Saline Irrigation for Productive Agroforestry Systems

J.C. Dagar and P.S. Minhas

Abstract

Land irrigation is playing a major role in enhancing food and livelihood security in the world over. Nevertheless, a typical scenario in the ground water-irrigated regions has emerged; the areas characterized by water scarcity also usually have underlying aquifers of poor quality. Though possibilities have now emerged to safely use waters otherwise designated unfit if the characteristics of water, soil, and intended usages are known. But it is neither feasible nor economical to use highly saline waters for crop production, especially on lands that are already degraded. Best land use under such situations is to retire these areas to alternative uses through agroforestry. With growing scientific and social recognition of many diversified uses of salt-tolerant plants, the research efforts have led to the development of planting technique and other practices for critical management of salts and water in root zone so as to rehabilitate the degraded lands successfully using saline irrigation. Several salt-tolerant plants have been identified with benefits as fuelwood, greening, fruits, forage, and medicinal and aromatic uses in addition to allowing for crop production activity underneath these (agroforestry). Many halophytes also have potential to be used as traditional food, forages and animal feeds, oil seeds, and energy crops.

Introduction

Land irrigation is playing a major role in enhancing food and livelihood security in the world over. About two-fifth of the world's total food and fiber output is now contributed by irrigated agriculture, although its area is only 17 %. In fact, the productivity of irrigated areas in arid and semiarid regions largely depends upon the ability to enlarge this

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resource base by better rainwater management and/or development of ground water. Globally, the aquifer withdrawal has increased manifold during the second half of the last century. For example, in the United States, the share of ground water used for irrigation increased from 23 % in 1950 to 42 % in 2000. In the Indian subcontinent, ground water use soared from 10–20 km^3 in 1950 to 240–260 km^3 during 2000. Nevertheless, a typical scenario in the ground water-irrigated regions has emerged; the areas characterized by water scarcity also usually have underlying aquifers of poor quality. These areas often have the greatest need for economic development, public welfare, and more food to supply the growing populations and regional conflicts over water and environmental degradation. But, driven by the pressure to produce more, even the brackish ground water is being increasingly diverted to irrigate agricultural lands. The use of such saline or alkali water to produce many conventional grain, forage, and feed crops as well as salt-tolerant plants and trees is prevalent particularly in Bangladesh, China, Egypt, India, Iran, Pakistan, Syria, and the United States (Tanwar 2003; Minhas 2012). The overexploitation of good-quality water in many developing countries and the alarming rate of decline in ground water levels are also putting aquifers at risk of contamination from adjoining poor-quality aquifers. Moreover, irrigation efficiency in most of the world's irrigated areas is of the order of 50 %, suggesting substantial secondary salinization from seeped water. About 20 % of the globally irrigated area is afflicted with varying levels of secondary salinity and sodicity (Ghassemi et al. 1995). The most technical method to combat irrigation-induced salinity being installation of expensive drainage systems and large amounts of drainage effluents of poor-quality are produced in areas covered with subsurface/surface drainage systems. In addition, recent trends in climate change and salt water intrusion suggest the influence of even greater volumes of the sea waters in agricultural production in coastal areas in the coming years.

Indiscriminate use of saline waters in the absence of proper soil–water–crop management strategies poses grave risks to soil health and environment (Minhas and Gupta 1992; Minhas and Bajwa 2001; Minhas and Samra 2004; Minhas 2012; Minhas et al. 2015). Development of salinity, sodicity, and toxicity problems in soils not only reduces crop productivity and quality but also limits the choice of crops. Its management signifies those methods, systems, and techniques of water conservation, remediation, development, application, use, and removal that provide for a socially and environmentally favorable level of water regime to agricultural production systems at the least economic cost (Hillel 2000). Though possibilities have now emerged to safely use waters otherwise designated unfit if the characteristics of water, soil, and intended usages are known (Minhas and Gupta 1992), and this has led to replacement of too conservative water-quality standards with site-specific guidelines, where factors like soil texture, rainfall, and crop tolerance have been given due consideration. The increased scientific use of these "degraded" waters such as brackish ground water, saline drainage water, and treated wastewaters therefore offers opportunities to address the current and future shortage (O'Connor et al. 2008). However, in some cases, it is neither feasible nor economical to use highly saline waters for crop production, especially on lands that are already degraded. Best land use under such situations is to retire such areas to alternative uses (through agroforestry), where salt-tolerant forest and fruit trees, crops, forage grasses, and medicinal and aromatic and other high value crops can be equally remunerative. Besides providing fuel, fodder, and timber, afforestation will also lead to bio-amelioration of salty lands. Afforestation of these lands should not only help in ecological and environmental considerations but also be useful in relieving pressure on traditionally cultivated lands and forests. These can be specifically beneficial for areas where periodic droughts along with extensive pressures from overgrazing and uncontrolled fuelwood gathering are substantially contributing to desertification and land degradation. Thus, this chapter briefly outlines several remedial management actions at the tree, root zone, and farm and irrigation system level strategies available for alleviating the hazards of highly saline waters and establishing tree-based systems.

Irrigation Management Strategies

Successful establishment of trees with saline irrigation requires appropriate planting techniques and site preparation for planting and post-planting irrigation management. Earlier researchers (Armitage 1984; Tomar and Gupta 1985; Yadav 1991; Gupta et al. 1994; Stevens et al. 1999) supported that the establishment of tree saplings is the most critical stage for raising plantations under the conditions of water and salt stress. However, there is general lack of information on the basic questions as how much and how long to irrigate tree plantations established in arid areas with saline waters. The traditional approach for sustaining the use of saline waters is to irrigate the arable crops more frequently and provide adequate leaching requirements. Nevertheless, such practices demand the application of additional quantities of saline water and thereby also result in enhancement of salt loads of soils (Minhas 1996). In fact, frequent irrigation is usually advocated for shallow-rooted crops in arid environments mainly because the added salts get pushed beyond the rooting zone. But in deep-rooted tree plantations, the additional salts going into the soil through enhanced frequency of irrigations may rather aggravate the problem as these are likely to persist within their expanding rooting zones and subsequently hinder the growth of trees. Though the longer-term data with saline irrigation are not available, but Fig. 1 (from Bandara et al. 2002) illustrates how salt concentrations vary with depth at plantation sites varying in soil conditions, depth to water table, and irrigated water salinities. No salt accumulation was observed at the Cobram site, which was irrigated with good-quality water, and peak concentration was relatively low at Nathalia (irrigated with 2.0–2.5 dS m^{-1} water) and at Mangalore, where the salinity of water applied was 1–1.5 dS m^{-1}. However, at the Tatura and Timmering sites, irrigated with water of 5 and 10 dS m^{-1}, respectively, there is clear evidence of salinity buildup in the upper 3 m of soil. Soils at Tatura and Timmering were also heavier textured than those at Nathalia and Mangalore. Thus, the impacts on plantation growth should be more pronounced where saline water is applied to clay soils rather than to sandy soils.

