery, vinegar, beverage, as a juice for sugar making, and its radicles (after germination of fruit) are eaten roasted. Many other wild species are consumed as food by locals. For example, seeds of *Cycas rumphii*, fruits of mangrove *Avicennia marina*, fruit pulp of *Balanites roxburghii*, leaves of *Basella album*, fruits of *Opuntia*, *Diospyros ferrea*, *Syzygium cuminii*. *S. samatangense*, *Rhodamania trinervia* and *Ximenia americana* are consumed. Other potentially useful genetic resources as fruit trees include species of *Lycium*, *Santalum acuminatum* (distributed widely in Australia), *Mangifera andamanica* (endemic in Andamans), *M. camptosperm*, and *Coccoloba uvifera*.

Halophytes as Fodder Crops

Halophytes have been used as forage in arid and semiarid parts of the world for millennia. Large number of salt-tolerant species has been incorporated in pasture improvement programs across the globe. Among trees, species of *Acacia* (*ampliceps*, *bivenosa*, *cyclopes*, *eburnea*, *holosericea*, *leucophloea*, *nilotica*, *salicina*, *saligna*, *senegal*, *tortilis*, *victoria*), *Prosopis* (*alba*, *chilensis*, *cineraria*, *glandulosa*, *juliflora*, *pallida*, *tamarugo*) and *Leucaena leucocephala* are widely cultivated in isolation or as agroforestry tree on field boundary or a constituent of silvo-pastoral system. Among other trees grown on salt-affected lands and used as forage for cattle, goats, sheep and camel include *Ailanthus excels*, *Anogeissus pendula*, *Azadirachta indica*, *Balanites roxburghii*, *Calophospermum mopane*, *Cordia rothii*, *Dalbergia sissoo*, *Dichrostachys cinerea*, *Ficus spp.*, *Parkinsonia aculeata*, *Pithecellobium dulce*, *Salvadora persica*, *S. oleoides*, *Tamarindus indica* and *Ziziphus mauritiana*. Among shrubs, saltbushes (species of *Atriplex*) are common throughout the Middle East region and *Atriplex*. *Mairiena brevifolia*, *Halosarica pergranulata*, *H. lepidosperma*, *H.*

Indica subsp *bidens* and Russian thistle (*Salsola iberica*) are common Australian species, now also introduced in many other countries; while *Haloxylon persicum*, *H. salicornicum*, *Kochia indica* and *Ziziphus nummularia* are common Indian forages. Among grasses Kallar grass (*Leptochloa fusca*), Silt grass (*Paspalum vaginatum*), salt grass (*Distichlis spectata*), channel-millet (*Echinochloa turnerana*), cord-grasses (*Spartina alterniflora*, *S. foliosa*, *S. patens*), Rhodes grass (*Chloris gayana*) and wheat grass (*Elytriga elongata*) are common potential sources for grazing. Indian grasses of fodder value include *Leptochloa fusca*, *Chloris gayana*, *C. barbata*, *Aeluropus lagopoides*, *Cynodon dactylon*, *Bothriochloa pertusa*, *Dichanthium annulatum*, *Brachiaria mutica*, *Paspalum conjugatum*, *Panicum laevifolium*, *P. maximum* and many others.

These are also constituents of silvo-pastoral systems developed on waterlogged saline lands in different agro-climatic regions [11,23].

In India, species of *Phragmites*, *Rumex*, *Polygonum*, *Typha*, *Coix*, *Brachiaria*, *Pasalum*, *Echinochloa*, *Scirpus*, *Cyperus*, *Saccharum* and *Vetiveria* are among the predominant herbaceous/grass species and species of *Salicornia*, *Suaeda*, *Haloxylon*, *Salsola*, *Tamarix* and *Ipomoea* are prominent shrubs or under-shrubs found in waterlogged saline situations. *Paspalum vaginatum* has an amazing ability to thrive in wet salty areas. *L. fusca*, *B. mutica* and species of *Paspalum* are excellent fodder grasses, which can be cultivated under waterlogged situations in Indian subcontinent. Species of *Atriplex*, *Kochia*, *Suaeda*, *Salsola*, *Haloxylon* and *Salvadora* are prominent forage shrubs of saline regions and relished by camel, sheep and goats.

Halophytes as Fuel Crops

The criteria for selecting potential genetic resources for use as fuel wood in saline environment may also include [15]: a rapid rate of growth and regrowth after cutting; easy establishment in salty environment; wide adaptation; and if possible, diverse use besides the fuel wood (e.g., wind breaks, livestock fences, nitrogen fixing, shade for forage crops, etc.). The most common genera used as fuelwood include [15]: *Acacia* (*ampliceps*, *crassicarpa*, *cyclops*, *floribunda*, *longiflora*, *oraria*, *pendula*, *pycnantha*, *redolens*, *retinodes*, *saligna*, *sophorae*, *stenophylla*), *Casuarina* (*camaldulensis*, *cristata*, *equistefolia*, *glaucua*, *obesa*), *Eucalyptus* (*angulosa*, *camaldulensis*, *calophylla*, *erythrocorys*, *incrassate*, *halophila*, *occidentalis*, *sargentii*, *spathulate*, *kondininensis*, *largiflorens*, *neglecta*, *tereticornis*, *loxophelba*) and *Prosopis* (*alba*, *articulata*, *cineraria*, *chilensis*, *nigra*, *flexuosa*, *juliflora*, *pallida*, *tamarugo*). In India, *Tamarix articulata*, *Acacia nilotica* and *Prosopis juliflora* are most commonly used. In coastal areas, mangrove and their associate species are commonly used as fuel wood.

Very few plants have been identified as potential source of liquid fuels under saline conditions. Among tree borne oil seeds (TBOS) *Pongamia pinnata* (36% seed oil), *Jatropha curcas* (37%), *J. gossypifolia* (40%), *J. podagrica* (35%), *Aphanomixis polystachya* (38%), *Calophyllum inophyllum* (51%), *Sapium baccatum* (49%) and *Simaruba glauca* (53%) are potential coastal plants [24]. Sugar beet (*Beta vulgaris*) and nipa palm (*Nypa fruticans*) are also among other potential species. The halophytes *Tamarix chinensis*, *Phragmites australis*, *Spartina alterniflora* and species of *Miscanthus* have been evaluated as bio-fuel crops for ethanol production in the coastal zone of China [25]; while many others such as *Halopyrum mucronatum*, *Desmostachya bipinnata*, *Phragmites karka*, *Typha domingensis* and *Panicum turgidum* are grown in coastal regions of Pakistan as source of bio-ethanol [26]. In addition, Kallar grass (*Leptochloa fusca*) has been identified as a source of gaseous fuel and the energy yield per hectare was estimated at 15×10^6 Kcal [15]. Screw pine (*Pandanus fascicularis*), quite predominant along Indian coast, is rich in methyl ether of betaphenyethyl alcohol and used as a perfume and flavouring ingredient. *Simmondsia chinensis* yields oil like sperm whale from its seeds, is viable salt-tolerant

commercial plant for dry regions. Similarly, *Salvadora persica*, *Ricinus communis* and *Pongamia pinnata* yield commercial oils and can be explored economically. *Euphorbia antisiphilitica* has been found a potential petro-crop producing huge biomass on sandy soils irrigating with saline water of EC 10 dS m⁻¹ [27].

Essential Oils

The male flowers of screw pine (*Pandanus fascicularis*) are a source of perfume and other flavouring ingredients. Flowers of winter annual *Matricaria chamomilla* (which can be cultivated with saline water) and *Mentha* (*M. arvensis*, *M. piperita*) both grow on saline and alkali soils, produce essential oil. Dagar [28] evaluated agronomic practices of lemon grass (*Cymbopogon flexuosus*) applying saline irrigation and identified suitable cultivars; Cultivar RRL 16 and OD 58 performed the best followed by *Premna* and OD 19 and rest being comparatively sensitive. Other plants with potential utilization in saline soils for production of essential oils include *Cymbopogon nardus*, *C. winterianus*, *C. martini*, *Tagetes minuta*, *Ocimum sanctum*, *O. kilimandscharicum*, *Anethum graveolens* and *Vetiveria zizanioides*.

Gums, Oils and Resins

Salt-tolerant plants for the production of gums and resins include *Acacia nilotica*, *A. senegal*, *Butea monosperma*, *Sesbania bispinosa*, *S. sesban*, *S. speciosa*, *Plantago crassifolia*, *Althaea officinalis* and cluster bean (*Cyamopsis tetragonoloba*) cultivated with saline water up to 10 dS m⁻¹. The resinous perennial shrubs *Grindelia camporum*, *G. humilis*, *G. stricta*, *G. latifolia* and *G. integrifolia* produce diterpene acid resins. Seed of Jojoba (*Simmondsia chinensis*) contain a unique oil resembling sperm whale can be cultivated with saline water of EC 10 dS m⁻¹. The perennial desert shrub guayule (*Parthenium argenatum*) is a source of natural rubber.

Pulp and Fibre

A number of salt-tolerant plants are being used as source of pulp and fibre. These include species of *Pandanus*, *Hibiscus cannabinus*, *H. tiliaceus*, *Phragmites australis*, *P. karka*, *Juncus rigidus*, *J. acutus*, *Typha domingensis* and grass *Urochondra setulosa*. There are many other grasses and sedges contributing to pulp resources.

