Land Degradation Due to Salinity, Extent of Losses in Crop Yield and Strategies for Management

B. K. Bandyopadhyay*, B. Maji and T. D. Lama

ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, South 24 Parganas -743329, West Bengal

Introduction

Out of the total geographic area of 328.7 million hectares in India, an estimated area of 146.82 million hectares suffers from various kinds of land degradation. Watershed areas, river corridors and rangelands have been extensively disturbed due to land degradation. Situation is frequently so bad that even cessation of land abuse may no longer be capable of bringing about self restoration of these lands. Adoption of inappropriate soil and crop, land and irrigation management practices has exacerbated the processes of land degradation resulting in rapid expansion of degraded lands in the country (Kiran *et al*. 2009). Among all land degradation due to erosion (water and wind erosion) and salt accumulation (saline and sodic soils) are on rapid increase as they are highly prone to management practices and climate change. According to Jamil *et al.* (2011) more than 50% of the arable land in the world will be degraded due to salinity by the year 2050. The task of providing food security to our country's burgeoning population is becoming increasingly difficult. This challenge needs to be met in the face of changing consumption patterns, impacts of climate change and degradation of the finite land and water resources. Per capita availability of land resource is rapidly declining in relation to annual population growth of about 1.4% in the country. Increasing GDP growth is expanding urbanization and industrialization and, therefore, more and more of agricultural lands are being converted for non-agricultural uses. Increasing human population and reduction in land available for cultivation are two threats for agricultural sustainability (Shahbaz and Ashraf 2013) in days to come. India supports 18 % of the world human population, 15 % of the global livestock population, but endowed with only 2.4 % of world land area (Mythili and Goedecke 2016). Thus, India has to face harder challenges in future to meet its food requirement in view of expanding land degradation. Globally, about 15% of the total land area of the world has been degraded by physical and chemical degradation including soil salinization (Wild 2003). According to Wild (2003)

*Corresponding author: Head, ICAR-CSSRI, RRS, Canning Town, and Former Emeritus Scientist (ICAR) e-mail: bimalbkb@gmail.com

global food production will need to increase by 38% by 2025 and by 57% by 2050, respectively if food supply for the growing world population is to be maintained at current levels. Throughout the world most of the normal (non-degraded) lands have been cultivated and expansion into new areas is rarely possible or desirable. In countries like India where agriculture supports the livelihood of majority of people the contribution of agriculture to national GDP is on decline (Table 1) in spite of substantial increase in agricultural production as the growth rate in agriculture is lagging behind the other sectors.

Table 1. Agriculture GDP in India as a percentage of GDP at 2004-05 prices

Year	Agriculture GDP as % of GDP			Percentage Growth of GDP at 2004-05 Prices		
	Agriculture	Industry	Services	Agriculture	Industry	Services
2004-05	16.0	27.9	53.0	-	-	-
2005-06	15.5	28.0	53.7	5.5	9.7	10.9
2006-07	14.7	28.7	54.0	4.1	12.2	10.1
2007-08	14.3	28.7	54.4	6.3	9.7	10.3
008-09	13.4	28.1	56.1	-0.3	4.4	10.0
2009-10	12.3	28.3	57.1	0.4	9.2	10.5
2010-11	12.4	27.9	57.5	9.5	7.6	9.7

(Source: Agricultural Statistics at a Glance, 2016)

With increasing trend of land degradation the relative contribution of agriculture to national economy will further decline leading to loss of huge man-days and increased food insecurities.

Land Degradation Process

Land degradation may broadly be defined as ‘any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience’. In short, land degradation is a process of diminishing the productive capacity of a land. Land degradation is intrinsically linked with the degradation of other natural resources like, soil, water, forests and biosphere. Land degradation thus, encompasses the whole environment with individual factors like, soils, water resources, forests, grasslands, croplands, biodiversity and the climate. Schematic diagram of major degradation processes is presented in Fig. 1. It is clear from the figure that land degradation may be of physical, chemical and biological in nature. Population explosion, intensive cultivation, over exploitation of natural resources, industrialization, urbanization, deforestation, over-grazing, shifting cultivation, over mining of soil, poorly managed irrigation projects, unscientific crop cultivation practices, etc. are the major causes of land degradation in India. The advent of Green revolution in India, in mid sixties, has led to increased use of pesticides which has not only polluted the atmosphere but also has caused a significant decline in floral and faunal population of the soil, which are responsible for the maintenance of soil fertility.

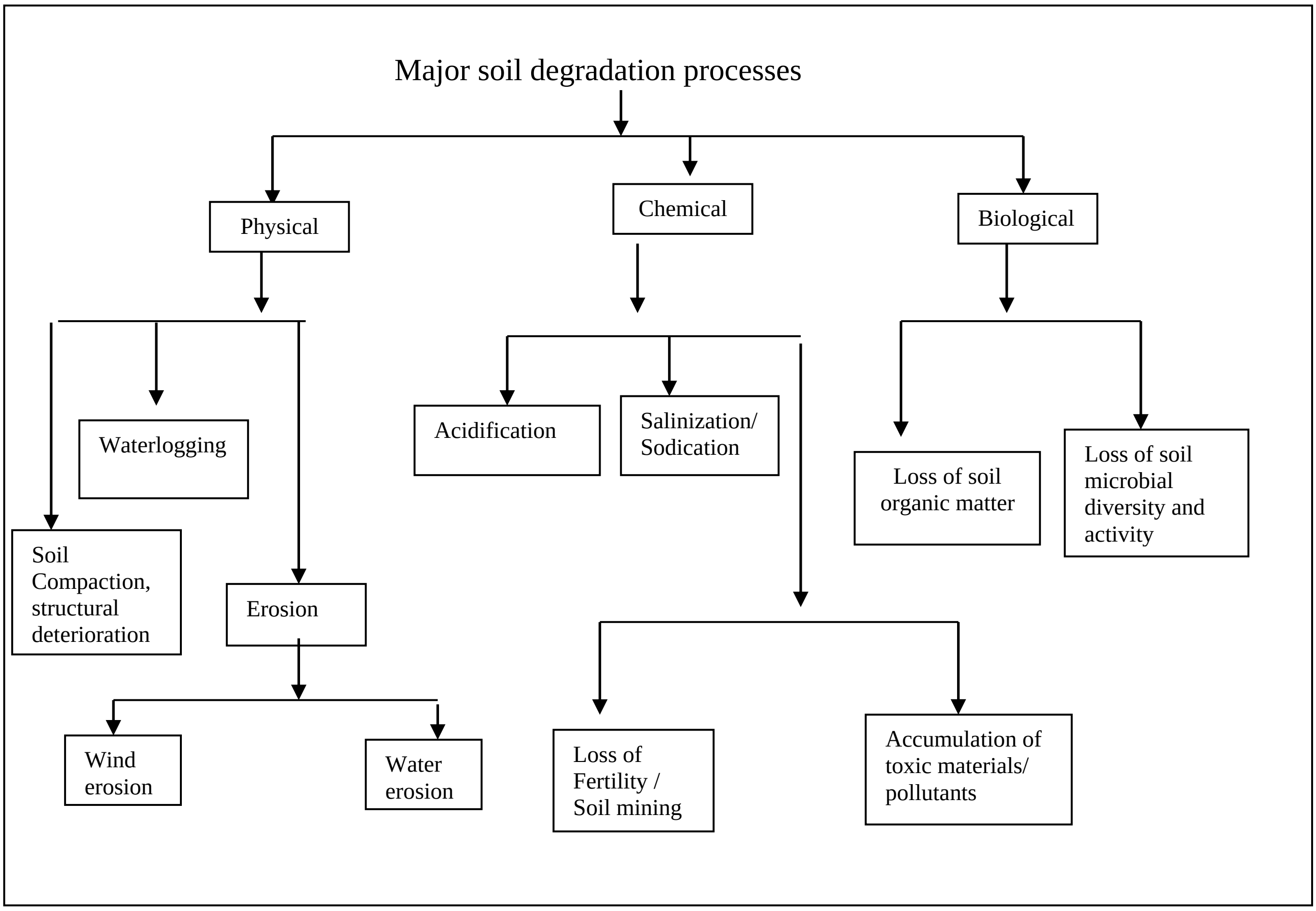

Fig. 1. Schematic diagram of major soil degradation processes

Over use of nitrogenous fertilizers (primarily urea) with meagre application of other nutrients for cultivation of high yielding crop varieties has led to soil acidity, nutrient imbalance and abusive mining of soil. Almost no use of organic manures declined the soil microbial activity and destroyed soil structure due to which the soil became prone to erosive forces of water and wind. Improper management of irrigation systems without proper drainage often resulted in rising of groundwater table which caused secondary salt accumulation in soil, turning huge areas of fertile lands into salt affected lands.