For proper irrigation scheduling in terms of frequency of irrigation and the amount of water applied each time, aim should be for maximizing productivity while conserving water and ensuring that irrigation systems are environmentally and economically sustainable. Decision on scheduling requires a good knowledge of crop water demand, tolerance to salinity, and soil water characteristics and must account for the type of irrigation method used. Theiveyanathan et al. (2000) predicted annual irrigation demand under flood irrigation to be 14–16 ML ha^{-1}. These volumes far exceed the normal operational rates of irrigation in that region, generally in the range 4–8 ML ha^{-1} $year^{-1}$. Understanding the relationship between the volumes of irrigation applied and growth is fundamental to developing efficient irrigation strategies. In Australia, the growth of trees was linearly related to irrigation rates up to the maximum of 8 ML ha^{-1} $year^{-1}$. The regression equation shows that diameters increased at the rate of 4.3 mm per ML of water applied, whether through irrigation or the sum of irrigation and rainfall.

Tree saplings with their roots located where these can access soil water of low salinity or lateral subsurface flows of salts would achieve better establishment and growth than those with more or less uniform salinity. Therefore, irrigation with saline waters should aim to create favorable niches for the better establishment of saplings and also eliminate the excessive salinity buildup in rooting zone. This could be achieved by using subsurface planting and furrow irrigation technique irrigating only the limited area under furrows planted with tree saplings (Minhas et al. 1996). In this technique, furrows (15–20 cm deep and 50–60 cm wide) are created at 3–5 m intervals and tree saplings are transplanted during rainy season (July-August) at the sill of furrows. The technique is now known as subsurface planting

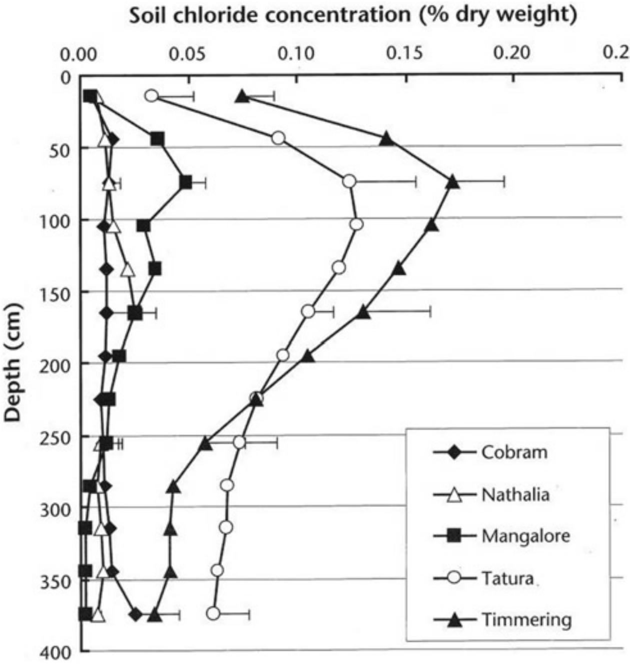

Fig. 1 Soil chloride concentrations at five plantation sites irrigated with water of different salinities, 7–9 years after planting. (Bars represent standard errors) (Source: Bandara et al. 2002)

and furrow irrigation system (SPFIS). Depending upon tree row spacing, furrow vis-a-vis irrigated area occupies only one to fifth to one to tenth of total land area depending upon the space of planting rows. The success of the system was attributed to both the reduced salt load with irrigation only a portion of land, creation of better soil moisture regimes in rooting medium during dry periods (October-June) and significant leaching and lateral distribution of salts by the concentration of rainwater through runoff into these furrows (Fig. 2). It was further reported that irrigation quantities equaling 10 % of open pan evaporation, though saline, sufficed for optimal growth of *Acacia nilotica* and *Dalbergia sissoo* plantations on a highly calcareous soil with little subsoil–water storage.

Though the initial irrigation to plantations may allow for their better establishment and promote growth as compared with un-irrigated, but objective should be to discontinue saline irrigation that may impact the tree growth with accumulation of salts. In a semiarid monsoonal climate, there was two- to four-fold improvement in establishment and growth of *Acacia nilotica* and *Dalbergia sissoo* tree saplings with saline irrigation (Minhas et al. 1997), and irrigation support for at least 2 years seemed necessary. From later experiments (Tomar et al. 2003b), it was concluded that for tolerant trees, saline irrigation may be provided for initial 3 years of transplanting, and thereafter irrigation may be applied once during winter to safeguard against the frost damage. Others (Rogers 1985; Morris et al. 1994) have also recommended a period of at least 5 years for irrigation.

Thorburn et al. (1995) suggested that if salinity in tree root zones increases for extended periods above salinity levels tolerated by particular species, roots are likely to become confined to an increasingly shallow part of the upper profile above the zone of salt accumulation thereby reducing plantation productivity. The long-term salinity dynamics need to be systematically studied but with adequate leaching, on soils with good hydraulic conductivity/lighter textured soils, salts can be moved out of the root zone. However, leaching of salts may be restricted when (Marcar and Morris 2005) (1) the root zone is deep — trees, depending on their growth rates, can exploit much of the soil-available water, and hence large volumes of water may be required to