Bioactive Derivatives

Valuable extracts from seed, leaves and bark of a number of halophytes have been characterized and used in health industry [14]. Coastal evergreen tree Alexandrian laurel (*Calophyllum inophyllum*) is a source of a complex phenyl coumarin used as Anti-inflammatory agent. The fruits of *Balanites roxburghii*, are a potential source of diosgenin, a precursor for the synthesis of a number of steroidal drugs [15]. Indian neem tree (*Azadirachta indica*) produces oil, used for soap making and its seed extracts are effective insecticides. Oil from mangrove *Cynometra ramiflora* has antibiotic properties and used in skin diseases. Salt-tolerant shrub *Adhatoda vasica* and seed of *Annona glabra* also possess insecticidal properties. Medicinal uses of some halophytes are shown in Table 1.

Table 1: Some important halophytes used as medicinal value.

Species	Medicinal use
<i>Acanthus ilicifolius</i>	In rheumatism, neuralgia, paralysis, asthma and as blood purifier
<i>A. volubilis</i>	Dressing boils and wounds.
<i>Achyranthes aspera</i>	In asthma, renal dropsis
<i>Acrostichum aureum</i>	Applied on wounds and boils
<i>Adhatoda vasica</i>	In asthmatic problems
<i>Aloe barbadensis</i>	Piles, rheumatism, boils and stomach problems.
<i>Barringtonia acutangula</i>	In diarrhoea, toothache
<i>B. racemosa</i>	In cough, asthma, diarrhoea, jaundice
<i>Calophyllum inophyllum</i>	Seed oil in rheumatism, skin diseases and leprosy
<i>Calotropis procera</i>	In skin diseases, tumours, piles, as abortifacient and anticoagulant
<i>Capparis decidua</i>	To cure cough, asthma, inflammations, cardiac troubles and biliousness
<i>Cerbera manghas</i>	In rheumatism
<i>Citrullus colocynthis</i>	In jaundice, rheumatism and urinary diseases.
<i>Clerodendrum inerme</i>	In malarial fever as substitute to quinine
<i>Cress cretica</i>	As tonic, aphrodisiac, stomachic
<i>Cynometra ramiflora</i>	In leprosy, scabies and cutaneous diseases
<i>Heritiera fomes</i>	To cure piles
<i>H. littoralis</i>	In diarrhoea and dysentery
<i>Jatropha curcas</i>	In diarrhoea, toothache, piles, rheumatism and skin diseases
<i>Kochia indica</i>	Cardiac stimulant
<i>Pandanus odoratissimus</i>	In leprosy, scabies, diseases of heart, oil as antispasmodic
<i>Pongamia pinnata</i>	In diarrhoea, cough, leprosy, gonorrhoea, rheumatic pains
<i>Ricinus communis</i>	In boils, sores, lumbago
<i>Salsola baryosma</i> , <i>S. kali</i>	Possess anthelmintic, emmenagogue, diuretic properties; ash for itch
<i>Salvadora persica</i> , <i>S. oleoides</i>	In cough, rheumatism, suppositories, toothache and piles.
<i>Solanum surattense</i>	In cough, asthma, sore throat, rheumatism. fever
<i>Sonneratia caseolaris</i>	As vermifuge
<i>Suaeda fruticosa</i>	As emetic and to cure sores on camel back
<i>Tamarix articulata</i> , <i>T. troupii</i>	In eczema, ulcers, piles, sore throat, diarrhoea, liver disorders
<i>Terminalia catappa</i>	In cutaneous diseases
<i>Thespesia populnea</i>	In stomach trouble
<i>Trianthema portulacastrum</i>	In asthma, amenorrhoea, dropsy, rheumatism, liver problems and as abortifacient
<i>Tribulus terrestris</i>	As tonic, diuretic and in painful micturition and calculous affections
<i>Vetiveria zizanioides</i>	In rheumatism, fever, headache, toothache and as tonic
<i>Withania somnifera</i>	In asthma, cough
<i>X. moluccensis</i> , <i>Xylocarpus granatum</i> ,	In dysentery and breast tumours
<i>Ziziphus nummularia</i>	In skin diseases, cold, cough, biliousness
<i>Zygophyllum simplex</i>	It has cardiac properties and applied in eye diseases

Catharanthus roseus withstands EC of 12 dS m⁻¹ and produces an alkaloid used in the treatment of leukemia [14]. Halophytes *Salsola richteri* and *S. kali* are sources of salsolinol and salsolidine, respectively; and *S. pestifer* is a source of carotene, whereas, *S. pestifer* and *S. gemmascens* are sources of ascorbic and citric acids [15]. A kind of soda is obtained in large quantities from species of *Suaeda*, *Salicornia*, *Salsola* and *Haloxylon*, used in soap making and in glass industry. Seed of *Salvadora persica* and *S. oleoides* yield 40-50% fat, rich in lauric acid and also used in soap industry. Seed oils from salt-tolerant *Azadirachta indica*, *Terminalia billirica*, *T. catappa*, *Calophyllum inophyllum*, *Cynometra ramiflora*, *Pandanus* spp., *Annona glabra*, *Salvadora persica*, *S. oleoides*, *Pongamia pinnata*, *Ricinus communis*, *Salicornia bigelovii*, *Xylocarpus granatum*, *X. mekongensis*, *X. moluccensis*, *Butea monosperma*, *Balanites roxburghii*, *Entada phaseoloides*, *Horsfieldia irya*, *Eruca sativa* (cultivated), *Sisymbrium irio* and *Lepidium sativum* (cultivated) are of medicinal values [10, 29-30] and can be explored for commercial purposes. Many medicinal and aromatic plants such as *Aloe vera*, *Asparagus racemosus*, *Adhatoda vasica*, *Cassia angustifolia*, *Catharanthus roseus*, *Citrullus colocynthis*, *Lepidium sativum*, *Ocimum sanctum*, *Plantago ovata*, *Glycyrrhiza glabra*, *Matricaria chamomilla*, *Cymbopogon flexuosus*, *C. martini* and *Vetiveria zizanioides* are successfully cultivated with saline water (EC up to 10 dS m⁻¹) irrigation [31-35]. Dagar and Singh [11] while exploring biodiversity of saline habitats including of coastal regions of India, listed about 400 salt-tolerant plants of medicinal value based on the uses reported in literature.

While exploring the ethno-botany and plant resources of Andaman-Nicobar Islands, Dagar and Dagar [36] and Dagar and Singh [37] reported several plant species utilized by the aborigines for medicinal purposes. Some common medicinal halophytes found in saline localities include *Acanthus ilicifolius*, *A. volubilis*, *Achyranthes aspera*, *Acrostichum aureum* (fern abundant behind mangroves in tidal zone), *Adhatoda vasica*, *Aloe barbadensis*, *Barringtonia acutangula*, *B. racemosa*, *Caesalpinia bonduc*, *C. crista*, *Calophyllum inophyllum*, *Catharanthus roseus*, *Cerbera manghas*, *Citrullus colocynthis*, *Clerodendron inerme*, *Cressa cretica*, *Cycus rumphii* (Gymnosperm), *Cynometra ramiflora*, *Desmodium umbellatum*, *Heritiera fomes*, *H. littoralis*, *Hernandia peltata*, *Hibiscus tiliaceus*, *Ipomoea pes-caprae* (also ornamental and good sand binder), *Manilcara littoralis*, *Macaranga peltata*, *Ochrosia oppositifolia* (also used as fish poison), *Pandanus* spp, *Pongamia pinnata*, *Ricinus communis*, *Scaevola sericea*, *Scyphiphora hydrophyllacea*, *Sophora tomentosa*, *Tabernaemontana crispa*, *Tournefortia ovata*, *Thespesia populnea*, *Vigna marina*, *Withania somnifera* and *Xylocarpus granatum*. Many of these have been domesticated for their high value products and more may be cultivated after getting their market assured. We are familiar that most of the mangroves are the good source of fuel wood and charcoal and are explored beyond repairs. In recent times, much attention is being given in using these potential resources for cultivating in saline habitats and also as salt-tolerant material for developing potential food crops.

Landscape and Ornamental Plants

Many attractive halophytes can be used as ornamental and landscape plants, especially in areas where water is scarce for irrigation. These may be trees, shrubs, succulents and semi-succulents, biennial and perennial ground cover and lawn grasses. Some of them are reported to tolerate irrigation water with EC of 15 to almost 50 dS m⁻¹ [38]. Plants such as *Batis maritima*, *Conocarpus erectus*, *Eucalyptus sargentii*, *Melaleuca halmaturorum*, species of *Casuarina* and *Ficus*; and the shrubs *Mairreana sedifolia*, *Borrchiea frutescens* and *Clerodendrum inerme* are already being used as landscaping [14]. *Aster tripolium*, *Crithmum maritimum*, *Eryngium maritimum*, *Inula crithmoides*, *Kalidium capsicum*, *Kochia scoparia*, *Suaeda vera*, *Ipomoea stolnifera*, *Limonium auriculaeifolium*, *L. californicum*, *L. cordatum*, *L. cylindrifolium*, *L. ferulacium*, *L. hirsuticalyx*, *L. sinuatum*, *L. vulgare*, *L. spiculata*, *Limoniastrum monopetalum*, *Lotus creticus*, *L. cystisoides*, *Plantago crassifolia*, *Otanthus maritimus*, *Tamarix nilotica*, *T. amnicola*, *T. galica*, *T. africana*, *T. salina*, *T. tetragyna*, *Cistanche fistulosum*, *Atriplex halimus*, *Sesuvium portulacastrum*, and *Noronhia emerginata* are some useful ornamental plants [15,39]. Some annual flowers such as *Chrysanthemum indicum*, *Calandula officinalis*, *Matthiola incana* and *Matricaria chamomilla* can be cultivated with saline water.

