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Haloculture: strategy for sustainable utilization of saline land and water resources

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Abstract

Land salinization is a major obstacle to the sustainable development of agriculture in arid regions. The demand for food, fiber, fuel and fresh water has increased in the recent decades, particularly in developing nations, due to alarming rise in population. As fresh water resources and productive lands for crop production are limited, new strategies for the sustainable utilization of marginal lands and water resources have become urgently necessary. The objective of this article is to propose Haloculture as a holistic approach for the sustainable management of saline resources, enhancement of environmental quality and improvements in socio-economic conditions in less developed salt affected regions. Haloculture refers to the sustainable production of agricultural and industrial products in saline environments. It is essentially an integrated production system that makes use of diverse salt tolerant aquatic species and halophytes to produce different economically and industrially valuable products such as food and fuel and environmental services from the salt affected lands. Although immense socio-economic, industrial and environmental benefits of Haloculture are increasingly becoming evident, careful ecological, cultural and economic considerations are a pre-condition for the successful implementation of Haloculture-led improvements in saline environments.

Keywords: Haloculture, Seawater agriculture, Biosaline agriculture, halophyte, saline aquaculture

1. Introduction

The alarming rise in world population in the recent decades has imposed great demands on natural resources to meet the growing needs for food, fiber, fuel and drinking water. According to FAO statistics, global food production needs to increase up to 70% by 2050 to ensure adequate and safe access to food to the burgeoning population (Panta et al. 2014). This is also true for arid and semi-arid regions, where fresh water resources are scarce and are in high demand for urban consumption. As most of the productive soils are being used for agricultural production and as inter-sectoral competition between agriculture and other segments of economy are increasing, there is little scope for agricultural expansion in prime lands (Qadir and Oster, 2004). About 950 Mha of land surfaces and 50% of irrigated lands (230 Mha) are salt affected in the world (Ruan et al. 2010). It is estimated that the global annual losses in agricultural production from salt affected lands amounts to more than US\$ 12 billion (Shabala 2013). In addition, out of 1386 billion cubic meters of total world water resources, less 1% (about 10.6 billion cubic meter) are actually available for human use, which are present in deep ground water aquifers and water bodies such as lakes and rivers (UNEP 2002).

The rise in world population, will also put more pressure on available good quality water resources, to meet the escalating demand for urban use and drinking water needs. It is believed that the need for increased food production cannot be achieved merely by cultivating the currently available arable lands (Shabala 2013). Consequently, using marginal lands, such as salt affected lands, and alternative water resources, such as saline waters, for agricultural production, could be an inevitable option to achieve the human food needs in future. Therefore, it is necessary to expand the utilization of more salt tolerant plants, particularly halophytes, and livestock that can tolerate saline drinking waters and halophyte forages, such as camel, as well as, expanding saline aquaculture to provide the necessary human food supplies in future.

Soil and water salinity, after erosion, are the most important limiting factors in agricultural development of Iran where vast tracts of such soils are found in different parts. Recent studies revealed that the extent of low to moderately saline soils ($4-16 \text{ dS m}^{-1}$) is about 25.5 million ha, and the soils with severe salinity ($16-32 \text{ dS m}^{-1}$) occupy about 8.5 million ha (Moameni et al. 1999). These marginal lands are spread all over the country in different agro-climatic zones. Furthermore, about 50% of irrigated lands in Iran are salt affected (Cheraghi 2004). The annual agricultural production losses from these salinized agricultural lands have been estimated to be at about 50% of the total potential production (Siadat

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et al. 1997). Therefore, it becomes imperative to precisely assess the potential of degraded and wastelands and non-conventional water resources to sustainably augment agricultural productivity and improving farmers' livelihoods in these challenging environments.