Extent of Degraded Salt Affected Land

Degraded lands occupy about 45% of the total geographic area in India (Table 2). Physical degradations like water and wind erosion combined occupy about 70% of the total degraded land in India followed by chemical degradations due to acidity and excess salt accumulation which together occupy about 15 %. Soils degraded due to excess salt accumulation are termed as salt affected soils which include saline, sodic and saline-sodic soils.

Table 2. Land degradation in India

Sr. No ..	Causes of land degradation	Area affected (in M ha)	Percent of total degraded area	Percent of total geographic area
1	Water Erosion	93.68	63.80	28.57
2	Wind Erosion	9.48	6.46	2.88
3	Water Logging	14.30	9.74	4.35
4	Salinity / Alkalinity	5.95	4.05	1.71
5	Soil Acidity	16.03	10.92	4.96
6	Complex Problems	7.38	5.03	2.26
	Total Degraded Land	146.82	100	44.67

(Source: Bhattacharyya *et al*. 2015)

It has been estimated that more than 50% of the arable land of the world will be salinized by the year 2050 (Jamil *et al.* 2011). Throughout the world salt affected soils extensively occur in arid and semiarid regions (Eynard *et al.* 2005). Among the different regions, Middle East has the largest salt affected lands (189 M ha) followed by Australia (169 M ha), North Africa (144 M ha), and the former USSR (126 M ha) (Wicke *et al*. 2011). Salt affected soils also extensively occur in areas where irrigation is practiced without proper natural or artificial drainage system because of which enough water does not seep through soil to leach out salts from soil. According to Allison (1964) about one-third of agricultural land in arid and semiarid regions of the world exhibits some degree of soil salinity. Based on the FAO/UNESCO soil map of the world and many other maps, data, and materials available at that time, Szabolcs (1989) estimated that total saline and sodic soils in the world to be 932.2 million hectares (Table 3), distributed over 100 countries extending over all the continents. It amounts to nearly 7 % of total land area or approximately 33 % of the potential arable land area of the world. According to a more recent report published by FAO in 2000, the total global area of salt-affected soils was 831 million hectares (Martinez-Beltran and Manzur 2005). UNEP (1992) estimated that there is about 1030 million ha of salt affected in the world out of which 412 million ha are affected by salinity and 618 million ha by sodicity.

As per Wicke *et al*. (2011) the global extent of salt affected land is 1128 M ha. Majority of these soils are saline (60%) while sodic and saline-sodic soils account for 26 % and 14 %, respectively. Squires and Glenn (2011) estimated that 60 million ha (about 20 per cent) of the total irrigated lands in the world (301 million ha) are salt affected, of which 35 million ha are located in four countries *viz*., India (20 million ha), China (7 million ha), United States (5.2 million ha) and Pakistan (3.2 million ha). According to Ghassemi *et al.* (1995) salt-affected soils occupy more than 20% of the global irrigated area (310 million ha) due to improper irrigation management. This percentage has increased with time (Metternicht and Zinck 2003; Patel *et al.* 2011) and in some countries, salt-affected land occurs on more than half of the irrigated land. There is an increasing trend of area under salt-affected soils in the irrigated areas from 45 million hectares (ha) in 1990 (Ghassemi *et al*. 1995) to 62 million ha in 2013 (Qadir *et al*. 2014). According to Qadir *et al*. (2014; 2015), salt-induced land degradation has been on the rise and every day the world is losing about 2,000 hectares of land due to salinity. Extensive areas of salt affected soils are present in the Aral Sea Basin in Central Asia, Indo-Gangetic Basin of India, Indus Basin of Pakistan, Chinese Yellow River Basin, Euphrates Basin, Australian Murray-Darling Basin and San Joaquin Valley in the United States.

According to study by FAO-AGL (2000) salt affected soils occupy 24% of the land in Bangladesh, 26% of the 16 M ha of irrigated land in Pakistan, 25% of the land area in Hungary, 22% land in Argentina, 60% of the cultivated lands in the Northern Delta in Egypt, 25% of irrigated lands in Mexico, almost 20% of irrigated land in India, Iran, Turkey and Australia. In China 30% of the irrigated and 21% of the rained arid lands are salinized (Dregne *et al.* 1996). In North and Latin America about 20% of irrigated land is salt affected (Halvorson 1990). Salt affected soils also extensively occur in the coastal regions of the world. The predicted increase of the sea level due to thermal expansion of seawater ranges from 15 cm to > 50 cm by the year 2100 (Warrick *et al.* 1996). The rise of seawater is likely to worsen salinity problems in coastal areas due to sea water inundation of lands and rise of groundwater rich in salts.

In India, out of 6.74 million ha of salt affected soils (Table 4) sodic soils constitute 66% (3.77 M ha) and saline soils constitute 44% (2.96 M ha) (Mandal *et al*. 2009). About 40% of total salt affected soils in India are present in the Indo-Gangetic plain (Fig. 2) extending over Punjab, Haryana, Uttar Pradesh, Bihar, Delhi, besides the arid and semi arid regions of Rajasthan, Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Madhya Pradesh. Of the total saline soils (2.95 M ha) in the country, inland saline soils occupy 1.71 M ha and coastal saline soils occupy 1.24 M ha. Coastal salt affected soils are present in all the coastal states, union territories and island groups.

Table 3. Global distribution of saline and sodic soils

Continent	Areas in million ha		
	Saline	Sodic	Total
South America	69.4	59.6	129.0
Africa	53.5	27.0	80.5
South Asia	83.3	1.8	85.1
North and Central Asia	91.6	120.1	211.7
Southeast Asia	20.0	–	20.0
Europe	7.8	22.9	30.7
Australasia	17.4	340.0	357.4
Total	351.5	581.0	932.2

Source: Szabolcs (1989)

Table 4. Extent of salt affected soils in India

Sl. No.	State	Total Geographical Area	Inland Saline Soils (ha)	Coastal Saline Soils (ha)	Sodic Soils (ha)	Total (ha)	Salt affected soil (%)
1.	Andhra Pradesh	27504500	-	77598	196609	274207	10.30
2.	Andaman & Nicobar Islands	824900	-	77000	-	77000	9.33
3.	Bihar	9416300	47301	-	105852	153153	1.62
4.	Gujarat	19624400	1218255	462315	541430	2222000	11.32
5.	Haryana	4421200	49157	-	183399	232556	5.26
6.	J & K	22223600	-	-	17500	17500	0.08
7.	Karnataka	19179100	1307	586	148136	150029	0.78
8.	Kerala	3885200	-	20000	-	20000	0.51
9.	Maharashtra	30771300	177093	6996	422670	606759	1.97
10.	Madhya Pradesh	30825200	-	-	139720	139720	0.45
11.	Odisha	15570700	-	147138	-	147138	0.94
12.	Punjab	5036200	-	-	151717	151717	3.01
13.	Rajasthan	34223900	195571	-	179371	374942	1.10
14.	Tamil Nadu	13006000	-	13231	354784	368015	2.83
15.	Uttar Pradesh	24092800	21989	-	1346971	1368960	5.68
16.	West Bengal	8875200	-	441272	-	441272	4.97
	Total	269480500	1710673	1246136	3788159	6744968	2.50

(Source: Based on data of ICAR-CSSRI)
(www.cssri.org/index.php?option=com_content&view=article&id=122...)