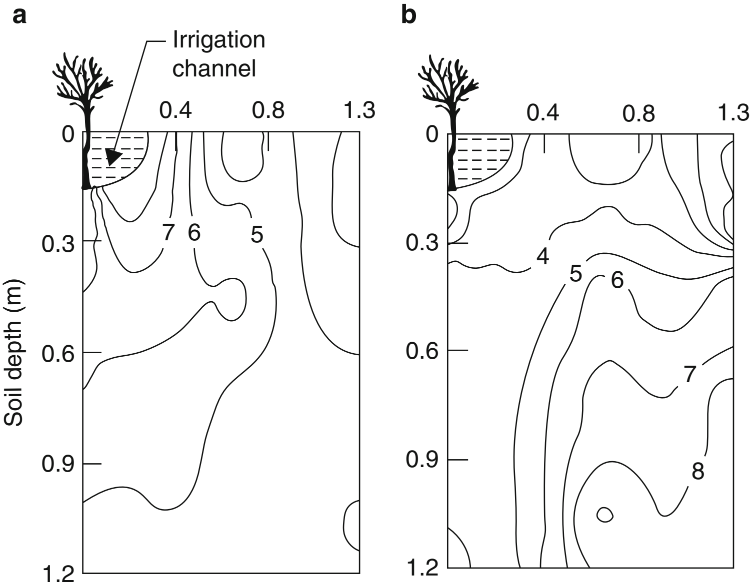

Fig. 2 Contour of soil salinity (**a**) before and (**b**) after monsoon rains in a tree plantation established with sub-surface planting and furrow irrigation (SPFIM) method (Source: Minhas et al. 1996)

leach salts; (2) a low infiltration rate in heavy-textured soils limits the volume of water that can be applied in an irrigation event; and (3) leaching of salt below the root zone may raise the water table and increase the likelihood of upward capillary rise of salt.

Tree Species for Saline Irrigation

Since the saline ground waters mostly exist under water scarcity zones, for sustaining viable wood-producing enterprise, tree species should both be tolerant to salinity and drought as well as well adapted to the local agro-climate. Drought-tolerant species, those develop deep, and extensive root systems are usually successful on long-term basis, although their early growth rates may be slower. Some species may show better growth when under irrigation but may slow down with the cessation of irrigation after establishment. Sufficient information is available about the tolerance of tree species to salinity from pot and short-term field studies (Schofield 1992; Yadav 1991; Ahmad and Ismail 1993a, b; Marcar et al. 1993; Davidson and Galloway 1993; Gupta et al. 1995; Marcar and Khanna 1997; Tomar and Minhas 1998; Barrett-Lennard 2003; Jaradat 2003; Dagar 2003; Dagar and Singh 2007), but knowledge of soil salinity tolerance of specific tree species under field conditions over a longer period of time is limited. With limited information due to lack of longer period field trials over a range of climate, cultural practices, soil types, and soil conditions (e.g., calcareousness goes along with aridity), it is very difficult to draw conclusions about the performance of individual tree species. In addition to salt tolerance as the selection criteria for specific sites, the socioeconomic and ameliorative role of trees has to be accorded due consideration in afforestation programs.

The information on establishment of trees and their subsequent growth under saline-irrigated conditions is mainly available from the Indian subcontinent. Ahmad et al. (1985) observed the faster growth of *Melia azedarach* than *Azadirachta indica* with saline irrigation (ECiw 4.5–14.0 dS m^{-1}), while the performance of *Prosopis juliflora*, *Acacia nilotica*, *Terminalia arjuna*, *Syzygium cuminii*, *Albizia lebbeck*, *Pongamia pinnata*, *Cassia articulata*, and *Cassia siamea* was better with waters ranging from EC 4.0–6.1 dS m^{-1} (Chaturvedi 1984, 1985). Jain et al. (1983, 1985) reported that *P. juliflora* and *Tamarix articulata* tolerated irrigation water salinity of 8 dS m^{-1}, and *Eucalyptus hybrid* and *Leucaena leucocephala* were moderately tolerant to saline irrigation (ECiw ~ 6 dS m^{-1}). Ahmad et al. (1987) and Ahmad and Ismail (1993a, b) observed that certain species of fuelwood and salt bushes show luxuriant growth at sandy strata when irrigated with saline water of oceanic strength. In trees such as *Azadirachta indica*, *Casuarina equisetifolia*, and *Eucalyptus camaldulensis*, three-fourth of the potential biomass could be obtained with waters having ECiw 15 dS m^{-1}; in *Prosopis juliflora*, it was 20 dS m^{-1}, while in *Tamarix articulata*, only beyond 30 dS m^{-1}. It is reported from Pakistan that tree species such as *Prosopis cineraria, P. juliflora, Acacia nilotica, Tamarix articulata*, *T. indica*, *T. stricta*, *Salvadora persica*, *S. oleoides*, and *Leucaena leucocephala* could be successfully utilized for revegetation of desert land (Thal, Thar, Choliston, and Chaki-Kharan) using waters from saline aquifers ECiw 4 to 18 dS m^{-1} (Qureshi et al. 1993a, b). Hussain and Gul (1993) evaluated 35 tree species on sodic to saline sodic waterlogged sites in Peshawar region and found that local species such as *Tamarix articulata*, *Acacia modesta*, and *A. nilotica* performed well but the exotics *Acacia stenophylla*, *A. ampliceps*, *Casuarina obesa, Eucalyptus camaldulensis,* and *Prosopis chilensis. P. siliquastrum* and *P. alba* exhibited better performance showing their suitability for saline environment.

Systematic efforts were made by Tomar et al. (2003b) to evaluate long-term performance of 31 tree species when irrigated initially with saline water (ECw ~ 8.6–10 dS m^{-1}) on a highly calcareous soil (*Typic Haplustalf*) in a semiarid part of north-west India (rainfall 499 mm $year^{-1}$; PAN-E 1888 mm $year^{-1}$). After 8 years of planting, the best performing tree rated on the basis of survival, vigor, and biomass yields was *Tamarix articulata* (73.5 Mg ha^{-1}) followed by *Acacia nilotica* (22.4 Mg ha^{-1}), *Prosopis juliflora* (20.2 Mg ha^{-1}), and *Eucalyptus tereticornis* (14.8 Mg ha^{-1}). Even after 20 years of growth, the highest biomass-yielding trees continued to be *Tamarix articulata* followed by *Acacia nilotica*,*A. tortilis*, *Eucalyptus tereticornis, Prosopis juliflora*, and *Azadirachta indica* (Fig. 3). In addition to fuelwood, the other benefit was improvement in organic matter of soils (>5 g kg^{-1} soil), e.g., *Acacia nilotica, A. tortilis, Azadirachta indica, Eucalyptus tereticornis*, *Feronia limonia, Tamarix articulata*, and *Guazuma ulmifolia* species from the original (3 g kg^{-1}). Working on the same site, Dagar et al. (2004, 2005, 2006, 2012) reported successful raising of *Salvadora persica*, *Catharanthus roseus*, *Cordia rothii*, and *Adhatoda vasica.*