Cultivation of salt tolerant crops and halophytes is seen as a practically feasible and economically viable option for utilizing the saline soil and water resources, and conserving fresh water for other much needed purposes (Glenn et al. 1998, 1999; Ladeira 2012; Ventura and Sagi 2013; Panta et al. 2014; Agnihotri and Kumar 2015; Sharma and Singh 2015; Ventura et al. 2015). Agricultural production of halophytes using seawater and other saline resources has been investigated. Conventional agriculture under saline conditions often requires heavy leaching, irrigation with fresh water, and adequate drainage to ensure good yields. Factors such as fresh water shortages, high capital investments, and poor access to appropriate technology often force the farmers to abandon such lands after a few years of salinity development. The lands not cultivated for years exhibit accelerated rates of land and ecosystem

degradation that adversely affect the socio-economic well-being of the local communities. Under these circumstances, the need for a technology that is practical, requires low inputs and is sustainable in longer runs becomes imperative. *Haloculture* can be an important option under such conditions. The objective of this article is to introduce and discuss Haloculture as a practical and sustainable production method in saline environments.

2. Haloculture Fundamentals and Production System

Haloculture is proposed a holistic approach for (i) sustainable management and utilization of saline soil and water resources, (ii) combating the damage caused by desertification, erosion and dust storms, and (iii) increased agricultural production, creation of employment opportunities and socio-economic improvements in the less developed regions. Haloculture is defined as the sustainable production of different agricultural and industrial products in saline environments (Fig. 1).

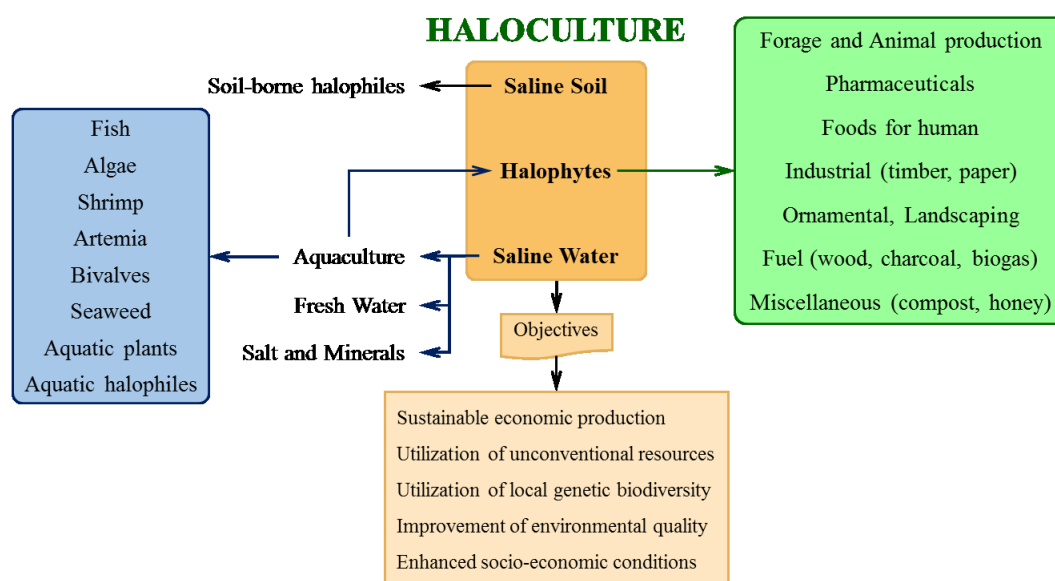


Fig 1: Schematic representation of the principals and objectives of Haloculture

Agricultural products include diverse output from plant (agronomic, horticultural, forestry, range, ornamentals and medicinal plants), animal (small and large livestock, poultry, honey bees, etc.) and aquaculture (fishes, shrimps, seaweed, algae, artemia, halophiles, etc.) resources. Similarly, *industrial products* refer to processed forms of the agricultural products as well as the production of water, salt and energy. Genetic biodiversity is the key to the productive use of saline environments. It includes plant, animal and microbial

resources that can be grown in salinized lands and/or aquatic environments. Due to significant differences in agro-climatic conditions, Iran boasts rich genetic diversity of crops, animals and microorganisms for profitable Haloculture under varying saline conditions in different geographic locations. Availability of diverse potential resources- either individually or in combination with each other- literally means a diversified Haloculture. Based on empirical evidences regarding the shortcomings of crop monocultures

(Hennessy 2004, Suárez and Emanuelli 2009), it is always desirable to have an integrated Haloculture production system. This will enable the efficient use of the available resources and will minimize the risks caused by inimical conditions (e.g., extreme climate events) by enhancing the resilience of the system (Hendrickson et al. 2008, Manjunatha et al. 2014).