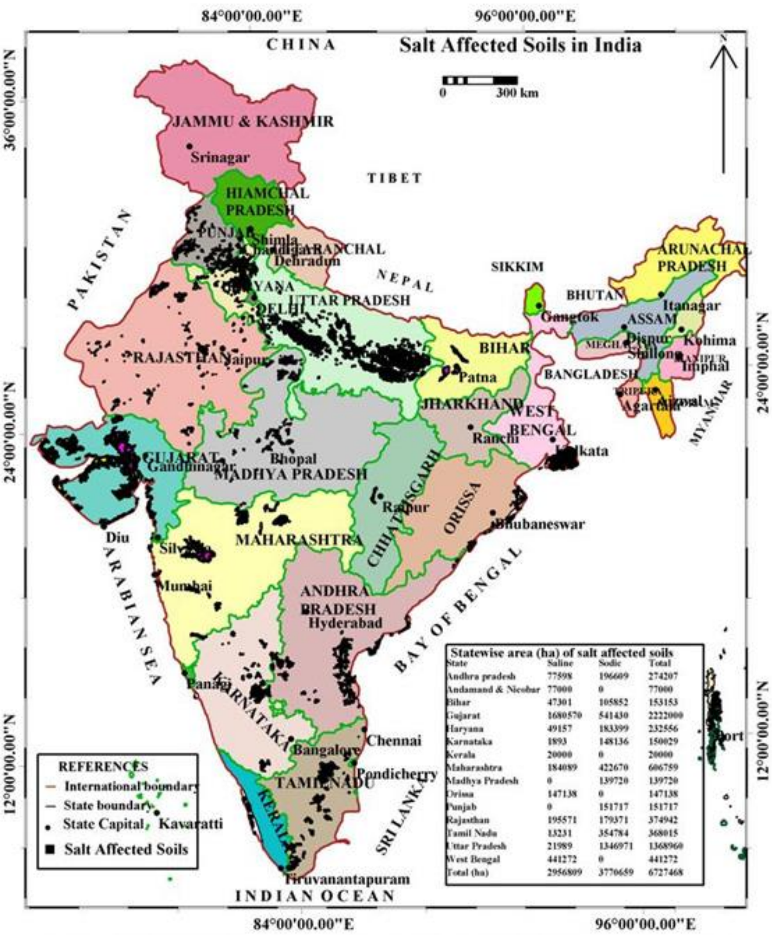

Fig.2 Map of salt affected soils in India

According to Sharma *et al*. (2014), the present area under salt-affected soils (6.74 million ha) in country is most likely to increase by three folds to about 20 million ha by 2050 due to expansion in area under irrigation and over exploitation of the natural resources. It has been observed that salt-affected soils are prevalent in areas with poor quality waters and the problem of poor quality waters is likely to increase in coming years (Sharma *et al*. 2011; Sharma and Singh 2015).

Salt-Affected Soils and their Formation

Excess accumulation of salts in soil poses enormous problems for agriculture. Salt-affected soils can be defined as soils on which the growth of most crop plants is limited by an excess of easily soluble salts (Rengasamy 2006). Saline soils contain excessive amount of either soluble salts or exchangeable sodium or both affecting crop yields. Salts are considered easily soluble when they are more soluble than gypsum ($CaSO_4.2H_2O$) in water. Salts may include chlorides, sulphates, carbonates and bicarbonates of sodium, potassium, magnesium, and calcium. The salt concentration in the soil solution is usually measured by the electrical conductivity (EC) of saturation extract (ECe) of soil. Traditionally, a soil is saline if ECe of the soil solution is greater than 4 dSm^{-1} (SSSA 1997). However, for sensitive plants growth may be severely affected at much lower levels of ECe than 4 dS m^{-1}. Considering this the Soil Science Society of America proposed to lower the boundary level of ECe at 2 dSm^{-1} (Bohn *et al.* 1985) for saline soils, but the traditional limit of 4 dSm^{-1} is widely accepted (Soil Survey Staff 1999) till date. The critical ECe value for reduction of crop yield may vary over time, space, crop, soil-water regime, soil type, climate, etc. (Abdel-Ghany *et al.* 1996; Maas 1986).

Salt affected soils having exchangeable Na percent (ESP) more than 15% due to dominance of sodium carbonate and sodium carbonate salts in soil are termed as sodic or alkali soils (US Salinity Staff Laboratory 1954). In sodic soils ECe may be high or relatively low. When the ECe of sodic soil is more than 4 dSm^{-1} it is termed as saline-sodic or saline-alkali soils. For delineating saline-sodic and sodic soils it requires the measurement of the exchangeable Na percentage (ESP) or the Na adsorption ratio (SAR) in addition to the ECe (SSSA 1997). The critical level of ESP (> 15%) for reduction of crop yields depends on many interacting factors. In Australia, soils are considered sodic if the ESP is > 6 % instead of > 15 % (Rengasamy and Olsson 1991). Considering the management issue, a group of workers in India have classified the salt affected soils into two groups: saline soils (saline+saline-sodic) and sodic soils instead of three groups viz. saline, saline-sodic and sodic since, saline-sodic soils and saline soils have similar management problems.

Land degradation due to salts involves two major processes: *Salinzation* and *Sodication*. Salinization is the process of accumulation of salts in soil while, sodication is the process of increasing exchangeable Na^+ in soil following accumulation of salts. Environmental factors favorable to salinization/ sodication are arid and semiarid climates where the evapo-transpiration loss is much greater than precipitation (aridic, ustic or xeric soil water regimes). Salt accumulation in soil may lead to the formation of a *Salic* soil horizon (SSSA 1997). Often the term salinization is used to indicate the process of secondary salinization, consequent upon human activities like, irrigation. Irrigation water is usually more saline than rainwater. The concentration of irrigation water increases several fold in soil due to evapo-transpiration loss of moisture from soil. Even with good drainage the soil solution is on the average 3-4 times more saline than the irrigation water and without proper drainage it may 10-20 times or more saline (Bernstein 1974). For soils with saline groundwater table at shallow depth the capillary rise of saline water tends to concentrate salts in surface horizon. In coastal flat basins saline groundwater table is usually close to surface making the soil saline. Intrusion of saline sea water is also common in coastal areas. Further, disposal of industrial wastes, excessive fertilization, and use of saline water for irrigation may lead to salinization (Bohn *et al.* 1985). In Thailand salinization is in large part related to large-scale shrimp culture with saline water on arable lands (FAO-AGL 2000).

Soils irrigated with water high SAR (sodium adsorption ratio) and RSC (residual sodium carbonate) may lead to formation of sodic soils having high exchangeable Na^+ on clay colloids. Sodication is a due to precipitation of divalent salts, primarily calcium salts from soil solution. Salt precipitation depends on the relative solubility of the ionic species present in soil solution. The most soluble ions stay in solution at high concentrations. Sodium forms the most soluble salts that stay longer in solution with increasing salt concentration in soil solution while, less soluble salts (Ca^{2+} and Mg^{2+} salts) precipitate, particularly, when the pH is higher. As the relative concentration of Na^+ ion increases in soil solution, Na^+ becomes the dominant cation resulting in replacement of divalent cations (Ca^+ and Mg^+) on clay colloids by Na^+ and rise in pH of soil due to formation of NaOH, $NaHCO_3$, Na_2CO_3, etc. salts. Clay colloids rich in exchangeable Na^+ disperse, particularly, when excess soluble salts are leached out from soil. The dispersed clay colloid leads to breaking of soil structure. *Argilluviation* of dispersed clay forms a *Natric* soil horizon which is the characteristic horizon for sodic soils. Desalinization in absence of enough divalent cations is the major cause of secondary sodication.