Fruit and Oil-Yielding Tree Species

Most of the fruit trees with the exception of date palm (*Phoenix dactylifera*), pistachio (*Pistachio vera*), pomegranate (*Punica granatum*), olive tree (*Olea europaea*), Ber (*Ziziphus mauritiana*), and a few others are relatively sensitive to salinity stress. The most efficient method of using saline waters in widely spaced fruit trees is the drip irrigation. Enough information is available on cultivation of fruit trees with saline irrigation (Bernstein 1980; Bielorai et al. 1983, 1985; Mass 1986; Hoffman et al. 1988; Aronson et al. 1989; Picchioni and Miyamoto 1990; Banuls and Primo-Millo 1995; Aksoy et al. 1997; Boman 2000; Levy and Syvertsen 2004; Wiesman et al. 2004; Weissbein et al. 2008; Zeinadini et al. 2009; Kamiab et al. 2012) which helps in understanding the mechanism and preliminary concepts of salt tolerance. Mass (1986) rated date palm (*Phoenix dactilifera*) as tolerant; fig (*Ficus carica*), jujube (*Ziziphus mauritiana*), olive (*Olea europaea*), papaya (*Carica papaya*), pineapple (*Ananas comosus*), and pomegranate (*Punica granatum*) as moderately tolerant; grape (*Vitis vinifera*) as moderately sensitive; and almond (*Prunus dulcis*), apricot (*P. armeniaca*), sweet cherry (*P. avium*), sand cherry (*P. bessey*), peach (*P. persica*), plum (*P. domestica*), apple (*Malus sylvestris*), avocado (*Persea americana*), boysenberry (*Rubus ursinus*), cherimoya (*Annona cherimola*), grape fruit (*Citrus paradisiaca*), lemon (*C. limon*), lime (*C. aurantifolia*), orange (*C. sinensis*), pummel (*C. maxima*), tangerine (*C. reticulata*), loquat (*Eriobotrya japonica*), mango (*Mangifera indica*), passion fruit (*Passiflora

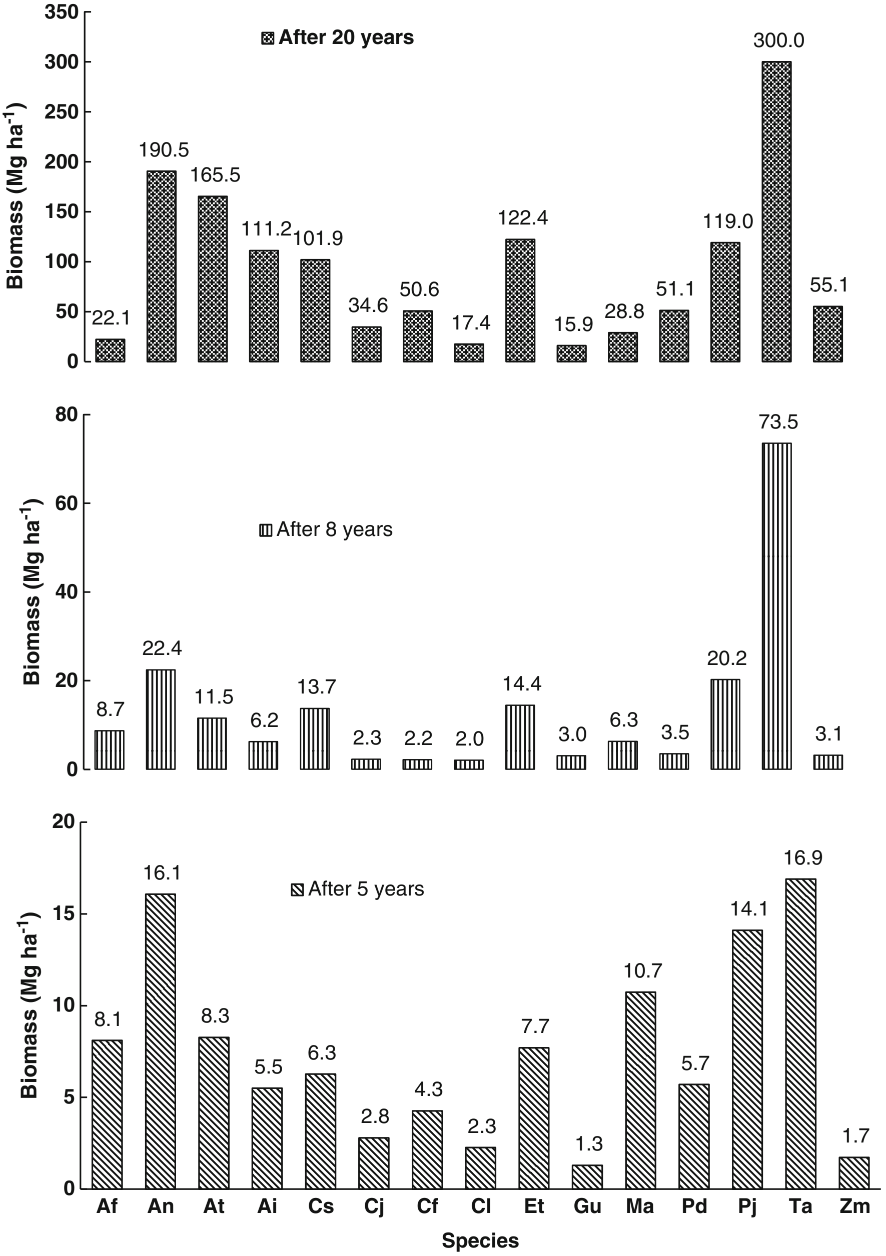

Fig. 3 Biomass of trees harvested after 5, 8, and 20 years of growth. Depictions: Af=*Acacia farnesiana*, An=*Acacia nilotica*, At=*A. tortilis*, Ai=*Azadirachta indica*, Cs=*Cassia siamea*, Cj=*C. javanica*, Cf=*C. fistula*, Cl=*Callistemon lanceolatus*, Et=*Eucalyptus tereticornis*, Gu=*Guazuma ulmifolia, Ma*=*Melia azedarach, Pd*=*Pithecellobium dulce, Pj*=*Prosopis juliflora, Ta*=*Tamarix articulata, Zm*=*Ziziphus mauritiana* (Source: Tomar et al. 2003b and Dagar et al. 2015, in review)

edulis), pear (*Pyrus communis*), persimmon (*Diospyros virginiana*), raspberry (*Rubus idaeus*), sapota white (*Casimiroa edulis*), and rose apple (*Syzygium jambos*) as sensitive to saline irrigation. Mostly olives are grown on well-drained soils and can tolerate moderate salinity of irrigation water. Generally, it is believed that high salinity levels reduce olive yields (Gucci and

Tattini 1997), but Klein et al. (1994) reported higher olive yield in Manzanillo trees irrigated with waters of ECiw 7.5 dS m^{-1}. Wiesman et al. (2004) reported average annual olive yield of Barnea trees to be 15.1, 18.5, and 15.5 Mg ha^{-1} when irrigated with water of ECiw 1.2, 4.2, and 7.5 dS m^{-1}, respectively, indicating yields enhancement under moderate salinity.