Environmental Protection

Most of the mangroves and their associates [30,40,24] play very important role in protecting the coastline and restoration of coastal ecosystem. Mangroves bear a net of aerial roots protecting the coastal area of their habitats from cyclonic tidal waves. They also provide life support system through food web to different organisms including coastal wild life. Animals such as saltwater crocodiles, turtles, water monitor lizards, snakes, wild pig, monkeys, deer, even tiger (in Sunderbans), several indigenous and migratory birds, mud skippers, molluscs, insects and crustaceans take shelter in mangrove ecosystem. Many species such as *Aeluropus lagopoides*, *Clerodendron inerme*, *Clitorea turnesia*, *Fimbristilis littoralis*, *Heliotropium curassavicum*, *Ipomoea pes-caprae*, *Launea sarmentosa*, *Sesuvium portulacastrum*, *Spinifex littoreus*, *Suaeda maritima*, *Zoysia matrella*, etc. are found frequently along sandy beaches and protect sand from erosion. Dagar [10, 23, 41] the role of mangrove vegetation for coastal protection and livelihood security. Tree and grass species grown for sand stabilization in desert areas are dealt in detail by Dagar [42,43] and Dagar and Gupta [44].

Environmental and Economical Sustainability of Biosaline Agriculture

The success and long-term sustainability of any farming system based on halophytes will depend on continued efforts on selecting, domesticating and breeding halophytic crops [45,46]. As is evident from above account, there is already a considerable information available regarding potential species, which can contribute valuable and economic production. Moreover, halophytic germplasm may provide useful salt-tolerant genes for genetic engineering research

and the development of stress tolerant crops [47], particularly in the scenario of climate change. The introduction of halophytes in farming systems will depend to large extent upon the socio-economic needs and climate related adaptation compulsions. The environmental and economical sustainability of saline agriculture largely depends upon:

(i) Bio-reclamation (remediation) of Salt-affected soils using halophytic crops

(ii) Use of saline water for irrigation so that minimum damage is done to soil health, and

(iii) Sustainable and remunerative yield from saline agriculture

Saline agroforestry can also be a potential strategy for sustainable and assured crop production and reducing carbon dioxide in the atmosphere through carbon sequestration in Salt-affected and also waterlogged areas [48,49]. Since the halophytes can reduce the salt content of soil considerably over time [5]. Based on several studies conducted in Indian sub-continent and reported from time to time [50, 28, 2, 3], it can safely be concluded that tree based saline agriculture (biosaline agroforestry) is time tested, sustainable to climate related changes, and economically viable. Some of these examples have been discussed here.

Agroforestry-based Agricultural Systems

Conventional agriculture on highly salt-affected soils and also irrigating with water of high salinity is economically not viable because of low crop yields and physically removal of salts is expensive for most of the farmers [51]. However, saline agroforestry systems may be an alternative land use option for these soils. This is because some tree species are less susceptible to extreme salinity/sodicity as compared to arable crops and these have the capability of removing salts and reclamation of these soils [52,53,27]. Some tree species such as *Casuarina obesa*, *Eucalyptus camaldulensis* and *Tamarix articulata* adapt to waterlogging conditions by developing root aerenchyma and adventitious (nodal) roots [54]. Though many biosaline agroforestry systems have been developed in South Asia and elsewhere in the world [55-60]. Only a few studies have evaluated the economic performance of such systems [61,62]. With respect to environmental performance of these studies emphasis has been given on amelioration of soil and organic carbon content in the soil [63-65], but has not studied other environmental factors, especially the balance of greenhouse gases in these systems. Recently, Wicke [62] explored the greenhouse gas balance and the economic performance (i.e. net present value (NPV) and production costs) of agroforestry and forestry systems on Salt-affected soils based on three case studies in South Asia.

The economic impact of trading carbon credits generated by biosaline agroforestry was also assessed as a potential additional source of income. The greenhouse gas balance showed carbon sequestration over the plantation lifetime of 24 Mg CO₂-eq. ha⁻¹ in

a rice *Eucalyptus camaldulensis* agroforestry system on moderately saline soils in coastal Bangladesh (case study 1), 6 Mg CO₂-eq. ha⁻¹ in the rice wheat *Eucalyptus tereticornis* agroforestry system (trees on boundary only) on sodic/saline sodic soils in Haryana state, India (case study 2), and 96 Mg CO₂-eq. ha⁻¹ in the compact tree (*Acacia nilotica*) plantation on saline-sodic soils in Punjab province of Pakistan. The NPV at a discount rate of 10% was reported to be 1.1 k€ ha⁻¹ for case study 1, 4.8 k€ ha⁻¹ for case study 2, and 2.8 k€ ha⁻¹ for case study 3. According to them, carbon sequestration translates into economic values that increase the NPV by 1-12% in case study 1, 0.1-1% in case study 2, and 2-24% in case study 3 depending on the carbon credit price (1-15 € Mg CO₂-eq). The analysis of the three cases indicated that the economic performance strongly depends on the type and severity of salt affectedness (which affect the type and setup of the agroforestry system, the tree species and the biomass yield), markets for wood products, possibility of trading carbon credits, and discount rate.

Recent research efforts have greatly improved the understanding of biology and management of forestry plantations on saline environments. By adopting reclamation technologies growing halophytes, the salt-affected lands can be productively used for arable agriculture after some time. Worldwide experiences suggest that though the human induced salinity problems can develop rapidly but the hydrological and engineering solutions (through sub-surface drainage) are very expensive. Thus, despite the availability of technical knows how, the rehabilitation of the Salt-affected land is progressing at a very slow pace. Moreover, implementation of these solutions is also constrained due to socio-economic and political considerations. Therefore, agroforestry based technology is considered effective and cheap alternative solution, hence, agroforestry systems are now considered as viable alternatives. Though the salinity and waterlogging stresses can be hostile for the woody tree species, these are known to tolerate these stresses better than the annual arable crop species. Therefore, the existing information is collated here in brief on site specific agroforestry systems and appropriate afforestation technologies for saline and waterlogged environments of the varied agro climatic situations.

Agroforestry in Sodic/Alkali Lands

Though the records of plantations on alkali soils are available from 1874 [66-68], but in India systematic experimentations were initiated only after 1980s after developing pit-auger-hole technique for piercing the hard kankar (calcite) pan present in sub-surface layer of highly sodic soils with pH exceeding 10 [69,70,53]. Based on the performance of tree saplings in alkali soils (pH >9), relative tolerance of some species was in the order: *Prosopis juliflora* > *Acacia nilotica* > *Haplophragma adenophyllum* > *Albizia lebbek* > *Syzygium cuminii* [71]. In another study, Dagar [56] evaluated several tree species and found that *Prosopis juliflora*, *Acacia nilotica* and *Tamarix articulata* recorded good growth and were economically suitable in highly alkali (pH 10.1-10.6) soil.

After 10 years of energy plantation, Singh, et al. [72] observed the maximum biomass by *Prosopis juliflora* (56.5 Mg ha⁻¹) followed by *Acacia nilotica* (50.8 Mg ha⁻¹), *Casuarina equisetifolia* (42.1 Mg ha⁻¹) and *Tamarix articulata* with 41.6 Mg ha⁻¹.

Table 2: Change in soil properties as influenced by trees after 12 years of growth on highly sodic soil [133].

Tree specie	pHs	Organic C (g kg ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
<i>Acacia nilotica</i>	8.5	8.5	14	165
<i>Acacia catechu</i>	8.3	6.7	20	225
<i>Albizia procera</i>	8.3	4.5	9	125
<i>Azadirachta indica</i>	8.5	7.5	12	240
<i>Cassia siamea</i>	8.3	8.5	23	165
<i>Dalbergia sissoo</i>	8.6	6.1	14	210
<i>Eucalyptus tereticornis</i>	7.2	5.3	9	140
<i>Leucaena leucocephala</i>	7.8	5.6	11	210
<i>Morus alba</i>	8.4	6.1	14	210
<i>Terminalia arjuna</i>	8.7	5.8	11	175
Initial soil	>10.0	1.2	6	85

Tree plantations in sodic soil can ameliorate the soil (Table 2) within 10-12 years of growth to the extent that arable crops can be grown after their harvest. This process of amelioration can be hastened if we raise trees in silvo-pastoral mode [53]. Data of long-term growth of trees (20 years) showed that there is only marginal improvement in soil during next 10 years of growth, therefore, to get arable crops from sodic soils, trees may be harvested after 10-12 years of growth. The sodic lands are very poor in forage production under open grazing, but when brought under judicious management after protecting from grazing these could be explored successfully for sustainable fodder and fuel wood production. Grasses such as *Leptochloa fusca*, *Brachiaria mutica*, *Chloris gayana*, *Panicum maximum*, *P. antidotale* and *Panicum laevifolium* were found most promising and successful for these soils and can constitute viable silvo-pastoral system. *L. fusca* could be adjudged the most promising grass for high sodicity (pH > 10), saline and waterlogged soils. This also fixes atmospheric nitrogen and absorbs high quantity of salt, hence helps in quick reclamation of these soils. On an average this grass produced 16-18 Mg ha⁻¹ dry biomass along with *P. juliflora* and *Acacia nilotica* trees [53].