Effect of Salts on Plants

Reduction in yield of crops in salt-affected soils results primarily from alteration of various metabolic processes in plants under salt stress. Negative effects of excess of salts in the soil solution include increased osmotic pressure limiting water uptake (physiological drought), high pH (in case of sodic soils) and ionic competition limiting nutrient uptake (Meiri 1984; Letey *et al*. 1990; Munns 2002). The first signs of salt stress are wilting, yellowed leaves, and stunted growth. In a second phase the damage manifests as chlorosis of green parts, leaf tip burning, necrosis of leaves, and oldest leaves display scorching (Shannon and Grieve 1998). Under prolonged stress, the leaves turn greenish-blue in color, with thickened and waxy leaf surface (Ayers and Westcot 1985). Excess salts in root zone causes not only the osmotic stress but also disrupts cell ion homeostasis by inducing both the inhibition in uptake of essential elements such as K^+, Ca^{2+}, and NO_3^- and the accumulation of Na^+ and Cl^- (Paranychianakis and Chartzoulakis 2005).

Salt stresses are also ion-specific. Specific ion toxicities result from the accumulation of sodium, chloride, and/or boron in the tissue of transpiring leaves to damaging levels. Imbalances of ions causes disorders in enzyme activities, membrane permeability and metabolic activities in the plant (Hasegawa *et al*. 2000; Murphy *et al*. 2003). Accumulation of injurious ions may affect photosynthesis, protein synthesis, enzyme activities, and damage chloroplasts and other organelles in plant (Taiz and Zeiger 2002). Deficiencies of several nutrients and nutritional imbalances in plant may be caused by the higher concentration of Na^+ and Cl^- in the soil solution derived from ionic competitions like, Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^-/NO_3^- , etc. in plant tissues (Grattan and Grieve 1992). The effect of salinity on reduction of plant growth is considered to be a time dependent. Munns *et al*. (1995) proposed a two-phase model to depict the response of plant growth to salinity over time. The first phase is very rapid and growth reduction is ascribed to development of a water deficit, while the slow second phase is due to the accumulation of salts in the shoot at toxic levels. However it is difficult to access the relative importance of the two phases as they overlap each other.

Salinity has been found to affect photosynthesis by decreasing CO_2 availability as a result of diffusion limitations of cell membrane (Flexas *et al*. 2007) and a reduction of the contents of photosynthetic pigments (Delfine *et al*. 1999; Alvino *et al*. 2000; Saleh and Maftoun 2008; Ashraf and Harris, 2013). There is a decrease in the total photosynthetic capacity of the plant due to reduced leaf growth and inhibited photosynthesis, limiting its ability to grow (Netondo *et al.* 2004; Yeo 2007). Salinity stress results in decreased growth and development of crop plants in terms of biomass, leaf area, root growth and ultimately crop yield (Djanaguiraman *et al*. 2003; Sairam and Tyagi 2004; Rahman *et al*. 2008; Rogers *et al*. 2009; Razzaque *et al.* 2009; Giuffrida *et al*. 2013).

In sodic soils, excess exchangeable Na^+ may lead to swelling and/or dispersion of soil colloids resulting in breaking of soil structure. These result in poor water infiltration and permeability, poor aeration, inadequate root respiration, poor root penetration, hard crust formation and formation of compacted subsoil layers. Soils rich in exchangeable Na^+ ion show stickiness when wet, hard when dry. High pH in sodic soils causes solubilisation of soil organic matter resulting in loss of organic matter from soil. Plant growth on sodic soils are poor due to adverse soil physical condition, reduced nutrient availability, imbalanced nutrient uptake and toxicity of specific ions, particularly, Na^+ ion.

Extent of Loss in Crop Yield

Crop losses caused by salinity/ sodicity are difficult to assess but is estimated to be substantial and is expected to increase with time (Vijayvargiya and Kumar 2011). The cost of salinity/ sodicity in terms of loss in agricultural production is estimated conservatively to be about US$ 12 billion a year, and is expected to increase as soils are further affected (Ghassemi *et al*. 1995). In addition to this enormous financial loss in agricultural production, there are other serious impacts of salinity on infrastructure, water supplies, employment, soil structure, stability of communities, etc. The global income loss due to salinity was about US $11.4 billion per year in irrigated areas and US $1.2 billion per year in non-irrigated areas as reported in 1996 (Dregne *et al*. 1996). The inflation-adjusted cost of salt-induced land degradation in 2013 was estimated at US $ 441 per hectare, yielding an estimate of global economic losses at US $ 27.3 billion per year (Qadir *et al.* 2014). The study by IWEH (2014) indicated that in Indus Basin in Pakistan, wheat grain yield losses ranged 20-43 per cent with an overall average loss of 32 per cent, whereas for rice, the crop yield losses accounted to 36-69 per cent with an overall average loss of 48 per cent. Even in the Colorado River Basin of United States annual economic loss of salt-induced land degradation in irrigated areas was estimated at US $ 750 million.

Land degradation poses considerable challenge to agricultural growth and poverty reduction in India. The estimates made by various workers indicated that loss of production in India due to salinity and alkalinity alone was 0.67 million tons (0.2 % of GDP) in 1989 which rose to 3.80 million tons (0.3 % of GDP) in 1994 (Mythili and Goedecke 2016). The major affected area is Indo-Gangetic Basin. The land degradation due to salinity in Indo-Gangetic basin could result in crop yield losses for wheat, rice, sugarcane and cotton up to 40 per cent, 45 percent, 48 per cent, and 63 per cent, respectively (Table 5). In addition, there were employment losses of about 50 to 80 man-days ha^{-1} along with 20-40% increase in human health problems and 15-50% increase in animal health problems (Tripathi 2009; Qadir *et. al.* 2014). According to Brandon *et al*. (1995), the loss in crop production due to salinity in India amounts to 6.2 million tons (FAO data) and 9.7 million tons (Indian data). In North West India, a farm level study by Datta *et al*. (2004) revealed that the per hectare income loss due to different salinity level ranged from 963 to 2,166 rupees (5-11 %) in paddy and 1,146 to 3,851 rupees (6-19 %) for wheat (Table 6). The loss on income was higher in wheat as compared to paddy. According to Samra *et al*. (2006) the productivity losses due to secondary salinization were to the extent of 42%, 38% and 61 % in rice, wheat and sugarcane, respectively.

Table 5. Comparative evaluation of crop yields from salt-affected and non-affected (normal) lands in the Indo-Gangetic Basin in India

Crop	Crop yield (t ha^{-1})		Yield loss (%)*
	Normal land	Salt-affected land	
Rice	3.99	2.18	45
Wheat	2.59	1.57	40
Cotton	1.63	0.61	63
Sugarcane	63.68	33.02	41

(Source: Qadir *et al.* 2014)

Table 6. Crop wise estimate economic loss at different salinity level

Salinity Level (EC_e)	Absolute level income loss (Rupees/hectare) on		Percentage wise economic loss from the existing income level	
	Paddy	Wheat	Paddy	Wheat
8	963	1146	4.96	5.54
12	1506	2186	776	10.56
16	1882	3145	970	1519
20	2166	3851	1117	18.60

Source: Datta *et al*. (2004)

Sharma *et al*. (2015) estimated that the loss in annual crop yields in India due to salinity was about 5.66 million tons valued at 80.02 million rupees. Among the states, the production losses were highest in Gujarat (2.73 million tons) followed by Maharashtra (0.92 million tons) and West Bengal (0.89 million tons). The share of cash crops, cereals, oilseeds and pulses were 43.38 %, 41.58 %, 10.4 % and 4.19 %, respectively in the total crop production losses. Cereal accounted for the highest monetary loss (30.23 billion rupees) followed by oilseeds (22.87 billion rupees) and cash crops (20.02 billion rupees).

Strategies for Management of Salt Affected Soils

There are several strategies for effective management of salt affected lands (Sen *et al.* 2000). The most important of those are: (i) drainage management, (ii) irrigation management, (iii) cultivation of salt tolerant crops, (iv) use of amendments for reclamation (v) nutrient management, (vi) land shaping and rain water harvesting and (vii) Brackish water aquaculture. The application of one or more of these techniques will depend on the location of the farm, farm size, climate, economic capability of the farmer, suitability of the technique for the farm, etc.