Weissbein et al. (2008) observed that in semiarid Israeli Negev area, saline irrigation treatment at 4.2 dS m^{-1} demonstrated only a low rate of retardation effect on growth and yield of olive trees compared with water at 1.2 dS m^{-1}. From the observations of many workers (Munns 1993; Klein et al. 1994; Gucci and Tattini 1997; Wiesman et al. 2004; Aragues et al. 2005; Weissbein et al. 2008), it could be concluded that different cultivars behaved differently, and most of these clearly showed the advantage of using water of ECw 4.2 dS m^{-1} for optimization of the horticultural performance. Further, leaching methodology based on drip irrigation enabled reduction of the salt level in the developing root zone to a level lower than 6 dS m^{-1}, which is essential for normal olive development. Because of salinity tolerance, the cultivation of pistachio is common in California, Arizona, southern New Mexico, and far west Texas. Picchioni and Miyamoto (1990) consider it to be potentially an alternative to salt-sensitive pecan (*Carya illinoensis*) and almond (*Prunus amygdalus*), and *Pistacia atlantica, P. terebinthus*, and *P. integerrima* are the major rootstock of the domestic pistachio industry. Interestingly, most pistachio plantations in all over the world are on saline soils (ECe > 6 dS m^{-1}) and irrigated with low quality and saline water (Kamiab et al. 2012). In recent years, however, due to increasing salinity of soil and water, the pistachio yields have reduced. This negative influence was significant at concentrations exceeding 100 Mm salinity. The data reported by Kamiab et al. (2012) also showed that the mechanism of tolerance to salinity in *P. vera* cv. Badami–Zarad rootstock might be attributed to the better K^+-Na^+ discrimination and accumulation of osmolytes (proline and reduced sugars) under salt stress condition. The characteristics of Badami pistachio could be introduced as a mechanism for increasing to salt tolerance. Ahmad et al. (1987) and Ahmad and Ismail (1993a, b) observed that in some fruit trees such as date palm (*Phoenix dactylifera*), *Achras zapota, Grewia asiatica*, and *Ziziphus mauritiana* reduction in growth and fruit yield only with saline irrigation of ECiw 8–10 dS m^{-1}. Further, Dagar et al. (2008) and Dagar (2014) evaluated *Carissa carandas*, *Aegle marmelos*, *Emblica officinalis, Ziziphus mauritiana*, and *Feronia limonia* to be the most suitable fruit trees in a semiarid part of north-west India, and these could perform satisfactorily with saline water of ECiw ~ 10 dS m^{-1}. But there is need to evaluate proper rootstocks and cultivars of most of the salt-tolerant species of fruit trees in India.

At least 50 species of seed-bearing halophytic plants are potential sources of edible or industrial oil and proteins which can successfully be cultivated using sea water or highly saline ground water. Among the most important include *Salicornia bigelovii* (Glenn et al. 1991), *Terminalia catappa* and *Pandanus* spp. (Dagar 2003), *Suaeda moquinii* (Weber et al. 2001), *S. aralocaspica* (Wang et al. 2012), *Kosteletzkya virginica* (Gallagher 1985), *Salvadora persica* (Dagar 2003; Gururaja-Rao et al. 2004; Reddy et al. 2008), *Batis maritima* (Marcone 2003), *Crithmum maritimum* and *Zygophyllum album* (Zarrouk et al. 2003), *Nitraria sibiria, Suaeda salsa*, *Chenopodium glaucum*, and *Descurainia sophia* (Yajun et al. 2003). Importantly, in all these cases, seeds are relatively salt-free although there may be significantly higher concentrations of salts in other parts of the plant (Jaradat 2003).

Agroforestry Systems

Nonconventional crops (including halophytic crops) are now seen as alternative for farming in saline water-irrigated areas. Many of these crops along with salt-tolerant glycophytes may form constituents of viable and sustainable agroforestrysystems including silvopastoral systems. A perennial salt grass *Distichlis palmeri* (fiber content 8.4 %), used for making biscuits and bread, performs well in flooded and hypersaline conditions producing 1.25 Mg ha^{-1} grains (Pearlsteina et al. 2012). In coastal areas, it can be grown as an understory crop with trees like coconut palm (*Cocos nucifera*), coastal almond (*Terminalia catappa*), pongam (*Pongamia pinnata*), *Casuarina glauca*, and *Pandanus* spp. Quinoa (*Chenopodium quinoa*) is another food crop that can tolerate ECe up to 40 dS m^{-1} (Adolf et al. 2013) and is sold as a nutritious food item at a premium price. Similarly, psyllium (*Plantago ovata*) having medicinal value can be cultivated with saline water (ECw < 10 dS m^{-1}) with trees like *Acacia nilotica*, *A. tortilis, Tamarix articulata*, and *Feronia limonia* in dry regions of India (Tomar et al. 2010). Many mangrove species such as *Avicennia marina* and A. *germinans* are also used as food (Leith et al. 2000). A typical example of agri-horticultural system has been reported by Dagar et al. (2015b) where some of the crops like pearl-millet (*Pennisetum typhoides*), cluster bean (*Cyamopsis tetragonoloba*), barley (*Hordeum vulgare*), and mustard (*Brassica juncea*) could be taken on calcareous soil in low rainfall (<500 mm) areas in India along with fruit trees like Karonda (*Carissa carandas*), Indian Goose Berry (*Emblica officinalis*), and Bael (*Aegle marmelos*) with irrigation waters of (ECiw 8.5–10.0 dS m^{-1}). After 5 years, all fruit trees (Karonda, Goose berry, and Bael) started bearing fruits and recorded yields of 1.6, 0.5, and 3.5 Mg ha^{-1} fruits, respectively. The crop yields at different stages and growth of fruit trees are shown in Table 1.

