Pak. J. Bot., 44: 69-75, Special Issue May 2012.

REHABILITATION OF SALINE ECOSYSTEMS THROUGH CULTIVATION OF SALT TOLERANT PLANTS

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Abstract

In Pakistan, salt-affected regions have been drastically disturbed by unchecked activities of local populations. Removal of deep-rooted perennials and overgrazing destroy the native vegetation leading to rapid desertification. Shallow-rooted agricultural crops are grown on marginal soils on limited area that is not enough with respect to the spread of salinity problem. Sustainable restoration of these ecosystems requires a large scale integration of perennial plants (trees, shrubs and herbs) back in to farming systems. However, salinization processes continue because the available options for cultivation of perennial plants prove less profitable than agricultural crops. This study relates to resort the salt-affected lands for plant production and develop a technology for sustainable saline ecosystem. Plants, having salt tolerance potential, have been identified and introduced on salt-affected wastelands to develop a sustainable ecosystem with increased productivity. The biomass so produced can be used directly as forage, fuel, and even as food or feed. In addition, fish aquaculture, and some value-added products make this ecosystem more sustainable. This technology is practically demonstrated at Biosaline Research Station of Nuclear Institute for Agriculture and Biology (NIAB), Pakka Anna, Faisalabad, Pakistan. The marginally saline soils and wastelands ameliorated as a result of growing salt tolerant perennials can also be used for growing salt tolerant cultivars of conventional crops like wheat, barley and mustard. So, through proper management the saline ecosystem can become economical and profitable.

Introduction

Productivity of an ecosystem is one of the major factors in maintenance of biological diversity as a source of food and other products necessary for heterotrophs particularly human beings (Aga, 2009; Ahmad *et al.*, 2010). Saline ecosystem may be developed due to erosion, desertification and poor management practices for producing valuable food, forage, fuel and other products. Saline ecosystems are rapidly increasing and have reached at alarming levels (995 millions hectares) in the arid and semi-arid regions of world (Anon., 2001-02; Abdel-Dayem, 2005; Naz *et al.*, 2010a). Furthermore, scarcity of fresh water due to increasing consumption by human population and its non availability for the agricultural production is the main impediment that leads to secondary salinization of prime agricultural ecosystems. Similarly, the sub-standard canal irrigation system in arid regions has substantially decreased the productivity of 400 million hectares of agricultural ecosystems (Akinel & Simsek, 2004).

Soil salinity adversely reduces the overall productivity of ecosystem as plants face numerous abnormal morphological, physiological and biochemical changes that cause delayed germination, high seedling mortality, poor crop stand, stunted growth and reduce yields (Ashraf *et al*., 2002; Ahmad *et al.*, 2010 b). Increase in soil salinity decreases productivity to a level where growth of non-halophytes becomes impossible. Yokoi *et al*. (2002) estimated that 50% of agricultural land is salt stressed in the arid and semi-arid regions of the world which is a serious threat limiting crop production (Munns, 2002; Ahmad *et al.*, 2009).

Recent estimates (Meijerink & Roza, 2007) show that 44 countries in Asia and Africa are facing critical shortage of agricultural land to support their populations. In addition, fuelwood and industrial raw material supplies are being rapidly and severely depleted by over-utilization of soils (Boland *et al*., 1996). The African and South Asian countries contain 183 x 10 ha of salt-affected land (Khan & Glenn, 1996), of which 91 x 10 ha has electrical conductivity of the saturation extract (ECe) levels of 1500 mS m^{-1} within the upper 0.75 to 1.25 m of soil. Such soils are suitable for growing of halophytic plants but not for the normal glycophytic crop plants (Malcolm, 1985). A further 11 countries in Central America are critically short of land for agriculture but there are only 2 x 10 ha of salt-affected land in this region (Ashraf, 2007).

Saline ecosystems are usually highly erosive, due to high exchangeable sodium levels; they remain frequently bare due to over-utilization, and generate salt and/or soil laden winds or run-off to streams or adjacent land (Hameed *et al.*, 2008; Qadir *et al*., 2009). The poor vegetative cover on many salt-affected areas is ineffective in using saline groundwater; as a consequence groundwater levels are unnecessarily high and may contribute to streams or underground water reserves. Revegetation of saline areas controls wind and water erosion, assists in using excess groundwater, provides food and cover for domestic animals or wildlife and/or provides fuel-wood and improves aesthetics (Naz *et al.*, 2010 b).