(i)Drainage Management

Saline soils can be reclaimed by leaching the excess salts from soil through ponding the land with good quality water followed by drainage of excess water (Rhodes 1974). Drains may be surface or subsurface. For surface drains, depending on soil, land, groundwater characteristics and economic capacity of the farmer, surface drainage channels are dug out at specified depth and spacing with provision for pumping out of drainage water collected in field open wells. In areas affected with secondary salinization, subsurface drainage technology has been identified as a potential and effective technology to overcome the twin problems of water logging and salinity (Gupta 2002). The system consists of mechanical installation of perforated PVC pipes covered with synthetic filter, at specific spacing and depth below soil surface as per the design. Drainage water containing salts are collected in open wells and are thrown away by pumping (Chaudhari 2013). This technology has been widely successful in salinity affected areas of several states like Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra, Madhya Pradesh and Karnataka where about 1,10,000 ha waterlogged saline soils have been reclaimed and put under crop production. In such reclaimed saline lands, considerable increases in crop yields have been obtained (45% in paddy, 111% in wheat and 215% in cotton) (Sharma and Singh 2015). In low lying coastal areas land should first be protected from saline water inundation by suitable embankments (Rao 1991) followed by installation of suitable surface/ subsurface drains suited for the area and pumping out the drainage water collected in open wells.

(ii)Irrigation Management

The presence of limited quantity of good quality water and preponderance of saline ground water makes irrigation management a challenge for salt affected areas. With the development of technological options, poor quality water can also be safely used. It is possible to maintain a high level of soil moisture, and low level of salts and exchangeable sodium in rhizosphere with appropriate irrigation technique and scheduling. Irrigated agriculture can be highly sustainable and profitable with better irrigation practices (Tyagi 2003) such as, adoption of partial root zone drying methodology, and drip/ micro-jet, sprinkler and pitcher irrigations to optimize use of water. Improved irrigation techniques are more efficient than the conventional flood irrigation methods as relatively less amount of water is required for irrigation. *Dorvu* irrigation technique which involves skimming of fresh water found floating over the saline water has been found to be very successful in areas with light texture soil (Singh 2005). The spread of dry land salinity can be contained by reducing the amount of water passing beyond the roots. This can be done by introducing deep rooted perennial plants that continue to grow and use water during the seasons that do not support annual crop plants. This may restore the balance between rainfall and water use, thus preventing rising water tables and the movement of salt to the soil surface (Manchanda and Garg 2008).

(iii)Land Shaping and Rain Water Harvesting

Extensive areas of the coastal regions in India receive high monsoon rains. In many of these areas, lands are low lying, salt affected and drainage congested. The lands are subjected to submergence in monsoon season, while they remain dry with high soil salinity during remaining period of the year as rainfall during non-monsoon months is very limited. As a result, lands remain fallow during non-monsoon period as there is hardly any irrigation source (Bandyopadhyay *et al*. 2011). The lands are mostly mono-cropped growing rice in monsoon season. A major portion of the rain water received during monsoon season is lost as runoff to the sea. Experiments have shown that excess rain water in monsoon months can be harvested in farm channels/ farm ponds created through different land shaping techniques. There different kinds land shaping techniques are: farm ponds, deep furrow & high ridge, broad bed & furrow, etc. Water stored in such structures in farm can be used for irrigation and pisciculture. The elevation of a portion of farm land can also be raised with dugout soil received from making of ponds/ channels. The raised land is used for multiple crops cultivation, instead of mono-cropping, throughout the year using the harvested rain water as source of irrigation for enhancing farm productivity (Bandyopadhyay *et al*. 2009). Large numbers of demonstrations in farmers’ fields in coastal areas have shown that by adoption of land shaping technologies, the net incomes of farmers were increased by more than five times (Burman *et al*. 2015).

(iv)Use of Amendments

Sodic soils can be reclaimed by application of amendment like gypsum or equivalent materials. Powdered amendments are thoroughly mixed with soil followed by ponding of land with good quality water. Water is allowed to leach through the soil and subsequently drained out. Application of chemical amendments along with organic manures such as green manure, farmyard manure, poultry manure, municipal solid waste compost, rice straw, etc., are very useful and this will reduce the dose of chemical amendments besides improving the soil physical condition of sodic soils. Gupta and Abrol (1990) in a review discussed reclamation of sodic soils in details. It has been shown that instead of full dose of gypsum, application of 50% or even 25% dose of gypsum with appropriate agronomic practices can produce good yield of crops on sodic soils. Many low-cost industrial by-products such as press-mud and distillery spent wash, etc. are also used as amendments for reclamation of sodic soils (Rangaraj *et al*. 2007). Saline soils with high acidity (acid sulphate/ acid saline soils) are present in coastal areas of West Bengal, Odisha, Kerala, Andaman & Nicobar Islands, etc. (Bandyopadhyay and Maji 1995; Maji and Bandyopadhyay 1995; Mongia *et al*. 1989). Application of lime and higher doses of phosphatic fertilizers along with green manure is highly beneficial for amelioration of such soils (Maji and Bandyopadhyay 1996; Burman *et al*. 2010).

(v)Nutrient Management

Most of the salt affected soils are deficient in nitrogen and a major portion of the applied N fertilizer is lost through volatilization (Sen and Bandyopadhyay 1987; Swarup 1994). Zinc deficiency is also wide-spread in salt affected soils, particularly, in sodic soils. Application of Zn containing fertilizers (commonly zinc sulphate) is necessary to rectify Zn deficiency. Reclamation of sodic soils improves their Zn availability. Phosphorus deficiency is common in coastal acid sulphate/ acid saline soils. Integrated application of inorganic fertilizers along with organic manures has been found to improve not only the nutrient status of soil but also the soil physical condition and quality of salt affected soils. Recycling of organic wastes and use of bio-fertilizers, viz., *Rhizobium* cultures may play a significant role in nutrient management of salt affected soils (Kundu and Pillai 1992; Bandyopadhyay and Rao 2001; Bandyopadhyay *et al.* 2006).

(vi)Salt Tolerant Crops and Varieties

Using the salt-tolerant crops is one of the most important strategies for management of salt affected soils. Crops and their varieties vary widely in their tolerance to salinity and sodicity. Worldwide, extensive research is being carried out, to develop strategies to cope up with salinity/ sodicity and other abiotic stresses, through development of salt and drought tolerant varieties. Although a lot of attempts have been made for development of salt tolerant plants by transgenics, complete success is not yet achieved. The existence of salt-tolerant plants, *halophytes*, and differences in salt tolerance among the varieties/ species of *glycophytes* indicate that there is a genetic basis to salt tolerance in plant (Yamaguchi and Blumwald 2005).

Tolerant crops and varieties can produce satisfactory yield even under high salinity/ sodicity. Tolerant crops will also allow use of poor quality water for irrigation. Cotton and barley can produce satisfactory yields at much higher salinity levels than corn and soybeans because certain crops can make osmotic adjustments that enable them to extract more water from a saline soil. Farming systems can also be changed to incorporate perennial plants in rotation with annual crops (phase farming), in mixed plantings (alley farming, intercropping), or in site-specific plantings (precision farming). Evolving efficient, low cost, easily adaptable techniques, shifting the crop calendars, resource management practices, etc. are very important for management of salinity/ sodicity or other abiotic stresses (Venkateswarlu and Shanker 2009). In recent years, attention is being paid worldwide to accommodate the salt tolerant *halophyte* plants of industrial importance for highly saline degraded areas including coastal marshes. Some oil yielding *halophyte* species such as *Salicornia bigelovii, Salvadora persica, S. oleoides, Terminalia catappa, Calophyllum inophyllum* and species of *Pandanus* are important and can be grown in highly saline areas irrigating with sea water or water of high salinity (Arora *et al*. 2013).