Basically, integrated Haloculture production system, may be divided into four components (Fig. 2). The salt-affected water resources that can be used productively, include saline ground water, sea water, agricultural drainage water and effluents from desalination plants. A Haloculture Agro-Industry Complex is called *Haloventure*. The first phase of Haloventure starts with saline aquaculture through fish, shrimp and/or algae. The water discharged from aquaculture is used for halophyte production for various purposes. Halophytes play an important role in non-aquaculture production. In fact, halophytes are regarded as new agronomic crops in

Haloculture with various economic uses (Fig. 1). Most often, the salinity of such lands is too high for economic production of conventional agronomic crops. Even if the existing conditions permit the cultivation of conventional crops, it is suggested to include them in the production system as well. The drainage water from halophyte fields may be collected and reused in the aquaculture component (phase 3). This drainage water has more salinity than the water used in phases 1 and 2 of Haloventure. Therefore, salt tolerant marine and aquatic species such as artemia are preferred in this phase. The highly saline water or brine discharged from phase 3 should be disposed properly in phase 4 to make economic uses, and more importantly, prevent the environmental damages. The economic activities in this phase may include salt and mineral harvesting (Ahmed et al. 2000, Surinaidu et al. 2016) or producing energy by salinity gradient solar ponds (Malik 2011, Saifullah et al. 2012).

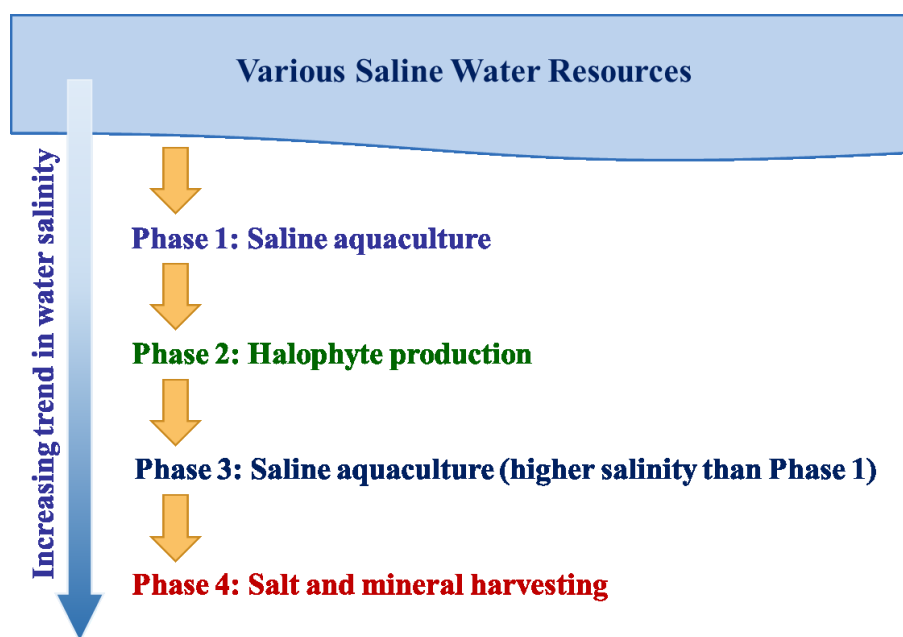


Fig 2: The main phases of integrated Haloculture

Haloculture integrated production system may be practiced as Haloventure in saline lands by using high salinity waters in coastal areas available from seas and oceans. Brines discharged from coastal desalination plants can also be a viable resource (Fig. 3). Similarly, inland saline water from different sources such as rivers and lakes, ground water, agricultural drainage waters and brines from inland desalination plants (Fig. 4). The main factors to be considered while deciding the type of economic activities in Haloventure are as follows.

- Environmental factors: such as the quantity and quality of the available saline soil and water , and local climate,
- Economic factors such as the amount of capital investment, and short and long term profitability,
- Management and expertise capability,
- Availability of technologies,
- Human capital issues such as availability of expert personnel and skilled work forces,
- Distance to market as well as local, regional, national and international market needs, and
- Regional natural and infrastructural capacity: such as genetic biodiversity, processing factories, electricity, roads and tourism.