Salinity and water-logging problem is implicated in decline of several ancient civilizations. At present, it is threatening the agricultural production system of developing countries in arid and semi-arid areas; 25% of the Indus Basin, 40% of Nile Delta, almost 50% of the irrigated areas of some countries in central Asia, most of the Mesopotamian plain and substantial areas in North Africa have been affected by moderate to severe salinity problem. Many of the poor and undernourished people live in these areas. Population is growing so quickly that the land and water resources cannot sustain them; prime farmland and fresh water have been already fully utilized. There is a clear need to bring salt-affected land and water resources into production.

For rehabilitation of the saline ecosystem under study, an integrated approach by using genetic resources (plants, animals, fish, insects and micro-organisms), saline groundwater, improved cultural practices to obtain adequate productivity from saline area on a sustainable basis without employing costly reclamation measures was adopted.

Materials and Methods

Location and climate of selected saline ecosystem: The selected saline ecosystem is located near Pakka Anna at a distance of 40 km in the South-West of Faisalabad, Pakistan (longitude 73°.05'E and latitude 31°.24'N) with an elevation of 190 m above sea level. It comprises of 400 ha of salt-affected land. The land was not cultivated earlier and lying barren since decades. The climate of this ecosystem is semi-arid with an annual average rainfall of 325 mm and evaporation exceeds 1600 mm. The annual average temperature in the area is 32°C.

Soil and water: The soil and water samples from the ecosystem were collected and analyzed according to the methods described in US Staff handbook-60 (Anon., 1962) for their physico-chemical characteristics which are summarized in Table 1.

Table 1. Characteristics of soil and water of BSRS Pakka Anna ecosystem, NIAB, Faisalabad, Pakistan.

Characteristics	Soil	Water
	Range	Rang
Soil texture	Sandy loam	-
Clay (%)	14 ± 1.4	-
Silt (%)	18 ± 1.5	-
Sand (%)	68 ± 3.1	-
EC (dS m^{-1})	5.2-49.24	4.97
TDS (mg L^{-1})	-	3878
Saturation percentage	25.36-31.45	-
pH	7.82-8.92	8.2
Bulk density (g cm^{-3})	1.38-1.58	-
CO_3 (me L^{-1})	-	1.5
HCO_3 (me L^{-1})	-	21.75
$CaCO_3$ (%)	1.2-2.3	-
$CaSO_4.2H_2O$ (%)	2.56-4.15	-
SAR	-	40.5
SAR adj	-	101.25
RSC	-	21.60
Na^+(me L^{-1})	-	51.2
K^+ (me L^{-1})	-	0.4
Ca^{2+}+Mg^{2+} (me L^{-1})	-	3.21
Cl^- (me L^{-1})	-	13.75
SO_4 (me L^{-1})	-	17.35

The soil was saline-sodic to sodic with medium to light texture. Soil salinity is highly variable; electrical conductivity (EC_e) ranges from <5 dS m^{-1} in the sandy patches to >50 dS m^{-1} but is mostly between 10 to 20 dS m^{-1}. The $CaCO_3$ content ranges from 1.2 to 2.3% in the 0-30 cm soil. The groundwater is shallow and brackish with EC = 4.97 dS m^{-1}, SAR = 40 and RSC = 21. Salt concentration in the groundwater increases with depth; it ranges from 4000 to 6000 ppm in shallow to 100 m depth. This water is thus unfit for irrigation and of hazardous category. At present, water table in the area is 5-6 m deep which was 1-2 m initially when work started there in 1992.

Natural vegetation: The natural vegetation of ecosystem was sparse represented by scrub type consisting of *Prosopis juliflora*, *Suaeda fruticosa*, *Aeluropus lagopoides* and *Eleusine flagellifera*. Salinity levels in soils under these species differed greatly but the soil was invariably sodic. *Aeluropus* was dominant species on very highly saline (EC_e = 40 dS m^{-1}) and *Eleusine* on highly saline (EC_e = 23 dS m^{-1}) soils. *Suaeda* had wide distribution and was an important species in these communities. Total plant cover was higher in area of low salinity.