(vii)Brakishwater Aquaculture

The importance of simultaneous development of both agriculture and fisheries has been well recognized (Halwart and Gupta 2004; Pandey *et al*. 2005). Brackishwater aquaculture has great potentiality as there are vast resources of both surface and brackish water in the country as well as vast world-wide market potentials. In coastal areas where cultivation of normal crops is difficult due to low lying nature of land, soil-water salinity and frequent saline water inundation of land with brackishwater, fish cultivation has great scope to increase the productivity of these lands (http://www.fao.org/fishery/ countrysector/naso_india/en). Brackishwater aquaculture in coastal areas will be more and more important in coming days in view of sea-level rise due to climate change since, vast lands in coastal areas is predicted to be under sea water inundation. Brackishwater aquaculture in coastal areas, with or without mangrove vegetation, may be important source for production of common fish, shellfish, finfish and seaweed. Most of the brackish-water aquaculture (particularly the shrimp farms) has developed in coastal areas under mangrove ecosystem which promotes growth of brackishwater fishes. Brackishwater fish cultivation along with prawn has the potential to fetch very high income and provides ample scope for employment generation in degraded salt affected areas (Sharma and Singh 2015; Mitra 2013; Subba Rao and Mantri 2006). Seaweed cultivation is also a potential area and has emerged as an attractive proposition to harness the productivity of poorly drained saline lands (Sharma and Singh 2015). In India, seaweeds are being used for industrial production of agar and alginate and as a fertilizer. However, it is yet to be utilized on a large scale for various purposes (Dhargalkar and Pereira 2005). Seaweed cultivation provides several other opportunities such as carbon sequestration, provision of breeding grounds for fish and shellfish, pollution abatement and diversified uses as animal feed and fertilizers (NAAS 2003).

Epilogue

Soil is a very precious natural resource; even a handful of soil cannot be created. Soil degradation causes huge productivity losses in agriculture and leads to degradation of the whole ecosystem. In the present era, all the natural resources like air, water, soil and the entire ecosystem is under threat of degradation on account of excessive human interferences. Soil is the victim of rapid degradation as more and more agricultural lands are being converted into non-agricultural uses like, urbanization, industrialization, structures and road constructions, while, there is demand for more agricultural production to meet the increasing requirements of burgeoning population. This is particularly true for countries like India where population growth rate is very high. Unscientific use of available normal lands for quick bumper increase in production and profits without caring for soil health has lead to rapid degradation of soils in India. Irrigation projects have been developed in wide areas of the country for more production from land. This is particularly true for arid and semiarid regions where crop production is possible only with irrigation. Underground waters have been lifted injudiciously and river waters have been diverted to facilitate irrigation, while, no attention has been given to educate farmers for using only judicious amount of limited water resources and to develop proper drainage of land. Rampant use of irrigation water has resulted in rise of groundwater table. As consequent, vast areas of fertile land in the country has been degraded into salt affected unproductive lands due to secondary salinization. Excess lifting of underground water and diversion of river waters have created several other ecological problems. Sea level rise following global warming is expected to further complicate salinity problem in coastal areas due to sea water inundation of vast areas of coastal land. It is now required that all-round measures are to be taken urgently to arrest land degradation of any form. Lands degraded due to salinity are to be used judiciously for sustainable high production and regeneration. Land reclamation, appropriate improved irrigation technique, suitable drainage method to keep the groundwater table below critical depth, growing of suitable tolerant crops/ varieties, land shaping with rainwater harvesting, appropriate agronomic & nutrient management practices and alternate use of land under highly degraded situations are some of the useful field techniques to enhance the productivity of degraded salt affected lands. It is hoped that in years to come it will be possible to check land degradation due to salinity more effectively and higher sustainable production will be obtainable from degraded salt affected lands through use of advanced research tools by application of nano-technology, bio-technology, geo-informatics, etc.

References

Abdel-Ghany, M.B., Abdel-Dayem, M.S. and Nasralla, M.R. (1996) Impact of drainage on groundwater table soil salinity and crop yield. In: *Proceedings of 6th Drainage Workshop on Drainage and the Environment.* pp 706-717. 21-23 April 1996, International Commission on Irrigation and Drainage, Ljubljana, Slovenia

Agricultural Statistics at a Glance (2016) Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture, and Farmers Welfare, Govt. of India, New Delhi.

Allison, L.E. (1964) Salinity in relation to irrigation. *Advances in Agronomy* **16**, 139-180.

Alvino, A., D'Andria, R., Delfine, S., Lavini, A. and Zanetti, P. (2000) Effect of water and salinity stress on radiation absorption and efficiency in sunflower. *Italian Journal of Agronomy* **4**, 53-60.

Arora, S., Bhuva, C., Solanki, R.B. and Rao, G.G. (2013) Halophytes for bio-saline agro-forestry and phyto-remediation of coastal saline lands. *Journal of Soil and Water Conservation* **12**, 252-259,

Ashraf, M. and Harris, P.J.C. (2013) Photosynthesis under stressful environments: An overview. *Photosynthetica* **51**, 163-190.

Ayers, R.S. and Westcot, D.W. (1985) Water quality for agriculture. *FAO Irrigation and Drainage Paper 29*, FAO, Rome.

Bandyopadhyay, B. K. and Maji, B. (1995) Nature of acid soils of Sundarbans delta and suitability of classifying them as acid sulphate or potential acid sulphate soils. *Journal of the Indian Society of Soil Science* **43**, 251-255.

Bandyopadhyay, B.K. and Rao, D.L.N. (2001) Integrated nutrient management in saline soils. *Journal of the Indian Society of Coastal Agricultural Research* **19,** 35-58.

Bandyopadhyay, B.K., Burman, D. and Mandal, S. (2011) Improving agricultural productivity in degraded coastal land of India - experiences gained and lessons learned. *Journal of the Indian Society of Coastal Agricultural Research* **29**, 1-9.

Bandyopadhyay, B.K., Burman, D., Majumder, A., Prasad, P.R.K., Dawood, M. Sheik and Mahata, K.R. (2006) Integrated nutrient management for coastal salt affected soils of India under rice-based cropping system. *Journal of the Indian Society of Coastal Agricultural Research* **24**,130-134.

Bandyopadhyay, B.K., Burman, D., Sarangi, S.K., Subhasis Mandal and Bal, A.R. (2009) Land-shaping techniques to alleviate salinity and waterlogging problems of mon-cropped coastal land for muti-crop cultivation. *Journal of the Indian Society of Coastal Agricultural Research*. **27**, 13-17.

Bernstein, L. (1974) Crop growth and salinity. In *Drainage for Agriculture, Agronomy, 17* (J. van Schilfgaarde, Ed.). pp 39-54. ASA, Madison, WI, USA.

Bhattacharyya, R., Ghosh, B.N., Mishra,P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K. M. and Franzluebbers, A.J. (2015) Soil degradation in India: challenges and potential solutions. *Sustainability* **7,** 3528-3570.

Bohn, H.L., McNeal, B.L. and O'Connor, G.A. (1985) *Soil Chemistry*. John Wiley & Sons, New York, USA.

Brandon, C., Hommann, K. and Kishor, N.M. (1995) The cost of inaction: valuing the economy wide cost of environmental degradation in India. *Paper presented at the UNU Conference on the Sustainable Future of the Global System*, Tokyo, Japan, October 16-18, 1995, pp 46-55.

Burman, D., Bandyopadhyaya, B.K. and Mahanta, K.K. (2010) Management of acid sulphate soil of coastal Sundarban region: observations under on-farm trial. *Journal of the Indian Society of Coastal Agricultural Research* **28**, 8-11.

Burman, D., Mandal, S., Bandopadhyay, B.K., Maji, B., Sharma, D.K., Mahanta, K.K., Sarangi, S.K., Mandal, U.K., Patra, S., De, S., Mandal, B., Maitra, N.J., Ghosal, T.K. and Velmurugan, A. (2015) Unlocking production potential of degraded coastal land through innovative land management practices: a synthesis. *Journal of Soil Salinity and Water Quality* **7**, 12-18.

Chaudhari, S.K. (2013) Best practices and procedures of saline soil reclamation systems in India. In: *Best Practices and Procedures of Saline Soil Reclamation Systems in SAARC Countries* (T.R. Gurung and A.K. Azad, Eds.), pp 40-104. SAARC Agriculture Centre (SAC), Dhaka, Bangladesh.