Table 1 Yield (Mg ha^{-1}) of intercrops grown alone or under agri-horticultural (AH) systems in north-western India

	Mean for 5 years (2003–2007)		Mean for 4 years (2008–2011)	
Treatment	Barley*	Cluster bean*	Mustard**	Cluster bean**
Control (without trees)				
Low	3.55	1.41	1.58	0.87
Low/high	3.45	1.32	1.68	0.82
High	3.25	1.98	1.58	0.78
Carissa carandas (AH)				
Low	3.43	1.36	1.41	0.77
Low/high	3.32	1.28	1.33	0.71
High	2.99	1.21	1.18	0.69
Emblica officinalis (AH)				
Low	3.56	1.38	1.73	0.83
Low/high	3.29	1.27	1.66	0.78
High	3.04	1.16	1.58	0.73
Aegle marmelos (AH)				
Low	3.27	1.30	1.26	0.78
Low/high	3.08	1.25	1.21	0.72
High	2.78	1.14	1.11	0.66

Source: Dagar et al. (2015)
*Average of first 4 years
**Average of last 3 years. Salinity of irrigation water low (ECiw 5 dS m^{-1}), high (ECiw 8–10 dS m^{-1}), low/high alternate irrigation with low and high salinity water

Silvopastoral Systems/Forage Grasses

Some salt-tolerant plants/halophytes have long been utilized as fodder crops, e.g., Le Houerou (1994) reported that about 0.1 million ha of saline land was planted with *Atriplex* species in the Mediterranean Basin. The other possible candidate is *Leptochloa fusca* (Aslam et al. 1993). The soils with sandy substratum are especially suited to halo-xeric forages with saline irrigation (Ahmad and Ismail 1993a, b). Ahmad et al. (1987) and Ahmad and Ismail (1993a, b) reported that three-fourth of the potential yields could be obtained in *Sporobolus arabicus*, *Panicum turgidum*, and *Thinopyrum ponticum* when irrigated with water of ECiw 10–15 dS m^{-1}, while in *Leptochloa fusca* the ECiw for similar yields was 20 dS m^{-1}.

In Pakistan, about 11 million ha land resources are desert (Thal, Thar, Choliston, and Chaki-Kharan), and 31.7 million ha in India, consisting of great tracts of sand dunes, which in places, are interspersed with sparsely vegetated clay flats and ground water is highly saline ranging from ECiw 4 to 18 dS m^{-1}. These areas can be brought under silvopastoral system utilizing the local vegetation as well as saltbushes consisting of trees (*Prosopis cineraria*, *P. juliflora*, *Acacia nilotica, Tamarix articulata*, *T. indica*, *T. stricta*, *Salvadora persica*, *S. oleoides*, *Leucaena leucocephala*) and forages and grasses (*Atriplex* spp., *Maireana* spp., *Leptochloa fusca, Echinochloa crusgalli*, *Cenchrus ciliaris*, *Arthrocnemum indicum*, *Salsola drummondii*, *Bienertia cycloptera*, *Indigofera oblongifolia*, and *I. cordifolia*) using saline aquifers (Qureshi et al. 1993a, b; Tewari et al. 2014). Further, Abdullah et al. (1993) tested 13 species of *Atriplex* and 8 of *Maireana* for their suitability in Cholistan desert with saline irrigation (~5 dS m^{-1}) and found that species of *Atriplex* (especially *amnicola, bunburyana, halimus,* and *lentiformis*) were most promising as compared to species of *Maireana*. Hanjra and Rasool (1993) reported a dry biomass of 23 Mg ha^{-1} in *L. leucocephala*, 8.0 Mg ha^{-1} in *Atriplex amnicola*, 7.5 Mg ha^{-1} in *Sesbania sesban*, 4.6 Mg ha^{-1} in *Cenchris ciliaris*, 4.3 Mg ha^{-1} in *Leptochloa fusca*, and 3.2 Mg ha^{-1} in *Panicum antidotale* showing their potential with saline irrigation as silvopastoral species in dry regions.

In the USA and Israel, the plantations of *Atriplex* raised with saline water are highly productive ranging from 12 to 20 Mg ha^{-1} dry matter per ha (Watson et al. 1987; Aronson et al. 1988). Malik et al. (1986) reported that *kallar* grass (*Leptochloa fusca*) grown on salty soil and irrigated with brackish water could produce 50 Mg ha^{-1} year^{-1} fresh biomass. Hades and Frankel (1982) showed that the use of brackish irrigation water increases the rate of infiltration into a saline sodic soil. However, Aslam et al. (1993) observed that the application of brackish water did not cause any change in soil properties. In contrast, the roots of *kallar* grass were able to penetrate to depth creating vertical fine channels accelerating the leaching of salts down below 3 m in depth and increasing the hydraulic capacity of the soil. Thus, the cultivation of salt-tolerant plants like *kallar* grass also initiates a soil improvement process by providing soluble Ca^{+2} to the soil through dissolution of native $CaCO_3$ which lowers the pH. Rashid et al. (1993) demonstrated in Peshawar valley that *Atriplex lentiformis* (accession 159) was the most productive of the 20 saltbushes tested irrigating with brackish water. The other promising accessions were *A. amnicola* (971), *A. lentiformis* (178), *A. cineraria* (524), *A. undulata* (471), and *A. amnicola* (573). These saltbushes along with productive salt-tolerant grasses and forage trees may form ideal silvopastoral system on these degraded lands. Qadir et al. (1995) reported the potential of forage biomass production of 32.3 Mg ha^{-1} by *Sesbania aculeata*, 24.6 Mg ha^{-1} by *Leptochloa fusca*, 22.6 Mg ha^{-1} by *Echinochloa colona*, and 5.4 Mg ha^{-1} by *Eleusine coracana* in saline-sodic environment, and these species helped in soil amelioration in terms of reducing soil pH and salinity and increasing nitrogen in the order S. *aculeata*>*L. fusca*>*E. colona*>*E. coracana*. In semiarid part of India, Tomar et al. (2003a) observed forage grasses like *Panicum laevifolium* and *P. maximum*