Based on the evaluation of > 60 species (through series of experimentation on sodic soils in Indian sub-continent), it could be concluded that *Prosopis juliflora* was the best candidate for high pH (> 10) sodic soils followed by *Tamarix articulata* and *Acacia nilotica*. Species such as *Eucalyptus tereticornis*, *Terminalia arjuna*, *Salvadora oleoides*, *Cordia rothii* and fruit trees such as *Carissa carandas*, *Emblica officinalis*, *Syzygium cuminii* and *Psidium guajava* could be grown with great success on moderate alkali (pH < 9.5) soil. Wider spaced (row to row 4-5m, plant to plant 4m) tree plantation was accommodated with arable crops in the interspaces. Egyptian clover (*Trifolium alexandrinum*), wheat, onion (*Allium sativum*) and garlic (*Allium cepa*) were grown successfully for three years with fruit trees *Carissa carandas*, *Punica granatum*, *Emblica officinalis*, *Psidium guajava*, *Syzygium cuminii* and *Ziziphus*

mauritiana. Understory intercrops such as fodder grass *Leptochloa fusca*, wheat for grain, and onion and garlic for bulbs could be cultivated profitably [73]. To avoid water stagnation problem in alkali soils during rainy season, Dagar [56] developed raised and sunken bed technology growing fruit trees on bunds and above mentioned arable and forage crops in sunken beds successfully. Another advantage of this technique is that moisture is conserved in sunken beds during lean period.

The Salt-affected black soils (saline/sodic vertisols) also can successfully be cultivated with forest and fruit trees. *P. juliflora*, *Salvadora persica* and *Azadirachta indica* are the most successful tree species for these soils. Among fruit trees, gooseberry (*Emblica officinalis*), ber (*Ziziphus mauritiana*) and sapota (*Achras zapota*) can be grown successfully and are highly profitable on sodic vertisols (ESP 25-60). Following raised and sunken bed technique, fruit trees like pomegranate (*Punica granatum*), Jamun (*Syzygium cuminii*) and goose berry (*Emblica officinalis*) can successfully be grown on raised bunds with rain fed rice during rainy season and suitable winter crops in residual moisture in sunken beds. Among grasses, *Aeluropus lagopoides*, *L. fusca*, *B. mutica*, *C.gayana*, *C. barbata*, *Dichanthium annulatum*, *D. caricosum*, *Bothriochloa pertusa* and species of *Eragrostis*, *Sporobolus* and *Panicum* are among the most suitable for silvo-pastoral system on sodic vertisols. In addition to their economic values, *L. fusca*, *B. mutica* and *Vetiver zizanioides* assimilated high amounts of sodium from soils. During three years, these grasses removed 144.8, 200.0 and 63.5 kg ha⁻¹ sodium from soil, respectively [74].

Aromatic grasses such as palmarosa (*Cymbopogon martini*) and lemon grass (*C. flexuosus*) tolerate moderate sodicity (pH ~9.2) while vetiver (*Vetiveria zizanioides*) withstands both high pH and water stagnation [73]. Medicinal psyllium (*Plantago ovata*) produced 1.47-1.58 Mg ha⁻¹ grain (including husk) at pH 9.2 and 1.03 to 1.12 Mg ha⁻¹ at pH 9.6 showing its potential for cultivation

on moderate alkali soil [75]. *Matricaria chamomile*, *Catharanthus roseus* and *Chrysanthemum indicum* are other interesting medicinal and flower yielding plants for moderate alkali soil [76]. All these crops can be blended suitably as understory inter-crops in agroforestry systems with both forest and fruit trees grown in wider spaces. Mulhatti (*Glycyrrhiza glabra*), a leguminous medicinal crop was found quite remunerative in moderate alkali soil (up to pH 9.6). Besides 2.4-6.2 Mg ha⁻¹ forage per annum from aerial branches after harvesting during winter, a root biomass (medicinal and commercial) of 6.0-7.9 Mg ha⁻¹ could be obtained after three years of growth, Dagar [77] fetching INR 6-8 lakhs ha⁻¹ i.e. 2.0-2.6 lakhs ha⁻¹ (1 lakh=100 thousand; ~63 INR=1\$ in 2015) per annum and the soil was ameliorated in terms of reduction in pH and ESP and increase in organic carbon significantly.

Agroforestry in Saline and Waterlogged Soils

It has been observed that many people to avoid stagnation of water plant trees on bunds in saline soils. It has been found that most of the salt deposit in these bunds and there is huge mortality. Therefore, technique of furrow planting was developed and found successful in waterlogged saline soils [78,23]. Based on long term experiments, it was found that energy plantation of *Prosopis juliflora*, *Tamarix articulata*, *T. traupii*, *Acacia farnesiana*, *Parkinsonia aculeata* and *Salvadora persica* could be raised successfully on saline soils having ECe up to 30-40 dS m⁻¹. Likewise, *A. nilotica*, *A. tortilis*, *A. pennatula*, *Casuarina glauca*, *C. obesa*, *C. equisetifolia*, *Callistemon lanceolatus*, *Eucalyptus camaldulensis*, *Feronia limonia*, *Leucaena leucocephala* and *Ziziphus mauritiana* are suitable for soils with ECe 10-20 dS m⁻¹. [For more details, consult Tomar [78] and Dagar [23].

Dagar Yadav [4] reviewed the results of several experiments and reported that among grasses, *Aeluropus lagopoides*, *Leptochloa fusca*, *Sporobolus helvolus*, *Cynodon dactylon*, *Brachiaria ramosa*, *Dactyloctenium aegyptium*, *Dichanthium annulatum*, *D. caricosum*, *Panicum maximum*, *Digitaria ciliaris* and *Eragrostis* sp. are among most suitable species for silvo-pastoral systems on saline conditions in Indian sub continent. Species such as *Atriplex amnicola*, *A. lentiformis*, *A. undulata*, *Acacia cambage* and *Leptachloa fusca* can produce potential forage biomass on saline soils of ECe 20-30 dS m⁻¹. While many others such as *Sesbania aculeata*, *Leucaena leucocephala*, *Medicago sativa*, *Lolium multiflorum*, *Echinochloa colonum*, and species of *Panicum* tolerate the salinity up to EC 10-12 dS m⁻¹. Samphires (*Halosarcia pergranulata*, *H. lepidosperma* and *H. indica* subsp. *bideris*) and blue bush (*Maireana brevifolia*) are highly salt-tolerant succulent perennial shrubs, which could be grown on waterlogged salt land pastures in Australia. *H. pergranulata* contains about 14% crude protein on oven dry basis and is better suited to sheep grazing [54]. Some of these species have been successfully introduced elsewhere also.

In tidal zones along coast, mangroves can be explored for economic use in saline areas of coastal regions. Some common mangrove and associate species include *Acanthus ilicifolius*, *A.*

volubilis, *Aegialitis rotundifolia*, *Aegiceras corniculatum*, *Avicennia marina*, *A. officinalis*, *Bruguera gymnorhiza*, *B. parviflora*, *B. cylindrica*, *Ceriops tagal*, *C. decandra*, *Cynometra ramiflora*, *C. iripa*, *Excoecaria agallocha*, *Heritiera fomes*, *H. littoralis*, *Kandelia candel*, *Lumnitzera racemosa*, (*L. littoris* in Andamans only), *Nypa fruticans*, *Phoenix paludosa*, *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Scyphiphora hydrophyllacea*, *Sonneratia alba*, *S. apetala*, *S. caseolaris*, *S. ovata*, *Xylocarpus gangeticus*, *X. granatum*. Other associated common salt-tolerant species include *Acrostichum aureum*, *Barringtonia asiatica*, *B. racemosa*, *Caesalpinia bonduc*, *C. crista*, *Calophyllum inophyllum*, *Casuarina equisetifolia*, *Cerbera floribunda*, *Erythrina indica*, *E. variegata*, *Hernandia peltata*, *Hibiscus tiliaceus*, *Intsia bijuga*, *Licuala spinosa*, *Manilkara littoralis*, *Morinda citrifolia*, *Ochrosia oppositifolia*, *Pongamia pinnata*, *Pandanus spp.*, *Scaevola taccada*, *Tabernaemontana crispa*, *Terminalia catappa*, *Thespesia populnea*, *Tournefortia ovata* and *Vitex negundo*. These also provide an important habitat for young stages of commercially important fish and prawns, and as breeding grounds for fish, shellfish and turtles and home for variety of wild life [79,80]. In scenario of climate change and sea level rise rehabilitation of mangrove areas planting mangrove and associate species will not only save the coastal areas from disasters like cyclones and tsunamis but it will sequester huge amount of carbon and protect wild coastal marine life.