Findings of our different studies indicated that introduction of salt tolerant grasses/plants on saline ecosystem reduced the soil EC, SAR and pH and improved the fertility of soils (Ashraf *et al*., 2010) by removing salts and increasing organic matter and essential nutrients necessary for the cultivation of conventional crops thus helped in rehabilitation of saline ecosystems.

Introduction of salt tolerant plants: About a dozen of the selected salt tolerant plants were introduced at the study site. Among these, forage grade species included *Leptochloa fusca* (Kallar grass), *Sporobolus arabicus*, *Brachiaria mutica* (Para grass), *Echinochloa* sp. (Swank), *Sesbania* spp. (Jantar), *Acacia ampliceps* and *Atriplex* spp. (Saltbush). Salt tolerant crop plants were grown in appropriate seasons.

Determination of nutritive values of forages: The halophyte species, viz. *Leptochloa fusca* (Kallar grass), *Sporobolus arabicus*, *Brachiaria mutica* (Para grass), *Echinochloa* sp. (Swank), *Sesbania* spp. (Jantar) and *Atriplex* spp. (Saltbush), *Suaeda fruticosa* (Lana) and *Kochia indica* (Kochia) were introduced at BSRS Pakka Anna. When the plants were at the feeding stage, samples were collected and evaluated for their nutritive values. Aboveground portions of above-mentioned salt tolerant plants were analyzed for dry biomass, crude protein, crude fiber, ether extract (EE) and ash by standard analytical methods after Anonymous (1990). Nitrogen free extract (NFE) was calculated by the following formula:

$$\% \text{NFE} = 100-(\%\text{CP} + \%\text{CF} + \%\text{EE} + \%\text{ash})$$

The aboveground plant material was digested according to Wolf (1982) and cations like Na^+, K^+ and Ca^{2+} were estimated by flame photometer (FP7, Jenway, England). From the same aliquot Mg was determined titrimeterically as described in US Salinity Lab Hand Book-60 (Anonymous 1962) and P using Barton's reagent (Jackson, 1962). The data were statistically analyzed (Steel & Torrie, 1980).

Results and Discussion

Selection of salt tolerant plants: To restore productivity of saline ecosystem, selection and introduction of multipurpose salt tolerant plants with desirable characteristics is necessary. So large number of plant species have been screened for their salt tolerance using hydroponics technique (Anon., 1997 and Aslam *et al*., 2009). The overall results of screening work on salt tolerant germplasm showed that the maximum amount and kind of salts that can be tolerated by salt tolerant plants varies among species and even varieties of a species. Many salt tolerant plants have a special and distinguishing feature; their growth was improved at low levels of salt. Dozen of the selected plants were introduced at selected saline ecosystem at BSRS Pakka Anna. These plant species comprised of trees, shrubs and grasses (Table 2).

Table 2. Salt tolerant plants introduced at BSRS Pakka Anna

Species	Root-zone salinity causing 50% yield reduction	
	EC (dS m^{-1})	% Salt
Grasses		
Leptochloa fusca	22.0-14.6	1.41-0.93
Sporobolus arabicus	21.7	1.39
Hordeum vulgare	19.5-10.0	1.25-0.64
Panicum antidotale	16.0	1.02
Echinochloa colonum	11.2	0.72
Shrubs		
Suaeda fruticosa	48.0	3.07
Kochia indica	38.0	2.43
Atriplex amnicola	33.0	2.11
Sesbania aculeata	13.0	0.83
Trees		
Acacia ampliceps	35.7	2.26
Prosopis chilensis	29.4-29.3	1.88-1.87
Acacia nilotica	27.9	1.78
Eucalyptus striaticalyx	26.2	1.68
Prosopis cineraria	24.4	1.56
Casuarina glauca	24.4	1.56
Prosopis tamarogo	22.7	1.45
Leucaena leucocephala	17.2	1.10
Vegetables		
Brasssica napus	19.5	1.25
Spinacea oleracea	14.8	0.94
Brassica carinata	14.0-12.5	0.90-0.80
Brassica juncea	12.4-8.44	0.79-0.54
Brassica compestris	09.9	0.63
Eruca sativa	09.6	0.61