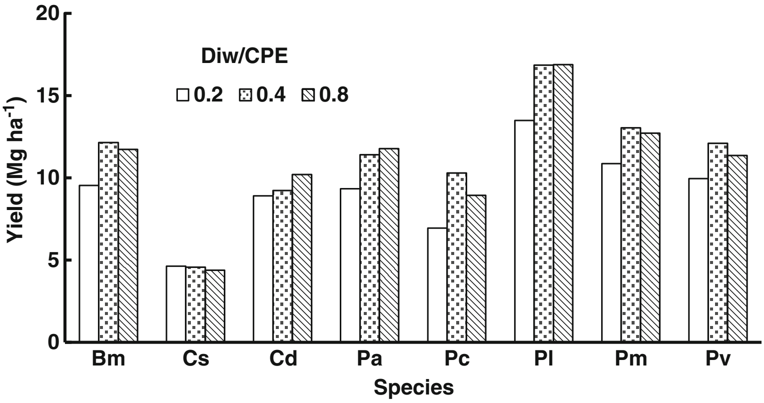

Fig. 4 Dry biomass yield of different grasses as affected by irrigation schedules with saline water of EC$_{iw}$ 10 dS m^{-1} (Diw and CPE denote depth of irrigation water and cumulative open pan evaporation). Grass species: Bm *Brachiaria mutica*, Cs *Cenchrus setigerus*, Cd *Cynodon dactylon*, Pa *Panicum antidotale*, Pc *Panicum coloratum*, Pl *Panicum laevifolium*, Pm *Panicum maximum*, and Pv *Panicum virgatum* (Source: Modified from Tomar et al. 2003a)

were most suitable species producing annually 14–17 Mg ha^{-1} dry forage with saline irrigation (Fig. 4). About 25–30 % of total forage was also available during lean period of summer when most of the nomads move to other areas in search of forage for their cattle. These grasses along with native *Cenchris setigerus* and C. *ciliaris* could also be raised with trees like *Acacia nilotica*, *A. tortilis*, *A. ampliceps*, *A. farnesiana*, *A. modesta*, *Azadirachta indica*, *Feronia limonia*, *Prosopis juliflora*, *P. cineraria, Tamarix articulata*, *Cordia rothii*, *Salvadora persica*, and *Cassia siamea* (Dagar et al. 2008). Despite regular forage during rainy season, about 3–4 Mg ha^{-1} biomass from protected local grazing stands may be obtained if provided irrigation with saline water (ECiw ~10 dS m^{-1}) during the lean period.

On saline vertisol soils, grasses such as *Aeluropus lagopoides*, *Leptochloa fusca*, *Brachiaria mutica*, *Chloris gayana*, *Dichanthium annulatum, Bothriochloa pertusa*, and species of *Eragrostis, Sporobolus*, and *Panicum* are most suited to saline irrigation. Oil-yielding bush *Salvadora persica* was grown in combination with forage grasses such as *Leptochloa fusca*, *Eragrostis* sp., and *Dichanthium annulatum* on heavy textured saline vertisol (pH 7.2–8.9; ECe 25–70 dS m^{-1}). The underground water was 0.5–2 m from surface with ECiw 55–60 dS m^{-1}. These grasses with saline irrigation could produce on an average 3.72, 1.0, and 1.8 Mg ha^{-1} of forage, respectively. During fourth year, the seed yield of *Salvadora persica* ranged from 1.84 to 2.65 Mg ha^{-1} with oil contents ranging from 576 to 868 kg ha^{-1} (Gururaja-Rao et al. 2003).

Other Nonconventional Crops

A large number of salt-tolerant species, besides those mentioned above, can be used as agroforestry or sole crops with saline irrigation; however, these exhibit large differences in salt tolerance based on number of factors, including life cycle, frost tolerance, soil type, and climatic factors. Many important crops which have not mentioned earlier include tubers and foliage crops such as *Eleocharis dulcis*, *Sesuvium portulacastrum, Beta vulgaris*, and *B. maritima*; fruit yielding trees like *Achras zapota, Manilkara hexandra*, *Morinda citrifolia,* and *Borassus flabellifer*; pickles (*Capparis decidua* and *Cordia rothii*); liquid fuels *Beta vulgaris* and *Nypa fruticans*; gums, oils, and resins yielding many species of *Acacia*, *Sesbania*, and *Grindelia*; oil-like sperm whale (*Simmondsia chinensis*); source of natural rubber (*Parthenium argentatum*); and bioactive derivative-yielding plants (*Calophyllum inophyllum, Balanites roxburghii*, *Azadirachta indica*, *Catharanthus roseus*) are some interesting crops already adopted in many parts of the world and grown with saline irrigation (NAS 1990; Jaradat 2003; Dagar 2003, 2014; Dagar et al. 2009). Kefu et al. (1995) reported utilization of halophytes in China as source of starch and protein (species of *Zostera, Chenopodium, Atriplex*), oil (*Salicornia, Suaeda*), food and therapeutic value (*Limonium bicolor*), fiber (*Apocynum venetum*), medicine (*Ephedra sinica, Lycium barbarum, Kochia scoparia, Xanthium sibiricum, Glycyrrhiza uralensis, Artemisia stelleriana*), essential oil (*Aster, Artemisia*), and valuable fodder for domestic animals (*Agropyron sibiricum, A. mongolicum, Pennisetum alopecuroides, Spartina anglica, Nitraria sihirwa, Elaeagnus angustifolia, E. umbellata*), which are cultivated in agroforestry systems in saline environments. A number of species including *Tamarix chinensis*, *Phragmites australis, Miscanthus* spp. and *Spartina alterniflora* were evaluated as biofuel crops for ethanol production in the coastal zone of China (Liu et al. 2012). Halophytic perennial grasses along coastal area of Indian subcontinent such as *Halopyrum mucronatum*, *Desmostachya bipinnata*, *Phragmites karka*, *P. australis*, *Typha domingensis*, and *Panicum turgidum* are also known to be highly suitable for bioethanol production (Abideen et al. 2011). *Panicum virgatum* like corn (*Zea mays*) grown extensively as a conventional food crop as well as ethanol production (Hendricks and Bushnell 2008). In addition, sugar beet (*Beta vulgaris*), nipa palm (*Nypa fruticans*), and *kallar* grass (*Leptochloa fusca*) are identified sources of liquid and gaseous fuel (Jaradat 2003). Species of *Tamarix* which are highly biomass-producing

Table 2 Impact of different irrigation schedule on fresh yield (Mg ha^{-1}) of lemon grass when irrigated with water of different salinity

ECiw (dS m^{-1})	Irrigation schedule (Diw/CPE ratio) 0.2	0.4	0.6	0.8	Mean
Low	10.85	11.93	13.03	14.28	12.52
Low/high	7.65	8.63	9.97	11.53	9.45
High	4.31	7.12	8.51	10.03	7.49
LSD ($p=0.05$) ECiw 2.37 Irrig. Sch. 0.98 Interaction: NS					

Source: Dagar et al. (2013)

halophytic species are also source of bioethanol production (Panta et al. 2014).