Introduction of canal irrigation in arid and semi-arid regions without provision of adequate drainage caused rise in groundwater leading to waterlogging and secondary salinization. Installation of sub-surface drainage is essential to overcome the aforesaid twin problems; however, it is very costly and disposal of saline effluents has inherent environmental problems. Tree plantations for biodrainage, which is 'pumping of excess soil water by deep rooted plants using bioenergy', can be a viable alternative. Heuperman [81] observed that the plantations act like groundwater pumps (tube wells), pumping out water @ 34460 m³ yr⁻¹ or 3.93 m³ hr⁻¹ ha⁻¹ of plantation. Plantations in the Indira Gandhi Nahar Paryojana (IGNP) command in India, was observed to use water @ 3446 mm yr⁻¹, which was about 1.4 Class A pan, without any significant increase in salinity of soils and groundwater.

There are many other evidences also which show that trees help in reducing salinity, lowering water table and checking seepage depending upon their salt tolerance [82]. Several plant species, from salt bush (*Atriplex*) to tall trees like species of *Eucalyptus*, *Casuarina equisetifolia*, *C. glauca*, *Pongamia pinnata* and *Syzygium cumini*, are found suitable for this purpose. The main physiological feature of such vegetation is profuse transpiration whenever the root system meets ground water. Several tree species have been shown to survive and grow in waterlogged and saline soils and being used increasingly to utilize and rehabilitate salt-affected and waterlogged areas [83-85].

One of the most promising tree species used for biodrainage is *Eucalyptus tereticornis* (Mysore gum) which is widely distributed

and fast growing under a wide range of climatic conditions. It grows straight with low shading effect and has luxurious water consumption excess soil moisture conditions. In waterlogged non-saline areas, it can be successfully grown by ridge planting. In saline waterlogged areas, sub-surface or furrow planting is more successful as compared to ridge method [78]. Area under *Eucalyptus* plantation has increased to 20 million ha in the world and its fast growth rate, favourable wood properties, and high carbon sequestration potential makes it a good option for biodrainage [86,87].

Block plantation of *E. tereticornis* along IGNP area, effectively lowered the water table by 15.7m over a period of six years [88]. Likewise, strip plantations at 1m × 1m space on acre line lowered shallow saline water table by 0.85 m during a period of 3 years

Table 3: Harvested dry biomass and carbon sequestration (Mg ha⁻¹) in different parts of clonal *Eucalyptus* after 6 years of growth when grown on bunds with different spacing and as block plantation along canal. (Values in parenthesis are for carbon sequestered).

Plant part	1m × 1m 300 trees ha ⁻¹ *	1m × 2 m 150 trees ha ⁻¹ *	1 m × 3 m 100 trees ha ⁻¹ *	Block (2m × 4 m) 1250 trees ha ⁻¹ *
Timber (main bole)	33.5 (15.5)	19.1 (8.9)	16.7 (7.7)	141.7 (66.5)
Twigs & leaves	2.6 (1.2)	1.5 (0.8)	1.3 (0.4)	9.8 (4.5)
Roots	13.4 (6.1)	8.0 (3.8)	5.4 (2.4)	41.4 (19.6)
Total	49.5 (22.8)	28.7 (13.5)	20.0 (9.5)	192.9 (90.6)

Note: *Number of trees planted per ha (most of the trees survived after gap filling) Source: Dagar et al. [49]

Agroforestry with Application of Saline Irrigation

In most of the dry ecologies due to scarcity of good quality water sustaining agriculture is major problem. The decrease of water availability in developing countries is more serious threat due to burgeoning population pressure and availability of limited arable land for cultivation. An innovative strategy for enhancing land and water availability is the use of salt-affected land and poor-quality water to develop saline agriculture as a practice. In arid and semiarid regions saline aquifers are available in plenty while in coastal areas use of sea water is inevitable. The strategy is not new, as, for example, the use of sea water for crop production in coastal deserts has already been suggested in the last four decades [1] using potential halophytes as crops. But in arid and semi-arid conditions, the use of saline water for irrigation has been limited.

Tomar, Minhas [90], Tomar [91,92], Dagar [93,94] and Dagar [23] have developed technologies for successful establishment and better growth of forest and fruit trees, grasses, arable and non conventional medicinal and aromatic crops in agroforestry system using saline groundwater for irrigation. Several salt-tolerant tree species (planted in furrows used for irrigation in a space of 2m × 2m) like *Tamarix articulata*, *Azadirachta indica*, *Acacia nilotica*, *A. tortilis*, *A. farnesiana*, *A. ampliceps*, *Cordia rothii*, *Cassia siamea*, *Eucalyptus tereticornis*, *Feronia limonia*, *Prosopis juliflora*, *Pithecellobium dulce*, *Salvadora persica*, *S. oleoides* and *Ziziphus mauritiana* could be established using sub-surface planting and furrow irrigation technique on degraded calcareous soil using saline water up to

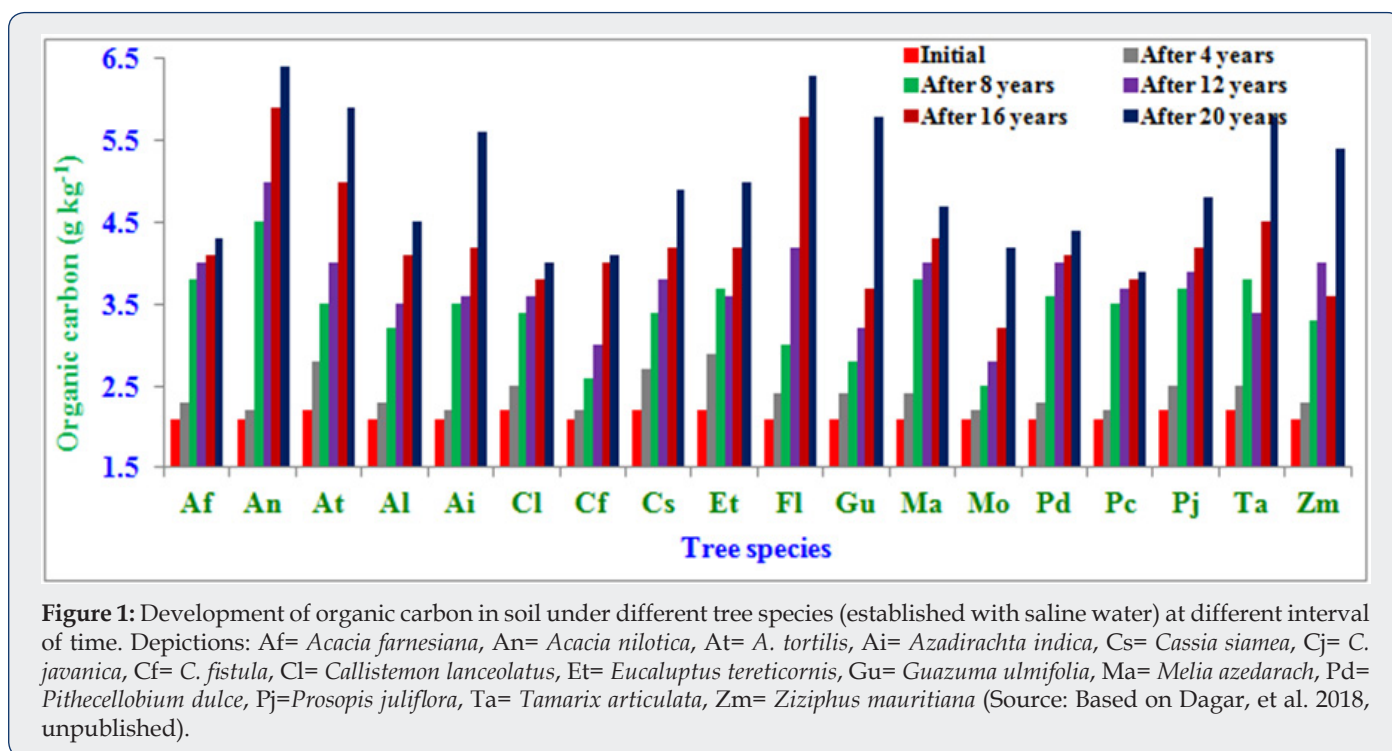
and ~ 2 m after 5 years [89]. The average above and below ground oven dry biomass and carbon sequestration of 5½ years old 240 surviving trees strip plantation reached 24.0 and 8.6Mg ha⁻¹ and 15.5 Mg ha⁻¹, respectively. The results of six years old cloned *Eucalyptus* plantation when raised in different spacings on acre line and as block plantations along canal produced 193 Mg ha⁻¹ biomass as compared to 49.5 Mg ha⁻¹ under 1m × 1m space planting on acre line. These plantations could sequester 9.5 to 22.8 Mg ha⁻¹ carbon in different spaces and 90.6 Mg ha⁻¹ in block plantation after 6 years of plantation (Table 3). The plantations maintained the water table < 2m throughout the growing season and thus helped farmers to cultivate both rice and wheat crops in time and yield was many fold as compared to those farmers who did not plant trees in their fields in the vicinity.