Utilization of salt tolerant plants for the rehabilitation of saline ecosystem, also called Biosaline Agriculture, is an untraditional approach and is an alternative to the traditional leaching and drainage solution (Dagar, 2009). It is rather developing and adopting methods to live with salinity (Khan, 2007). Since, it is a low input approach; it is beneficial and more appropriate for countries having adverse socio-economic conditions (Aslam *et al*., 2009). Through this approach underground brackish water and salt-affected soils can be utilized for developing sustainable ecosystems involving agro-forestry and animal husbandry on scientific lines. This technology provides a cheap alternative on interim basis for utilizing salt-affected and/or water-logged land and brackish groundwater to irrigate conventional crops, without employing costly reclamation measurers.

Potential uses of salt tolerant plants: It is necessary to exploit salt tolerant plants (Table 2) for food, feed, fodder and industrial raw materials. These plants may contain some unusual compounds. Some salttolerant plants have alkaloids, resins, essential oils, pharmaceutical feedstock and other unusual compounds (Adam, 1984). Nutritional characteristics or even potential toxicities have not been established for many edible salt tolerant plants (Naqvi *et al*., 2001). An understanding of the nature and concentration of such compounds is essential for two reasons. Firstly, such information would be useful in estimating the health hazards on the animals, if their feed consists of a greater proportion of these plants. Secondly, these unusual compounds may be of some economic value and may thus be useful to commercially extract them by developing suitable techniques. In essence, exploration for new species for the selection of desired genotypes, from a wide range of natural variability in individual salt tolerant plants should continue.

It was observed that farmers as well as livestock of saline ecosystems face great scarcity of food, fodder and feed. The farmers of these areas often arrange fodders for their livestock from other areas at very high cost (Ashraf, 2007). Some of the grass and bush species can be utilized as fodder but farmers are reluctant to use them because the high salt content may be toxic to livestock. Increased knowledge of the nutritive value of a range of salt tolerant plant species could result in their acceptance by farmers as fodder sources for livestock. In this study forage value and chemical composition of some salt tolerant plants were determined which showed that these plants have the potential to be utilized as forage for livestock.

Forage plants: The selected salt tolerant forage grade species included *Leptochloa fusca* (Kallar grass), *Sporobolus arabicus*, *Brachiaria mutica* (Para grass), *Echinochloa* sp. (Swank), *Sesbania* spp. (Jantar), *Acacia ampliceps* and *Atriplex* spp. (Saltbush). Kallar grass has high water requirements, needs excessive irrigations and tolerates very high soil and water salinity. Kallar grass is palatable with little salts in its leaves. It increases the hydraulic conductivity of soil and helps leach down salts from the root zone (Ashraf *et al*., 2010).

Sporobolus arabicus, a relatively low water requirement grass, provides soft fodder when harvested on 2-3 months interval and tolerates moderate salinity. Para grass, a perennial grass growing on saline soil, is very much liked by ruminants. It needs medium irrigation and tolerates salinity under irrigated conditions. It produces large quantity of palatable high quality biomass retaining little salts in fresh biomass.

Echinochloa and *Sesbania* are salinity tolerant summer fodders and produce soft palatable fodder biomass under well-irrigated conditions. Saltbushes (Atriplex) and *Suaeda fruticosa* are perennial species well adapted under arid environments that need very little irrigation and tolerate very high salinity. However, high salt contents in Atriplex and *Suaeda fruticosa* leaves reduce their value as forage. *Kochia indica*, a naturally occurring species, is successful under drought, high soil salinity and moderately elevated pH. Under irrigated conditions, it provides large quantity of good quality fodder biomass in summer.