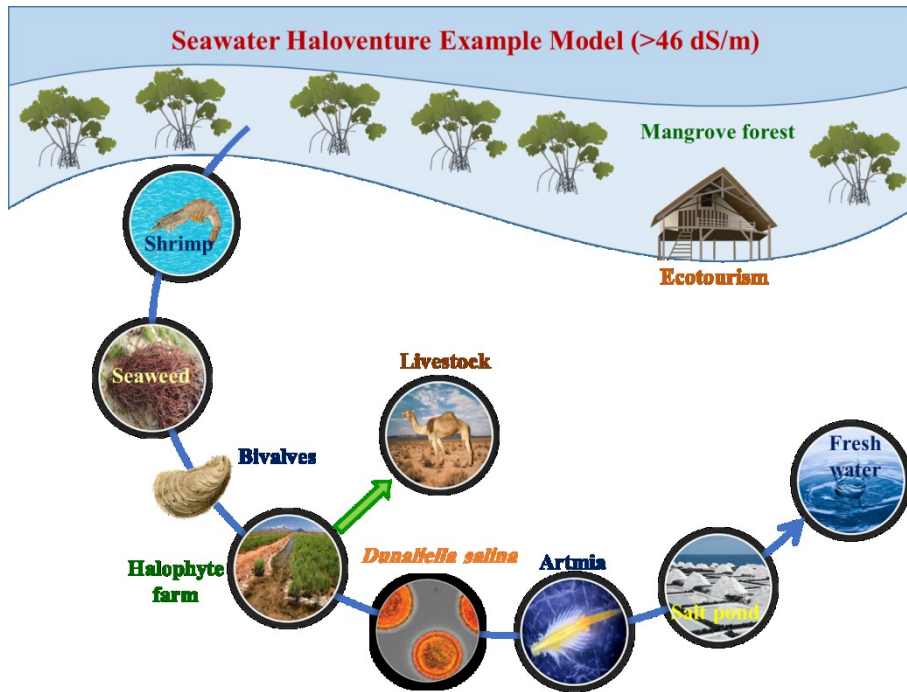


Fig 3: An example model of Haloventure in coastal areas using seawater

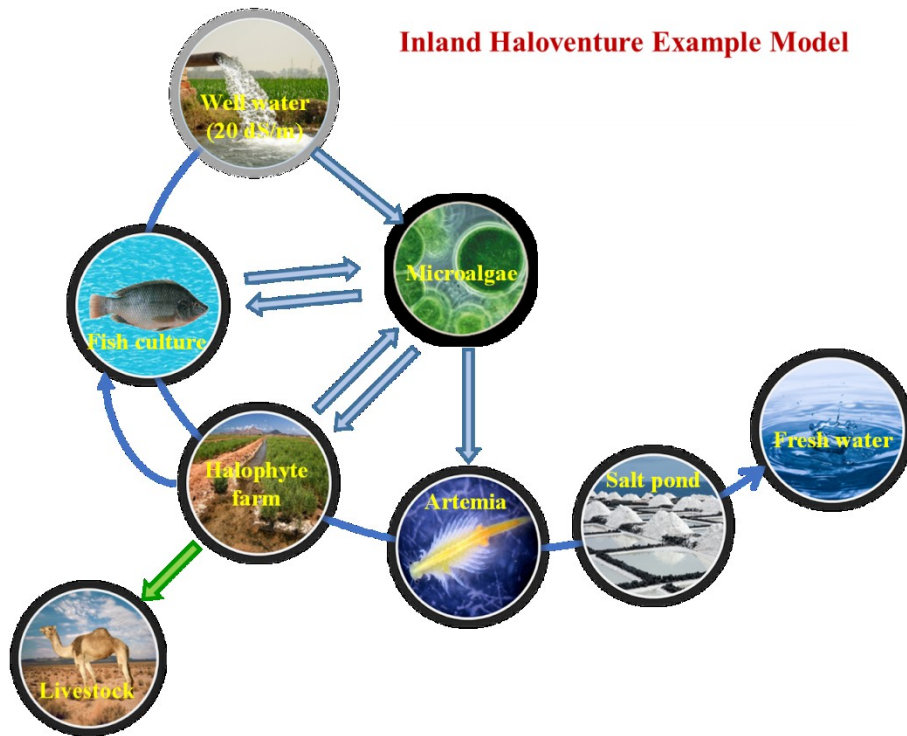


Fig 4: An example of Haloventure using inland water resources

3. Haloculture and Sustainability Principles

In order to gain wide acceptance, Haloculture as a new technology should be based on the three principles of sustainability: environmental stewardship, economic profitability and social acceptability.

3.1. Haloculture vs. Conventional Agriculture

Many of the economic activities in Haloculture, especially fish, shrimp and artemia production, animal husbandry and salt harvesting via solar salt ponds, are practiced all around the world including Iran. But, many other specialized activities particularly seaweed and microalgae production, although practiced in many parts of the world, are not practiced in commercially in Iran. Their commercial production in Iran can greatly contribute to the enhancement of biotechnology industry in Iran. These activities have been routinely practiced as monoculture in most parts of the world. Occasionally, in limited situations, they have also been tried as components of integrated production systems. For example, fish, shrimp and artemia farming as well as seaweed and microalgae production are common practices in many countries, all of which can use waters with salinities as high as sea water and even more. But few projects have operated as an integrated system of aquaculture, halophyte cultivation and livestock production. Manzanar Project in Eritrea, and the sea water farms in Eritrea and Mexico constitute relevant examples in this regard. Recently, integrated production systems comprising of fish farming + halophyte forage + goat production using brine waste from inland desalination plants has been shown to be viable and successful (Sanchez et al. 2015).

An important activity of Haloculture is agronomic production of highly salt tolerant plants and halophytes using saline wastelands and water. Halophytes are plant species that grow naturally in saline habitats (La Houerou 1994). They consist of thousands of grass species, shrubs and trees, and are distributed throughout different