EC of 10-12 dS m⁻¹. Alternate rows were harvested after 5 years; thereafter, alternate trees were harvested after 8 years to give space for growth.

After 20 years of growth trees of many of the species produced good biomass. For example, *T. articulata*, *A. nilotica*, *A. tortilis*, *P. juliflora*, *E. tereticornis*, *A. indica* and *C. siamea* produced 392, 230, 185, 154, 145, 123, and 122 Mg ha⁻¹ above ground biomass, respectively and *A. nilotica*, *Feronia limonia*, *A. tortilis*, *G. ulmifolia*, *T. articulata* and *A. indica* were among the most efficient in improving SOC (Figure 1) to > 5.5 g kg⁻¹ (Dagar, et al. 2018, unpublished). Among tested forage grasses, Tomar [95] cultivated using saline water (EC up to 10 dS m⁻¹) which also could be grown with trees as silvo-pastoral system include *Panicum laevifolium* which produced maximum annual forage dry biomass (16.9 Mg ha⁻¹) followed by *P. maximum* (13.7 Mg ha⁻¹). Among other species growing naturally, *Cenchrus ciliaris*, *C. setigerus*, *Sporobolus spp.*, *Panicum antidotale*, *Dichanthium annulatum*, *D. caricosum*, *Cynodon dactylon*, *Digitaria ciliaris*, *D. decumbense*, *Dactyloctenium aegyptium* and *D. indicum* are prominent. Sufficient forage can be made available from these perennial grasses with one or two irrigations with saline water (EC up to 12 dS m⁻¹) even in the lean period when people are forced to lead nomadic life along with their herds of cattle. One irrigation with saline water during summer improved forage yield of these grasses to 3-5 Mg ha⁻¹. Such use of saline groundwater is applicable for large grazing areas in dry ecologies having saline aquifers which otherwise remain barren. Rye grass (*Lolium sp.*), oat (*Avena sativa*)

and sorghum (*Sorghum* sp), producing satisfactory green forage of good proximate quality even with conjunctive irrigations of saline

drainage effluents and fresh water [96]; these can also be grown successfully with trees.



Among fruit trees, *Carissa carandas*, *Emblia officinalis*, *Feronia limonia*, *Ziziphus mauritiana* and *Aegle marmelos* were found promising. In the inter-spaces, crops such as pearl millet (*Pennisetum typhoides*), cluster bean (*Cyamopsis tetragonoloba*) and sesame (*Sesamum indicum*) during kharif and barley (*Hordium vulgare*) and mustard (*Brassica juncea*) during rabi were found highly profitable [77]. Medicinal crops such as psyllium (*Plantago ovata*), *Aloe vera*, and *Withania somnifera* may find place as inter-crops as these are found doing well in partial shade. Among other non-conventional crops, vasaka (*Adhatoda vasica*), castor (*Ricinus communis*), Dill (*Anethum graveolens*), tara-mira (*Eruca sativa*), periwinkle (*Catharanthus roseus*), vetiver (*Vetiveria zizanioides*) and lemon grass (*Cymbopogon flexuosus*) could be cultivated successfully. Their agronomic practices irrigating with saline water have been standardized [97].

Cassia senna and *Lepidium sativum* could also be cultivated successfully irrigating with saline water of EC 8 dS m⁻¹. All these high value crops can successfully be grown as inter crops with forest or fruit trees at least during initial years of establishment [82]. Dagar [23] and Gururaja Rao [98] advocated that highly saline black soils, both in irrigation commands and coastal areas, can successfully be brought under economic cultivation of halophytes, which can be cultivated both on saline lands and irrigating with saline water. Among trees, *Acacia nilotica*, *Azadirachta indica*, *Salvadora persica*, *Casuarina equisetifolia*, and *Prosopis juliflora* are found most successful. Fruit trees such as pomegranate (*Punica granatum*), *Carissa carandas*, Goose berry (*Emblia officinalis*), and *Ziziphus mauritiana* can be cultivated. Grasses such as *Distichlis spicata*, *Leptochloa fusca* and *Paspalum scrobiculatum* have performed very well in these soils irrigating with saline water (Table 4).

Table 4: Total dry matter production of three grass species irrigated with moderately saline and highly saline water.

Grass species	Total yield (kg ha ⁻¹)*	
	Moderate salinity	High salinity
<i>Distichlis spicata</i>	1444 ^a	817 ^b
<i>Leptochloa fusca</i>	215 ^d	256 ^d
<i>Paspalum scrobiculatum</i>	941 ^b	558 ^c
LSD (p≤0.05)	203	

Note: *Treatment means with the same superscript are not significantly different (p≤0.05).

Other grasses such as *Aeluropus lagopoides*, *Dichanthium annulatum*, species of *Eragrostis* and *Panicum* perform very well. *Salvadora persica* has been found economically viable species in these soils and can withstand very high salinity. Irrigation with saline water at flowering stage has been found very useful. The plant starts bearing during second year of growth and during 4th

and 5th year it could produce about 1800 kg seed per ha with 40-50% seed oil and it gives economic yield when irrigated water of EC up to 55 dS m⁻¹ (Table 5). This species giving economic yield at high salinity also provides eco-restoration and thus showing its niche for highly saline black soils.

Table 5: Seed production and economic returns of *Salvadora* plantation on highly saline black soils (ECe > 55 dS m⁻¹).

Year	Seed yield (kg ha ⁻¹)	Returns (INR ha ⁻¹)		Cost/Benefit ratio
		Gross	Net	
1 st year	Nil	Nil	Nil	Nil
2 nd year	725	3625	365	10.03
3 rd year	978	4890	4340	0.13
4 th year	1580	7900	7250	0.09
5 th year	1838	9190	8440	0.09

Source: Gururaja Rao, et al. [76]

Conjunctive use of saline water with stored surface/canal water either in mixing or cyclic mode forms is another option in these soils. Apart from halophytes, industrially important crops like dill, safflower, and mustard and cash crops like cotton can also be cultivated with saline irrigation in vertisols. In addition, the use of treated effluents from fertilizer and petro chemical industries for irrigation of oilseed crops, forages, flowering plants and bio-fuel species such as *Jatropha curcas* has been found quite remunerative in water scarce areas. Among other important crops species include castor (*Ricinus communis*), mustard (*Brassica campestris*), Tara-Mira (*Eruca sativa*), dill (*Anethum graveolens*), carum (*Trachyspermum ammi*), coriander (*Coriandrum sativum*), and fenugreek (*Trigonella foenum graceum*) are suitable for water-scarce areas.

Many of the groundwaters in arid and semiarid regions also test high in residual alkalinity/sodicity. These waters contain high concentration of dissolved carbonates and bicarbonates of sodium, and carbonates > chloride and sulphates, and high proportion of Na⁺ with respect to Ca⁺² + Mg⁺². The soluble Na percentage is generally >75 and the ratio of divalent cations to total cations is <25 for sodic waters. The alkalinity of water is expressed as sum of cations minus sum of anions other than carbonates. Residual alkalinity is expressed as:

$$[\text{HCO}_3^- + \text{CO}_3^{2-}] - [\text{Ca}^{+2} + \text{Mg}^{+2}]$$

Determines the potential of irrigation water to create alkalinity hazard in the soil. This is expressed as residual sodium carbonate (RSC), used as an index of water suitability for irrigation of crops. In general, waters having high RSC test low in EC; some waters termed as saline-sodic test high in RSC, SAR and EC. Waters having RSC <2.5, 2.5-5.0, and >5 meq L⁻¹ are considered safe, marginal, and unsafe, respectively. Sodium Adsorption Ratio (SAR) is expressed as:

$$[\text{SAR} = (\text{Na}) / \sqrt{(\text{Ca} + \text{Mg})/2}]$$

Choudhary (2014) has reviewed the work done in sodic water irrigation management. Application of gypsum to soil and passing

the sodic water through irrigation channel have been reported to be effective means. Use of organic materials, fertility management and conjunctive use of poor and good quality (when available) waters are also found useful in reducing the effect of alkalinity. The selection of suitable crops which can absorb more sodium is also important while using these waters for irrigation. The agroforestry systems, which are suitable for (as discussed above) are also suitable for using alkali water for irrigation.

Land-Reshaping Techniques for Coastal Waterlogged Saline Areas

Salinity and inundation are inherent problems in coastal areas. Efforts have been made to develop land-shaping techniques for improving drainage, rain water harvesting, salinity reduction and cultivation of plantations and vegetable crops on dykes and fish for livelihood and environmental security [99-101]. These were tested on ~400 ha degraded land in Sundarbans region of Ganges delta and tsunami affected areas in Andaman and Nicobar Islands. The soil in the study area was highly saline (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 land shaping technologies tested on farmers' fields included deep furrow and high ridge cultivation, shallow furrow and medium ridge cultivation, farm ponds, and paddy cum fish culture.