Kallar, *Sporobolus* and Para grasses excrete the absorbed salts through the salt glands present in their leaves (Wieneke *et al.,* 1987) so these species contained more water than other salt tolerant bushes (Aganga *et al.,* 2003; Venuto *et al*., 2003; Al-Khateeb, 2006). The palatability reports indicated that *Sporobolus,* Kallar and Para grasses are more palatable than salt bushes like Atriplex and Kochia (Squires & Ayoub, 1992; El Shaer *et al*. 2000; Aganga *et al.,* 2003). Similarly, Casson *et al*. (1996) and Ashraf (2007) reported that higher dry matter in salt tolerant plants is due to high accumulation of salts, which is very clear from the present study, because the total mineral contents were very high in the salt tolerant bushes (Table 3).

Table 3. Chemical composition of some salt tolerant plants used as fodder on dry matter basis

Name of fodder	Dry biomass	Crude protein	Crude fiber	Ash	EE	NFE
	(%)					
Kallar grass	33.45	9.78	24.56	11.23	2.15	52.28
Sporobolus	42.43	10.75	27.67	8.86	1.52	51.2
Para grass	36.45	7.54	28.45	9.76	1.78	52.47
Swank	31.24	14.78	26.34	14.56	3.21	41.11
Jantar	21.76	19.43	18.43	11.23	5.25	45.66
Atriplex	48.98	15.78	20.34	24.76	1.12	38
Kochia	21.23	12.14	20.67	21.86	1.74	43.59
Suaeda fruticosa	48.34	8.21	15.32	37.89	1.21	37.37
Acacia ampliceps	23.34	11.23	20.76	21.26	3.52	43.23
LSD ($p \leq 0.05$)	1.578	1.955	2.035	3.178	0.574	2.124

The ash content (minerals) were the maximum in *Atriplex lentiformis,* followed by *Suaeda fruticosa*, *Kochia indica*, *Leptochloa fusca, Sporobolus arabicus* and Para grass (Table 3), which confirmed that maximum salts were accumulated in salt bushes and minimum in grasses (Table 3; 4). On the basis of lower salt concentration, grasses are more palatable for livestock. Many reports indicated that the plants containing higher salts concentrations are toxic for livestock and are responsible for different types of diseases and physiological disorders (Ashraf, 2007). The literature indicates that the animals fed on plants having higher concentrations of salts cause lesion and rashes in the stomach of the animals (Atiq-Ur-Rehman *et al*., 1994). Many reports (Salem *et al*., 2004; Aganga *et al*., 2003) have suggested mixing of *Atriplex*, *Suaeda fruticosa* and Kochia in animal ration as a result of which Na^+ as well as other salt concentrations can be reduced in animal ration and can be made more palatable and digestible.

Table 4. Nitrogen, phosphorus and mineral contents in some salt tolerant plants used as fodder.

Name of fodder	N	P	K	Ca	Mg	Na
	mg g^{-1} DW					
Kallar grass	5.35	2.38	15.27	2.91	1.67	1.90
Sporobolus	6.79	2.27	16.34	2.64	1.54	1.82
Para grass	5.83	2.18	17.56	2.45	1.35	1.79
Swank	7.34	2.45	15.45	1.87	1.75	2.76
Jantar	3.48	2.13	18.34	2.25	2.25	2.98
Atriplex	7.84	2.67	19.89	6.67	2.19	5.84
Kochia	3.40	3.04	20.35	5.34	2.41	4.27
Suaeda fruticosa	7.73	3.35	18.78	4.59	2.48	6.81
Acacia ampliceps	3.73	2.25	16.85	3.12	1.25	2.99
LSD ($p \leq 0.05$)	1.218	0.547	1.579	0.758	0.458	0.345

Salt bushes had more protein than salt tolerant grasses while reverse was the case for crude fibers. Carbohydrates were the highest in *Sporobolus arabicus,* followed by Para grass, *Leptochloa fusca,* Swank, *Acacia amplicepes*, Kochia and *Atriplex.* So, grasses are more useful for animal health. However, saltbushes can be used as mixed ration.