ecosystems. Conventional production of normal agronomic crops in saline lands requires leaching, provision of some sort of drainage and irrigation with fresh water especially during the sensitive stages of crops (Sharma and Singh 2015, 2016). It thus becomes evident that appropriate modifications are necessary to enable better crop growth under such condition. In many cases, however, even the aforementioned practices fail to give desirable results leading to the poor crop growth and yields. In Haloculture, a plant is selected that adapts well to the existing highly saline environment to greatly minimize the dependence on labor and energy intensive and expensive practices of land modification. Unfortunately, most of the cultivated crops have low salt tolerance that results in limited availability of salt tolerant cultivars suited to different conditions. Among agronomic crops, barley, cotton, wheat, sugar beet and sorghum exhibit moderate to high salt tolerance which often breaks down

as salinity exceeds threshold (Maas and Grattan 1999). Sugar beet and date palm are the only conventional crop plants that have originated from halophytic ancestors. In Haloculture, land modification is not usually necessary. It requires water, but not fresh water, and the choice range for salt tolerant plants is quite high. When using saline irrigation water, careful monitoring is necessary to avoid excessive salt build up in the soil, and to prevent contamination of freshwater resources. Also, salt tolerant crops and halophytes should be introduced where physical or economic constraints limit the cultivation of conventional crops.

The biomass produced by halophytes can be utilized as forage for livestock production, food, leaf protein, fruit, and vegetable for human consumption, landscaping and ornamentals, medicinal and biochemical, and wood and paper. The biomass can also be utilized for other purposes such as biogas production, composting and mushroom production by the farmers or entrepreneurs. Halophytes can have potential uses in biotechnology industry as well as a source of salt-tolerance gene(s) to increase the salt tolerance of conventional agronomic crops (Munns 2005, Rozema and Schat 2013).