Datta, K. K., de Jong, C. and Rajashekharappa, M.T. (2004) Implication of land degradation on crop productivity - some evidences from saline areas in north-west India. *Indian Journal of Agricultural Economics* **59**, 151-163.

Delfine, S, Alvino, A., Villani, M.C. and Loreto, F. (1999) Restrictions to carbon dioxide conductance and photosynthesis in spinach leaves recovering from salt stress. *Plant Physiology*. **119**, 1101-1106.

Dhargalkar, V.K. and Pereira N. (2005) Seaweed: promising plant of the millennium. *Science and Culture* **71**, 60-66.

Djanaguiraman, M., Senthil, A. and Ramadass, R. (2003) Assessment of rice genotypes for salinity tolerance at germination and seedling stage. *Madras Agriculture Journal* **90**, 506-510.

Dregne, H.E., Xiong, Z. and Xiong, S. (1996) Soil salinity in China. *Desertification Control Bulletin* **28**, 28-33.

Eynard, A., Lal, R. and Wiebe, K. (2005) Crop response in salt-affected soils. *Journal of Sustainable Agriculture* 27, 5-50.

FAO-AGL. (2000) *Global Network on Integrated Soil Management for Sustainable Use of Salt-Affected Soils*. FAO-AGL, Land and Plant Nutrition Management Service (http://www.fao.org/ag/AGL/agll/spush).

Flexas, J., Diaz-Espejo, A., Galmes, J., Kaldenhoff, R., Medrano, H and Ribas-Carbo, M. (2007) Rapid variations of mesophyll conductance in response to changes in CO_2 concentration around leaves. *Plant Cell and Environment* **30**, 1284-1298.

Ghassemi, F., Jakeman, A.J. and Nix, A.H. (1995) *Salinization of Land and Water Resources: Human Causes, Extent, Management and Case Studies*. CABI Publishing, Wallingford, England.

Giuffrida, F., Scuderi, D., Giurato, R. and Leonardi, C. (2013) Physiological response of broccoli and cauliflower as affected by NaCl salinity. *Acta Horticulturae* **1005**, 435-441.

Grattan, S.R. and Grieve, C.M. (1992) Mineral element acquisition and growth response of plants grown in saline environments. *Agriculture Ecosystems and Environment* **38**, 275-300.

Gupta, R.K. and Abrol, I.P. (1990) Salt-affected soils: their reclamation and management for crop production. *Advances in Soil Science* **11**, 223-288.

Gupta, S.K. (2002) A century of subsurface drainage research in India. *Irrigation and Drainage Systems* **16**: 69-84.

Halvorson, A.D. (1990) Management of dryland saline seeps. In: *Agricultural Salinity Assessment and Management*, *ASCE Manuals and Reports No. 71* (K.K. Tanji, Ed.), pp 372-392. ASCE, New York, USA.

Halwart, M. and Gupta, M.V. (2004) *Culture of Fish in Rice Fields*, FAO, Rome and World Fish Center, Malayasia.

Hasegawa, P.M., Bressan, R.A., Zhu, J.K. and Bhonert, H.J. (2000) Plant cellular and molecular responses to high salinity. *Annual Review of Plant Physiology* **51,** 463-499.

IWEH (Institute for Water, Environment and Health of the United Nation University) (2014) https://plus.google.com/share?url=http%3A%2F%2Ffood.ndtv.com%2Fhealth%2Fsaltdegradation-affects-crop-yield-in-india-696369.

Jamil, A., Riaz S., Ashraf M. and Foolad M.R. (2011) Gene expression profiling of plants under salt stress. *Critical Reviews in Plant Sciences* **30**, 435–458.

Kiran, R.K., Rani, M. and Pal, A. (2009) Reclaiming degraded land in India through the cultivation of medicinal plants. *Botany Research International* **2**, 174-181.

Kundu, D.K. and Pillai, K.G. (1992) Integrated nutrient supply system in rice and rice based cropping systems. *Fertilizer News* **37**, 35-41.

Letey, J., Knapp, K. and Solomon, K. (1990) Crop-production functions under saline conditions. In: *Agricultural Salinity Assessment and Management*, *ASCE Manuals and Reports No. 71* (K.K. Tanji, Ed.), pp 305-326. ASCE, New York, USA.

Maas, E.V. (1986) Salt tolerance of plants. *Applied Agricultural Research* **1**, 12–25.

Maji, B. and Bandyopadhyay, B. K. (1996) Effect of liming on yield of safflower and nutrient availability in coastal acid saline soils of Sundarbans, West Bengal. *Journal of Indian Society of Coastal Agricultural Research* **14**, 47-51.

Maji, B. and Bandyopadhyay, B.K. (1995) Characterization and classification of coastal soils of various pH groups in Sundarbans, West Bengal. *Journal of the Indian Society of Soil Science* **43**, 103-107.

Manchanda, G. and Garg N. (2008) Salinity and its effects on the functional biology of legumes. *Acta Physiologica Plant* **30**, 595–618.

Mandal, A.K., Sharma, R.C. and Singh, G. (2009) Assessment of salt affected soils in India using GIS, *Geocarto International* **24**, 437-456.

Martinez-Beltran, J. and Manzur, C.L. (2005) Overview of salinity problems in the world and FAO strategies to address the problem. In: *Proceedings of the International Salinity Forum,* pp 311–313. Riverside, California.

Meiri, A. (1984) Plant response to salinity: experimental methodology and application to the field. In: *Soil Salinity under Irrigation: Processes and Management* (I. Shainberg and J. Shalhevet, Eds.) pp 284-297. Springer-Verlag, New York, USA.

Metternicht, G.I. and Zinck, J.A. (2003) Remote sensing of soil salinity: potentials and constraints. *Remote Sensing of Environment* **85,** 1–20.

Mitra, A. (2013) Brackish-water aquaculture: a new horizon in climate change matrix. In: *Sensitivity of Mangrove Ecosystem to Changing Climate*. pp 245-323. Springer, New Delhi, India.

Mongia, A.D., Ganeshamurthy, A.N. and Bandyopadhyay, A.K. 1989. Acid sulphate soils of Andamans and their potential for lowland rice production. In: *International*

Symposium of Rice Production on Acid Soil of the Tropics, Institute of Fundamental Studies, Kandy, Sri Lanka.

Munns, R. (2002) Comparative physiology of salt and water stress. *Plant, Cell and Environment* **25**, 239–250.

Munns, R., Schachtman, D.P. and Condon, A.G. (1995) The significance of a two-phase growth response to salinity in wheat and barley. *Functional Plant Biology* **22**, 561-569.

Murphy, L.R., Kinsey, S.T. and Durako, M.J. (2003) Physiological effects of short term salinity changes on *Ruppia maritima*. *Aquatic Botany* **75**, 293-309.

Mythili, G. and Goedecke J. (2016) Economics of Land Degradation in India. In: *Economics of Land Degradation and Improvement - A Global Assessment for Sustainable Development* (E. Nkonya, A. Mirzabae and J. von Braun, Eds.), pp 431-469. Springer International Publishing AG, Switzerland.

NAAS. (2003) *Seaweed Cultivation and Utilization. National Academy of Agricultural Sciences Policy Paper* **22**, 1-5.

Netondo, G.W., Onyango, J.C. and Beck, E. (2004) Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. *Crop Science* **44**, 806-811.

Pandey, P.K., Panda, S.N. and Pholane, L.P. (2005) Economic evaluation of rain water harvesting in on farm reservoirs for the integrated farming system - a sustainable approach for small farmers. *Environment and Ecology* **23**, 671-375.

Paranychianakis, N.V. and Chartzoulakis, K.S. (2005) Irrigation of Mediterranean crops with saline water: from physiology to management practices. *Agriculture Ecosystems and Environment* **106**, 171-187.

Patel, B.B., Patel Bharat, B. and Dave, R.S. (2011) Studies on infiltration of saline–alkali soils of several parts of Mehsana and Patan districts of north Gujarat. *Journal of Applied Technology in Environmental Sanitation* **1**, 87–92.