The palatability checked at NIAB (Anonymous, 1997) and at other places of the world also indicated that the grasses are more palatable and digestible than salt bushes like *Atriplex*, *Suaeda fruticosa* and *Kochia indica.* On the basis of above results grasses and *Acacia ampliceps* seemed more useful and close to the normal fodder for livestock. So, grasses were introduced in the ecosystem at BSRS Pakka Anna to produce fodder for livestock. The salt tolerant bushes are also grown to feed by mixing with other fodders containing lesser amount of salts. The findings of Animal Sciences Division, NIAB also proved that feeding of salt tolerant grasses and *Acacia amplicepes* had no adverse effects on health and reproduction of dwarf goats (Naqvi *et al*., 2001).

Livestock rearing: All non-conventional forages (shrubs, trees and grasses) having nutritive value were cultivated on large area of the BSRS Pakka Anna ecosystem. The biomass is being used successfully as forage for goat rearing. Initially dwarf (Teddy) goats were reared but now hybrid of local breed Beetal and dwarf goat that have good traits of both breeds (high weight, milk yield and prolificacy) are being reared at this selected ecosystem. The benefit-cost ratio of goat rearing was found to be 1.3 (Mahmood *et al*., 2011).

Saline aquaculture: Saline aquaculture is an important option for profitable use of saline water. Therefore, research efforts have been made to select suitable fish breeds for saline ecosystem and fish breeds like Thaila, Grass Carp, Silver Carp and Golden Gulfam proved their adaptation to saline environments by producing higher biomass than others. So, these were cultured and benefit: cost ratio was 1.37. The economics could be further improved by adopting certain measures; the ponds with raised embarkations are cheaper to develop thereby reducing the digging cost. Fish can be fed on biomass from salt tolerant plants along with supplements thus saving up to 50% in feed costs (Mahmood *et al*., 2011).

However, if these areas are utilized for developing pastures or rangelands with salt tolerant forage plants, good economic returns can be achieved (Ashraf, 2007). The present studies have been conducted with the aim to work out the forage values and their chemical composition. On the basis of their utilization as forage, these salt tolerant plants can be recommended for the livestock of saline areas and salt-affected wastelands can be utilized for better economic returns.

Salt tolerant crops: In crop plants, barley line PK-30118 showed most adaptability to saline environment, therefore, this along with other lines is being grown at this ecosystem under salinity (Mahmood, 2011). Similarly, among wheat cultivars, S-24, Bhakkar, Sarsabz, and a selected line AR-4 showed better adaptability to saline-sodic soil (Table 5). Among *Brassica* species (an important oilseed crop), *Brassica juncea* line SMP-13-78 and *B. napus* var. DGL were successful in producing higher seed at low soil salinity (EC = 10 dS m^{-1}). For high soil salinity (EC=20 dS m^{-1}), varieties RL-18 (*B. juncea*) and Shieralle (*B. napus*) proved better yielding. Another oilseed crop locally called Taramera (*Raphanus raphinastrum*) was also successful under low soil salinity (Table 6).

Table 5. Yield performance of different wheat cultivars grown at BSRS Pakka Anna saline ecosystem.

Wheat cultivars	Salinity levels (dS m^{-1})				Mean
	11.57	8.57	7.68	6.78	
	Grain yield (g m^{-2})				
S-24	368	454	453	457	433.00
AR-4	294	305	369.7	394	340.67
Sarsabz	318	371	392	403	371.00
Bhakkar	433	425	431	418	426.75
Sehar	383	437	448	449	429.25
Seta	347	386	423	413	392.25
Mean	**357.17**	**396.33**	**419.45**	**422.33**	
LSD ($p \leq 0.05$)		9.87 (salinity level)			14.75 (cultivar)

Salt tolerant shrubs and trees: Salt tolerant tree plants which are introduced in this saline ecosystem included four provenances each of *Eucalyptus camaldulensis, E. microtheca, Casuarina equisetifolia*, five of *C. glauca* and two each of *Acacia stenophylla* and *A. ampliceps*. In addition, 120 seedlots of *Eucalyptus camaldulensis* and 75 seedlots of *Acacia ampliceps,* mainly from CSIRO, Canberra, Australia were also tested for their field performance under environmental conditions of this saline ecosystem. Both species had impressive growth; however, wide variations were observed between the seedlots as well as provenances that have great potential for improvement by selection (Marcar *et al*., 1997; Mahmood *et al*., 2003). The *Eucalyptus* and *Acacia ampliceps* trees become ready for sale after 10-12 years, fetching average price of Rs.1000 per tree with an estimated annual income up to Rs. 180,000 and Rs. 100,000 per hectare, respectively.