For details see Burman, et al. [100]. For island conditions, Velmurugan [24] have reported several socially and economically viable farming and agroforestry systems. Mangrove-based integrated farming systems towards sea-front having aquaculture as predominant component are interesting features. The system is environment friendly and highly economical. Andaman and Nicobar Islands, being rich in biodiversity, are the veritable treasure house of valuable medicinal, aromatic and dye herbs, trees and shrubs which can be produced organically. There is also good scope for the production of tropical fruits like mangosteen (*Garcinia indica*, *G. cowa*), mango (*Mangifera indica*), guava (*Psidium guajava*), Sapota (*Achras zapota*), custard apple (*Annona squamosa*), pine

apple (*Ananas comosus*), durian (*Durio zibethinus*), dragon fruit (*Hylocereus undatus*), Rambutan (*Nephelium lappaceum*), jack fruit (*Artocarpus spp*), grapefruit (*Citrus paradisi*) and longan (*Euphoria longan*) which have high export potential. Besides, poultry, pig and cattle can be integrated with the crop components for efficient resource recycling and provide stability to farm income.

Some of the suitable multipurpose forest and fruit trees employed in agroforestry of islands include *Acacia auriculaeformis*,

Achras zapota, *Anacardium occidentale*, *Bixa orellana*, *Borassus flabellifer*, *Calophyllum inophyllum*, *Casuarina equisetifolia*, *Cocos nucifera*, *Erythrina indica*, *Ficus spp*, *Garcinia cowa*, *Hibiscus tiliaceus*, *Moringa oleifera*, *Musa paradisiaca*, *Trema tomentosa*, *Morinda citrifolia*, *Pandanus spp*, *Terminalia catappa*, *Pongamia pinnata*, *Ceiba pentendra*, *Gliricidia sepium*, and *Mangifera indica*. For more details see Dagar [27]. Many of these species are salt-tolerant (Table 6).

Table 6: Suitable trees and shrubs for coastal saline sites.

Strees condition	Suitable trees/ shrubs
Very high salinity (ECe > 35 dS m ⁻¹)	All mangrove species, associates e.g. <i>Hibiscus tiliaceus</i> , <i>Salvadora persica</i> , <i>Suaeda spp</i> , <i>Arthrocnemum indicum</i> , <i>Barringtonia asiatica</i> , <i>Manilkara littoralis</i> , <i>Morinda citrifolia</i> , <i>Calodendron inerme</i> , <i>Atriplex spp</i> , <i>Pandanus spp</i> , etc
High salt-tolerant (ECe 25-35 dS m ⁻¹)	<i>Casuarina equisetifolia</i> , <i>C. glauca</i> , <i>Pongamia pinnata</i> , <i>Terminalia catappa</i> , <i>Calophyllum inophyllum</i> , <i>Ficus retusa</i> , <i>Thespesia populnea</i> , <i>Anacardium occidentale</i> , <i>Clerodendron inerme</i> , <i>Acacia amplexans</i> and <i>Cocos nucifera</i> (on specific sites)
Tolerant (ECe 15-25 dS m ⁻¹)	<i>Acacia auriculaeformis</i> , <i>Achras zapota</i> , <i>Bixa orellana</i> , <i>Borassus flabellifer</i> , <i>Leucaena leucocephala</i> , <i>Albizia spp</i> , <i>Areca catechu</i> , <i>Desmodium umbellatum</i> , etc

Seaweed Cultivation and Aquaculture Keeping Mangroves Intact in Coastal Areas

Historically, coastal people have relied on seaweeds for food, minerals, medicine, insulation, fertilizer and fodder. Seaweed farming is the practice of cultivating and harvesting seaweed which is largely carried out as a diversification activity in mariculture. Many of the rocky beaches, mudflats, estuaries, coral reefs and lagoons provide ideal habitats for the growth of seaweeds. Seaweeds refer to any large marine benthic algae that are multicellular, macrothallic, and thus differentiated from most algae that are of microscopic size. They form an important renewable resource in the marine environment as evidenced from its annual production of about 7.0 - 8.0 million Mg of wet seaweed along the coastal regions of the world [102].

Seaweeds belonging to different genera are mainly used for edible and industrial purposes all over the world. In all, 271 genera and 1153 species of marine algae, including forms and varieties have been enumerated from the Indian waters by Krishnamurthy [103]. But, India presently harvests only about 2.5% of macro algae annually compared to a potential harvest of 870 thousand Mg, thus lot of scope for harnessing the unutilized seaweed potential. The edible seaweed are algae that can be eaten and used in the preparation of food that belong to one of several groups of multicellular algae viz., red algae, green algae, and brown algae. Alternatively seaweeds are also harvested or cultivated for the industrial extraction of alginate, agar and carrageenan substances collectively known as hydrocolloids or phycocolloids. Hydrocolloids have attained commercial significance, especially in food production as food additives. The food industry exploits the gelling, water retention, emulsifying and other physical properties of these hydrocolloids. In India seaweeds are used as raw materials for the production of agar, algininate and liquid seaweed fertilizers [104]. The sources of such materials and their cultivation methods are presented in Table 7.

In Lakshadweep, the estimated potential (fresh weight) is reported ranging from 4955 to 10,077 Mg within an average value of 7519 Mg while the Andaman and Nicobar Islands have been partly surveyed by Central Marine Fisheries Research Institute (CMFRI), Cochin and the highest standing crop of 19,111 Mg (fresh weight) was estimated for an area of 40km² in South Andaman. The total potential of the islands stands at 33363 Mg but the level of exploitation is negligible due to policy issues and infrastructural inadequacy [24]. Among them Green algae followed by Red algae constitute the major species composition? Recently, natural incidence of *Kappaphycus alvarezii* has been reported from Andaman Islands. Ecological studies have been undertaken regarding the cultivation of the species and no adverse effects to the ecosystem by the species have been reported. Therefore, large scale cultivation of *Kappaphycus alvarezii* can be undertaken in these Islands.

The red seaweed *Kappaphycus alvarezii* syn. *Euclheuma cottonii*, is the major source of carrageenan, a hydrocolloid used as thickening and stabilizing agent in food, cosmetics, pharmaceuticals etc. The current annual world production of *K. alvarezii* is about 200K Mg and its value added product carrageenan is about 50000 Mg yr⁻¹ [105]. In India, commercial farming of *K. alvarezii* was commenced in 2001 in Tamil Nadu. While fish catching is diminishing day by day and income is not predictable, therefore, *K. alvarezii* farming has become real alternative to the coastal people. Today, seaweeds are a multibillion dollar industry worldwide, providing food, fertilizers, nutritional supplements and valuable phycocolloids like agar, carrageenan and alginate. Although wild harvest supports a significant portion of seaweed industry, there is an ever increasing amount of seaweed production from aquaculture to meet the current demand. Seaweed aquaculture makes up a significant portion of organisms cultured worldwide (~19 million metric tons) with a value of ~US \$5.65 billion [105]. Aquaculture production is dominated by kelps (*Saccharina japonica* and *Undaria pinnatifida*),

tropical red algal species (*Kappaphycus* and *Eucheuma*), nori (including *Porphyra* and *Pyropia* species) and the red algal agarophyte species known as *Gracilaria*.

The average monthly income of a cultivator ranges from INR 15000 to 30000 based on his efforts and volume of cultivation area. Extract obtained from fresh form of *K. alvarezii* is rich source of potassium with other micro and macronutrients. It has also naturally occurring growth hormones and amino acids and can improve crop yields of a variety of crops anywhere from 15 to 40%

[105]. This provides a first ever opportunity to the farmers to have access to organic growth boosters at an affordable price in India. Most of the peninsular India is surrounding by sea, hence must be explored economically. Another interesting area is aquaculture keeping mangroves intact. Mangroves and corals are the base of food chain in marine ecosystem and are useful for seaweed cultivation. These systems along with agroforestry-based farming have potential to meet the food and other requirements of saline coastal ecosystem population, especially in the scenario of climate change (Table 7).

Table 7: Different types of marine algae cultivated in India and their uses.

Type of algae	Scientific name	Cultivation method	Use
Red algae	<i>Gracilaria edulis</i> , <i>G. crassa</i> , <i>G. foliifera</i> and <i>G. verrucosa</i>	Long-line ropes and nets by vegetative propagation	Agar manufacturing
	<i>Gracilaria edulis</i>	Single rope floating raft technique	Hydrocolloids
	<i>Gelidiella acerosa</i>	Bottom-culture method using coral stone as a substratum	Hydrocolloids
	<i>Kappaphycus alvarezii</i> ,	Net bag and raft method	Carrageenan and as food
Brown algae	<i>Sargassum</i> spp., <i>Turbinaria</i> spp. and <i>Cystoseira trinodis</i>	Collection and using nets	Production of alginates and liquid seaweed fertilizers

The island ecosystem offers suitable marine environment for the commercial cultivation of red algae but it is desirable to reduce the bulkiness by preprocessing before sending it to the mainland industries. It is also wise to promote integrated cultivation of shrimps and seaweeds in aquaculture as seaweeds act as scrubbers in reducing nutrient load and cleaning the environment. To utilize seaweed recourses in a sustainable manner, conservation as well as proper husbandry of these resources is a prerequisite. Planned promotion of diversified uses of seaweeds as feed, fodder, feed additives, fertilizers, biocides and antimicrobials will ensure sustained market for seaweeds and provide alternate livelihood to those living in waterlogged-saline areas in Andaman and Nicobar Islands.