Qadir, M., Noble, A. D., Karajeh, F. and George, B. (2015) Potential business opportunities from saline water and salt-affected land resources. *Resource Recovery and Reuse Series 5*. International Water Management Institute, Colombo, Sri Lanka.

Qadir, M., Quillerou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R.J., Drechsel, P. and Noble, A. (2014) Economics of salt induced land degradation and restoration. *Natural Resources Forum* **38**, 282-295.

Rahman, M., Soomro, U.A., Haq, M.Z. and Gul, S. (2008) Effects of NaCl salinity on wheat (*Triticum aestivum* L.) cultivars. *World Journal of Agriculture Science* **4**, 398-400.

Rangaraj, T., Somasundaram, E., Mohamed Amanullah, M., Thirumurugan, V., Ramesh, S. and Ravi, S. (2007) Effect of agro-industrial wastes on soil properties and yield of irrigated finger millet (*Eleusine coracana* L. Gaertn) in coastal soil. *Research Journal of Agriculture and Biological Sciences* **3**, 153-156.

Rao, K.V.G.K. (1991). On farm water management in coastal saline soils. *Journal of the Indian Society of Coastal Agricultural Research* **9**, 347-357.

Razzaque, M.A., Talukder, N.M., Islam, M.S., Bhadra, A.K. and Dutta, R.K. (2009) The effect of salinity on morphological characteristics of seven rice (*Oryza sativa*) genotypes differing in salt tolerance. *Pakistan Journal of Biological Science* **12**, 406-412.

Rengasamy, P. (2006) World salinization with emphasis on Australia. *Journal of Experimental Botany* **57**, 1017-1023.

Rengasamy, P. and K.A. Olsson. (1991) Sodicity and soil structure. *Australian Journal of Soil Research* **29,** 935-952.

Rhodes J. D. (1974) *Drainage for Salinity Control*. US Salinity Laboratory, ARS, USDA, Riverside, California.

Rogers, M.E., Colmer, T.D., Frost, K., Henry, D., Cornwall, D., Hulm, E., Hughes, S., Nichols, P.G.H. and Craig, A.D. (2009) The influence of NaCl salinity and hypoxia on aspects of growth in *Trifolium* species. *Crop Pasture Science* **60**, 71-82.

Sairam, R.K. and Tyagi, A. (2004) Physiology and molecular biology of salinity stress tolerance in plants. *Current Science* **86**, 407-421.

Saleh, J. and Maftoun, M. (2008) Interactive effect of NaCl levels and zinc sources and levels on the growth and mineral composition of rice. *Journal of Agriculture Science and Technology* **10**, 325-336.

Samra, J.S., Singh, G. and Ramakrishna, Y.S. (2006) *Drought Management Strategies in India*, Indian Council of Agricultural Research, New Delhi, India.

Sen, H.S. and Bandyopadhyay, B.K. (1987) Volatilization loss of nitrogen from submerged saline soil. *Soil Science* **143**, 34-39.

Sen, H.S., Bandopadhyay, B.K., Maji, B., Bal, A.R. and Yadav, J.S.P. (2000) Management of coastal agro-ecosystem. In: *Natural Resource Management for Agricultural Production in India* (J.S.P. Yadav and G.B. Singh, Eds.), pp 927-1014. International Conference on Managing Natural resources for Sustainable Agricultural Production in the 21st Century, February 14-18, 2000, New Delhi, India.

Shahbaz M., Ashraf M. (2013) Improving salinity tolerance in cereals. *Critical Reviews in Plant Sciences* **32**, 237–249.

Shannon, M.C. and Grieve, C.M. (1998) Tolerance of vegetable crops to salinity. *Scientia Horticulturae* **78**, 5-38.

Sharma, D.K. and Singh, A. (2015) Salinity research in India - achievements, challenges and future prospects. *Water and Energy International* 35-45.

Sharma, D.K., Chaudhari, S.K., Sharma, P.C. and Chinchmalatpure, A.R. (2014) CSSRI *Vision 2050*. Central Soil Salinity Research Institute, Karnal, Haryana.

Sharma, D.K., Dey P., Gupta, S.K. and Sharma, P.C. (2011) CSSRI Vision 2030. Central Soil Salinity Research Institute, Karnal, Haryana.

Sharma, D.K., Thimappa, K., Chinchmalatpure, A.R, Mandal, A.K., Yadav, R.K., Chaudhari, S.K., Kumar, S. and Sikka, A.K. (2015) *Assessment of Production and Monetary Losses from Salt-affected Soils in India*. *Technical Bulletin: ICAR-CSSRI/Karnal/2015/05*, ICAR-Central Soil Salninty Research Institute, Karnal, Haryana.

Singh, N.T. (2005) *Irrigation and soil salinity in Indian subcontinent: Past and Present*, Lehigh University Press, Bethlehem.

Soil Survey Staff. (1999) *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*, US Department of Agriculture. p 436.

Squires, V.R. and Glenn, E.P. (2011) Salination, desertification and soil erosion. In: *The Role of Food, Agriculture, Forestry and Fisheries in Human Nutrition: Volume III*. (V.R. Squires, Ed.) pp 102-123. Encyclopedia of Life Support Systems (EOLSS), Australia.

SSSA. (1997) *Glossary of Soil Science Terms*. Soil Science Society of America (SSSA), Madison, WI, USA. p. 134.

Subba Rao, P.V. and Mantri, V.A. (2006) Indian seaweed resources and sustainable utilization: scenario at the dawn of a new century. *Current Science* **91**, 164-174.

Swarup, A. (1994) Chemistry of salt affected soils and fertility management. In: *Salinity Management for Sustainable Agriculture* (D.L.N. Rao., N.T. Singh, R.K. Gupta and N.K. Tyagi, Eds.), pp 18-40. Central Soil Salinity Research Institute, Karnal, Haryana.

Szabolcs, I. (1989) Salt-Affected Soils. CRC Press, Boca Raton, Florida.
Taiz, L. and Zeiger, E. (2002) *Plant Physiology*, Third Edition, Sinauer, Sunderland, U.K.
Tripathi, R.S. (2009) *Alkali Land Reclamation*, Mittal Publications, New Delhi.
Tyagi, N.K. (2003) Managing saline and alkaline water for higher productivity. In: *Water Productivity in Agriculture: Limits and Opportunities for Improvement* (J.W. Kijne, R. Barker and D. Molden, Eds.) pp 70-87. CAB International, Wallingford, England.
UNEP. (1992) *Proceedings of the Ad-hoc Expert Group Meeting to Discuss Global Soil Databases and Appraisal of GLASOD/SOTER*, February 24-28. UNEP, Nairobi.
US Salinity Staff Laboratory. (1954) *Diagnosis and Improvement of Saline and Alkaline Soils. Agric. Handbook No. 60*. USDA, Washington, DC.
Venkateswarlu, B. and Shanker, A.K. (2009) Climate change and agriculture: adaptation and mitigation strategies. *Indian Journal of Agronomy* **54**, 226–230.
Vijayvargiya, S. and Kumar, A. (2011) *Influence of Salinity Stress on Plant Growth and Productivity: Salinity Stress Influences on Plant Growth*. Lambert Academic Publishers, Germany.
Warrick, R.A., LePrevost, C., Meier, M.F., Oerlemans, J. and Woodworth, P.L. (1996) Changes in sea level. In: *Climate Change* (J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, Eds.), pp. 263-405. Cambridge University Press, Cambridge, UK.
Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburga, W. and Faaij, A. (2011) The global technical and economic potential of bioenergy from salt-affected soils. *Energy and Environmental Science* **4**, 2669-2681.
Wild, A. (2003) *Soils, Land and Food: Managing the Land during the Twenty-First Century.* Cambridge University Press, Cambridge, UK.
Yamaguchi, T. and Blumwald, E. (2005) Developing salt-tolerant crop plants: challenges and opportunities. *Trends in Plant Science* **10**, 615–620.
Yeo, A.R. (2007) Salinity. In: *Plant Solute Transport* (A.R. Yeo and T.J. Flowers, Eds.), pp340-365. Blackwell, Oxford, U.K.