Acacia nilotica, a native species locally known as Kikar, produces good quality wood suitable for furniture. Application of ½ kg gypsum powder per tree at the time of planting proved highly effective for tree establishment. *A. nilotica* wood has good commercial value and may sell on the average price of Rs. 3000 per tree after 20 years growth.

Mesquite (*Prosopis juliflora*) is a naturally occurring species with low water requirement. If dressed to improve stem girth, it can be sold as good fire wood after 4-5 years. Other trees adapted to saline lands include *Parkinsonia*, Frash (*Tamarix*), Neem (*Azadirachta indica*) and Iple Iple (*Leucaena leucocephala*).

Table 6. Yield performance of different varieties of Brassica species under different salinity levels at BSRS Pakka Anna saline ecosystem.

Brassica spp./Variety	**Salinity levels (dS m^{-1})**				
	5.30	**10.35**	**20.76**	**27.89**	**Mean**
	Seed yield per plot (kg)				
Brassica carinata/Brown Raya	7.40	4.14	0.38	0.20	3.03
Brassica carinata/Peela Raya	14.90	9.60	6.68	6.05	9.31
Brassica juncea/SMP-13-78	14.61	8.30	3.50	2.10	7.13
Brassica juncea/Raya Anmol	6.60	5.00	1.40	0.01	3.25
Brassica juncea/ORI-50-60	9.10	7.36	7.42	0.88	6.19
Brassica juncea/RL-18	15.8	9.08	7.10	4.60	9.15
Brassica juncea/Toria	7.60	4.50	3.50	1.45	4.26
Brassica napus/Sheiaralle	20.85	8.80	8.20	4.60	10.61
*Brassica napus/*DGL	18.85	6.82	1.50	1.50	7.17
*Brassica campestris/*Saqsarson	5.98	2.04	1.55	1.33	2.72
*Brassica campestris/*BSA	7.68	2.00	0.40	0.01	2.52
Raphanus raphinastrum/ Taramira	13.91	6.30	1.50	0.15	5.46
Mean	**11.94**	**6.16**	**3.59**	**1.91**	

LSD ($p \leq 0.05$) salinity level = 2.237 LSD ($p<0.05$) variety = 3.785

Some selected salt tolerant fruit plant species including Pomegranate (*Punica granatum*), Guava (*Psidium guajava*), Jaman (*Syzygium cuminii*), Beri (*Ziziphus jujuba*), Date palm (*Phoenix dactylifera*) and Corunda (*Capparis corunda*) have also been tested for adaptability. Among these, pomegranate has been the most successfully adapted species tolerating moderate salinity and sodicity stress.

Value added products (*Eucalyptus* leaves oil): *Eucalyptus* is among the most suitable tree species for saline and water-logged environments. Apart from the timber and fuel wood, it provides a lot of leaf biomass that contains essential oils. The oil extracted from eucalyptus leaves has good market value for its commercial and medicinal uses. A pilot scale plant for oil extraction from eucalyptus leaf biomass has been installed at the station for demonstration. The process is simple and profitable with a benefit: cost ratio of 2.1.

Conclusions

The findings of present study provide sustainable solution for rehabilitation of saline ecosystems through the cultivation of salt tolerant plants. The Bio-saline Research Station, Pakka Anna especially has, over the last 20 years, served as demonstration site for stakeholders, and has helped disseminate the Biosaline Agriculture Technology both at national and international levels. Using brackish groundwater for irrigation, a number of plant species/varieties of barley, forage grasses, saltbushes, and tree species can be grown under saline environment with considerable productivity. The biomass so produced can be utilized as forage, fuel, and even food/feed. In addition, fish aquaculture, and some value addition enterprises proved very productive and economical for contributing the sustainability of the ecosystem. An integration of the possible interventions may make the ecosystem rehabilitation efforts economically feasible on a self-sustained basis.

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(Received for publication 16 April 2012)