Lemongrass (*Cymbopogon flexuosus*) has also been found promising crop with saline irrigation (Dagar et al. 2013). The average fresh foliage yield was found to be 12.5, 7.5, and 9.5 Mg ha^{-1}, respectively, when irrigated with water of low salinity (ECiw 4.0 dS m^{-1}), high salinity (ECiw 8.6 dS m^{-1}), and alternately with two waters. There was increase in yield with increase in irrigation water (Diw/CPE ratio) average yield ranging from 7.60 to 11.95 Mg ha^{-1} (Table 2). Furrow planting was superior to other methods. The yield with furrow, flat, and top of bund planting was 9.1, 5.7, and 3.1 Mg ha^{-1}, respectively (Dagar et al. 2013).

There lie varietal differences in salt tolerance of many of these species. For example, in lemongrass varieties, OD-58 and RRL-16 could produce 10–20 times biomass as compared to other tested varieties (Dagar et al. 2013), and among psyllium (*Plantago ovata*) varieties, JI-4 was found far superior followed by Sel-10 and Niharika when cultivated with saline water of ECiw 10 dS m^{-1} (Tomar et al. 2010). In another experiment, the aromatic grasses such as vetiver (*Vetiveria zizanoides*), lemon grass, and palmarosa (*Cymbopogon martini*), when irrigated with saline water (EC 8.5 dS m^{-1}) could produce on an average of 90.9, 10.4, and 24.3 Mg ha^{-1} dry biomass, respectively (Tomar and Minhas 2004a). Medicinal *Aloe barbadensis* was also equally tolerant and could produce 18 Mg ha^{-1} fresh leaves under partial shade. *Ocimum sanctum* yielded 910 kg ha^{-1} dry shoot biomass, while dill (*Anethum graveolens*), taramira (*Eruca sativa*), and castor (*Ricinus communis*) yields equaled 931, 965, and 3535 kg seeds per ha, respectively (Dagar et al. 2008). *Cassia senna* and *Lepidium sativum* could also be raised successfully. Among seed spices, fennel (*Foeniculum vulgare*) could be cultivated successfully producing 1.56 Mg ha^{-1} seed without showing any yield penalty when irrigated with water of ECiw 8.6 dS m^{-1} (Meena et al. 2014).

Floriculture

Skimina (1992) conducted a trial on about 100 ornamental species grown in 2.8 L containers and showed the feasibility of growing plants with recycled water without any yield reduction. Experiments conducted in Israel (Shillo et al. 2002), in California (Carter et al. 2002; Carter and Grieve 2008; Grieve et al. 2008a, b), and elsewhere (Niu and Cabrera 2010) proved the feasibility of growing ornamental plants and cut flowers even when the EC of irrigation water was not optimal for growth of other crops. These workers identified species of *Limonium, Dianthus, Celosia, Chrysanthemum, Antirrhinum, Gypsophila*, and *Matthiola* suitable for reuse system. Tomar and Minhas (2002, 2004a, b) and Dagar et al. (2008) reported that most of these species could be raised with water of ECiw 8.6 dS m^{-1}, and yield was higher when established with good-quality canal water. *Chrysanthemum indicum* and medicinal and aromatic oil yielding *Matricaria chamomilla* were the most tolerant. Recently, Cassaniti et al. (2013) have analyzed the potential use of brackish water for growing ornamentals. They have highlighted the effects of salt stress on floricultural crops, halophytic floriculture, importance of genetic traits in developing new crops, and management practices. Many halophytes have significant economic potential in terms of ornamental purpose. For example, *Maireana sedifolia* is used for its cut branches and exported to Europe from Israel. Ornamental species such as *Clianthus formosus, C. puniceus*, and many cultivars of *Portulaca oleracea* can successfully be grown using water of EC 5–15 dS m^{-1}. Interestingly, Cassaniti et al. (2013) identified 42 suitable halophytic species under 24 botanical genera found naturally in the Mediterranean environments and may be grown successfully as ornamental plants. Species such as *Limonium sinuatum, L. perezii, Trachelium caeruleum, Eustoma grandiflorum, Hippeastrum hybridum, Ornithogalum arabicum*, and several others have been identified suitable for saline irrigation having ECiw ranging from 2.5 to 11.5 dS m^{-1} (Grieve et al. 2008a, b).

Conclusions

In most of the arid and semiarid regions, good-quality water is scarce, and utilization of poor-quality water for agricultural purposes is inevitable. For that, we need to use adaptable, sustainable, viable, and affordable techniques and suitable salt-tolerant plants. Alternate land uses/agroforestry is ideal preposition for such areas involving hardy salt-tolerant forest and fruit trees, forage grasses, and low water requiring conventional and nonconventional crops including ornamental plants. There are opportunities to increase the salt tolerance of existing crops using conventional plant breeding and molecular approaches. There is need to produce low water (stress)-requiring and more salt-tolerant plant types. In the scenario of climate change, we also must conserve all the salt-tolerant, stress-tolerant, and also submergence-tolerant land races. Human resource development at all levels and strengthening extension network is as important as technology development. Recently, the attention is being paid toward commercial forestry, raising block plantation of commercial trees and also of biodiesel-yielding plantations like *Pongamia pinnata*, *Jatropha curcas* and *Euphorbia antisyphilitica*. Moreover, biomass from fast-growing trees like *Prosopis* and agricultural wastes may be used to generate electrical energy. Species such as *Tamarix articulata* and *Prosopis juliflora* producing huge biomass under saline conditions prove them ideal candidates for energy plantations. This approach will change the economic scenario by reducing the import of fossil fuels. Adopting biosaline agroforestry and silvopastoral systems, the nomadic behavior of large population will be checked in dry regions. This will have a tremendous social impact. Institutes already working in salinity-related problems may act as nodal institutes and may play more important role in promoting biosaline agriculture.

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