Breeding for Tolerance to Salinity, Waterlogging and Inundation

Salt-tolerant plants can be improved into new, salt (stress) resistant crops, or used as a source of genes to be introduced into conventional crop species that in general have their economical production decreased when soil salt levels increase. As discussed earlier, there are number of salt-tolerant plant species including extreme halophytes which have potential as crops of economic importance. Some of these can directly be domesticated while many others can be explored as gene resources to improve into high yielding salt-tolerant crops.

Salinity affects plant survival and growth because ions (mainly Na^+ and Cl^- , but also Ca^{2+} , Mg^{2+} and SO_4^{2-}) increase in the soil solution to concentrations that adversely decrease the availability of water to the plant due to the process of exosmosis. Water logging tolerance in crops is primarily associated with two major physiological traits that enable plants to avoid soil hypoxia [106,107]. These are, to form

root cortex aerenchyma to conduct O_2 and ability to form a barrier for radial oxygen loss that decreases its leakage from root inducing more internal diffusion to the tip. Conventional crop breeding program; for saline, waterlogged and inundation environments; is slow because the plant physiological responses to these stresses are complex with largely unknown genetic basis [108]. Mullan, Bannett Lennard [106] suggested three solutions to overcome the above disadvantages. These include seeking improvement within existing crop genomes; incorporating genetic information from halophytes into crop species; and domesticating the halophytes.

During recent years, some encouraging results have been obtained regarding release of improved salt-tolerant varieties. For example, Kharchia-65 in wheat; and Pokhali and Nona Bokra in rice have given good results. ICAR-Central Soil Salinity Research Institute (CSSRI) in India has developed higher production potential salt-tolerant varieties of rice (CSR 4, CSR 10, CSR 13, CSR 23, CSR 27, Basmati CSR 30, CSR 36 and CSR 43;), wheat (KRL 1-4, KRL 19, KRL 210 and KRL 213), and Indian mustard (CS 52, CS 54, CS 56 and CS 58). Further, three salt-affected varieties of rice (*Sumati*, *Bhootnath* and *Amalmana*) have also been released for coastal agro ecosystem by the Institute's Regional Research Station at Canning Town (West Bengal). They have also developed Canning 7 and Lunishree varieties. CIARI Port Blair has developed CARI Dhan-5 for island conditions. Sources of tolerance to waterlogging (*Westonia*, KRL 19) and elemental toxicities (KRL 35) in wheat have been identified in an ACIAR (Australian Council of International Agricultural Research) and CSSRI collaborative project [4].

Mackill [109], Xu, Mckill [110], Braun [111] and Ismail et al. [112] described the adaptive mechanism in rice under different hydrological stress environments including salinity and submergence in several released land races such as Samba Mahsuri-

Sub1 in Nepal, IR 64-Sub1 in Philippines and Indonesia, BR 11-Sub1 in Bangladesh and Ciherang-Sub1 in Indonesia. Likewise, *Hordeum marinum* has been identified as a source of genes for salt and waterlogging tolerance that can be transferred into bread wheat [113]. Yadav [114] reported dual purpose (fodder and grain) potential of *Hordeum vulgare*, under waterlogged saline conditions, which needs morphophysiological characterization for further exploitation in the wake of expected climatic changes. Besides this, protocols have been standardized for in vitro callus transformation in variety F1D 2967 for developing transgenic wheat with enhanced heat tolerance.

From Andaman and Nicobar Island several wild relatives of crop plants are collected and characterized in order to benefit

Table 8: Important wild relatives of crop plants found in Andaman & Nicobar Islands and their desirable traits.

Wild plants	Botanical name	Desirable traits
Khaariphall	<i>Ardisia solanacea</i> and <i>A. andamanica</i>	Salinity tolerant, grows even in waterlogged soils
Khaarikhajoor	<i>Phoenix paludosa</i>	Salinity tolerant
Legume	<i>Vigna marina</i>	Salinity tolerant
Rice	<i>Oryza indandamanica</i>	Drought tolerance
	<i>Black Burma (Oryza sp)</i>	Tolerance to salinity and aluminium toxicity
Pond apple	<i>Annona glabra</i>	Salinity tolerant, can be used as root stock
Noni	<i>Morinda citrifolia</i>	Salinity tolerant and adapted to hot, humid conditions
Knema	<i>Knema andamanica</i>	Can be used as root stock for Nutmeg to provide water stress tolerant
Banana	Varieties of <i>Musa acuminata</i> , <i>M. paradisiaca</i> , <i>M. textilis</i>	Drought tolerant
Rudraksh	Varieties of <i>Elaeocarpus sphaericus</i> and many spp of <i>Elaeocarpus</i>	Basic material to improve fruit quality
Betel	Many varieties of <i>Piper betel</i> , <i>P. caninum</i> and other spp of <i>Piper</i>	Base material to improve leaf quality, drought and disease tolerant
Mango	<i>Mangifera andamanica</i> , <i>M. camptosperma</i>	Root stock, disease and drought tolerant

Spices under organic management have tremendous potential in these islands but suffer from water stress during dry period. Experiments on grafting of cultivated nutmeg (*Myristica fragrans*) on *Knema andamanica* (of same family) rootstock have shown 20-30% success (Rema) and further studies revealed that such grafts were less affected by the water stress [103]. Further research on reducing the incompatibility will pave the way for development of nutmeg for rainfed conditions. A number of wild relatives of different commercial crops have also been reported to occur in the islands and further efforts are needed to conserve and utilize them to develop suitable varieties with desirable traits. Despite the low number of released cultivars for salt and waterlogging tolerance, there exists a large resource of potential germplasm for increasing the genetic base of crop plants. Colmer [115] listed 38 species as possible source of salt tolerance in Triticale, with examples from the *Aegilops*, *Elytrigia*, *Elymus*, *Hordium*, *Leymus*, *Thinopyrum* and *Triticum* species.

Munns [116] screened 54 *Triticum turgidum* tetraploids comprising the subspecies *durum*, *turgidum*, *polonicum*, *turanicum* and *carthlicum*; and identified large and useful genetic variations for improving the salt tolerance in durum wheat. In another project, around 3000 key rice germplasm has been evaluated for tolerance

from potential genes from them (Table 8). Fruit species such as *Khaariphall (Ardisia solanacea* and *A. andamanica*), *Khaarikhajoor (Phoenix paludosa)* and legume species *Vigna marina* are known to grow luxuriantly in coastal saline soils. *Oryza indandamanica*, a wild rice species reported from these islands, is considered to have physiological traits for drought tolerance (Gautam). Noni (*Morinda citrifolia*) is adapted to wide range of soil conditions and Rakshak is a promising variety of Noni tolerant to soil salinity. *Annona glabra*, commonly called as pond apple is observed to be tolerant to salinity and hence could be employed as a rootstock for other cultivated species of this group. A popular aromatic landrace Black Burma can be used as a donor for tolerance to salinity and aluminium toxicity in rice (Mandal).

to submergence, drought and salinity. Six short duration and seven medium and long duration popular rice varieties of Cauvery basin were grown during summer to assess the performance under higher temperature as summer season experienced 3-4°C higher than the growing season. Among the tested varieties; ADT 38, ADT 48, CO 43, ADT 36, ADT 37 and BPT 5204 withstood higher temperature and gave higher yields compared to others [117]. This indicates that these varieties can be recommended for the further warmer climate. Legumes are usually salt sensitive but the salt tolerance of *Vigna marina* along beaches of Andamans has encouraged scientists to inculcate salt-tolerant genes in green gram (*Vigna radiata*). In future, we can look towards transferring salt-tolerant genes from mangroves to cultivated food crops and fruit trees. Some attempts have been made in this direction by MS Swaminathan Research Foundation, Chennai, India.

Inference

With decreasing availability of arable land and fresh water for meeting the food requirement of ever-increasing population, we are bound to face the problem of sustainable development of agriculture. Therefore, utilization of salt-tolerant lands and poor-quality waters in modern agriculture is inevitable. For this, we

need innovations in biosaline agriculture by using these lands and salt-tolerant (halophytic) germplasm to develop new crops of high economic importance. Rising temperatures, increased climate variability and extreme weather events could significantly add to the problem having impact on food production, especially in developing countries including India, in the coming decades. The adverse impacts are likely to be more pronounced in already stressed salt-tolerant and drought-prone semi-arid to arid regions of the world [118-132].

Climatic events like cold wave, heat wave, drought, and floods have demonstrated the significant potential of weather factors to influence the production of food crops. Due to sea level rise more areas will be affected by salinity and waterlogging. Therefore, there is an urgent need for using modern science combined with indigenous wisdom of the farmers to enhance the resilience of agriculture to climate change. Development of multiple stress tolerant varieties using wild stress tolerant germplasm, domestication of wild halophytes as food and high value crops, and efficient and diverse agroforestry-based farming systems, which can help in mitigating the adverse impact of climate change and variability. Comparative to conventional crops and glycophytes, the stress tolerant halophytes can withstand the climate related changes in a better way. Further, alternate land use systems like agroforestry and other biological carbon capture systems can also help in both adaptation and mitigation of climate change.

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DOI: [10.32474/SJFN.2018.01.000115](https://doi.org/10.32474/SJFN.2018.01.000115)



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