Other agronomic benefits of halophyte production are organic matter addition to the soil, nitrogen fixation, improvement of soil structure and fertility, soil desalinization, and reduction of soil water evaporation (Manousaki and Kalogerakis 2011, Bailis and Yu 2012, Hasanuzzaman et al. 2014). Halophytes can also be incorporated into other agricultural systems through crop rotations and intercropping (Khan et al. 2009, Shamsutdinov and Shamsutdinov 2009, Qasim et al. 2011, Ventura et al. 2015). Khan et al. (2009) reported that a *Panicum-Suaeda* intercropping system maintained soil salinity at low levels, and annually produced 50 tons ha⁻¹ *Panicum turgidum* biomass as fodder. Research programs on halophyte potentials are necessary to develop an appropriate, simple technology that can be adapted easily by the poor resource farmers.

3.2. Environmental services of Haloculture

As previously mentioned, cultivation of highly salt tolerant crops and halophytes is one of the most important activities in Haloculture. Halophytes can be used either for environmental purposes or for biomass production. Environmental benefits and services of Haloculture are enormous. A self-explanatory example of such services is presented for a halophyte tree cultivation program in highly saline lands of Chah Afzal area, Yazd (Fig. 5). Environmental benefits of Haloculture include:

- Combating desertification,
- Combating soil erosion,
- Remediation of degraded lands (such as those contaminated by petroleum industries),
- Restoration of rangelands and greening of coastal areas,
- Reforestation of degraded salt-affected lands,

- Restoration and rehabilitation of wildlife and marine habitats, and
- Carbon sequestration and soil quality improvement through addition of organic matter, salt alleviation and soil structure improvement.

High capability of halophytes for phytoremediation of heavy metal contaminated soils and saline soils (Manousaki and Kalogerakis 2011; Hasanuzzaman et al. 2014) has been demonstrated. Haloculture is also a practical method for the prevention of environmental damages that may be caused by the disposal of saline agricultural drainage waters, nutrient rich waters

discharged from aquaculture farms, and saline and brine discharges from water desalination plants. Research results demonstrated that *Salicornia europaea* is as effective halophyte for biofiltration of saline wastewaters from commercial marine fish and shrimp farms (Webb et al. 2012). Studies in South America showed that integrated production of fish + halophyte forage + livestock production was a successful scheme for turning the environmental problem of brine reject disposal in inland areas, to a productive agricultural activities (Sanchez et al. 2015).



Fig 5: An example of valuable environmental services of Haloculture: left- a barren saline land and right- a rehabilitated saline land through halophyte planting (Chah Afzal, Yazd Province, Iran)

3.3. Environmental concerns about Haloculture

It should be mentioned that sustainability and environmental considerations with respect to Haloculture and other similar activities such as Biosaline agriculture or Seawater agriculture emanate from the damages caused by irrigated agriculture. In fact, many of the irrigation projects throughout the world have inflicted huge damages to soil and environmental health. The fact that a great proportion of global irrigated lands are currently severely affected by irrigation induced salinization is a convincing evidence to this claim (Munns 2005, Shabala 2013, Sharma and Singh 2015).

There may be some unintended environmental impacts of Haloculture that should be taken into considerations before initiating such projects. For example, utilization of local biodiversity in various economic activities of Haloculture as well as introduction of new plant and animal species from other regions or countries should be done with caution and under the advice of experts in the concerned field. Another legitimate concern about Haloculture, and in general about the use of saline water resources in agriculture, is the secondary soil salinization. In fact, if natural soil drainage capacity is

low, the continuous use of saline waters for irrigation, may lead to high salt accumulations in root zone inimical to even salt tolerant halophyte plants. Sanchez et al. (2015) reported progressive salinization of the land irrigated with saline water discharges from inland desalination plants. Therefore, it is strongly recommended that in areas having restricted soil drainage, artificial drainage systems may be installed to ensure the sustained reuse of the saline drainage water in activities such as artificial wetlands or solar salt ponds.

Studies with saline discharges from desalination plants in southern Arizona, United States (5% leaching fraction) revealed that these farms can be productively utilized through halophyte plants for at least 100 years without negatively affecting the groundwater quality more than conventional irrigated agriculture under the similar conditions (Riley et al. 1997). Haloculture is recommended in areas where conventional agriculture is not physically and/or economically feasible. Such areas include highly saline agricultural lands, salt marshes and degraded desert lands with sparse vegetation

3.4. Socio-economic implications of Haloculture

Besides long run environmental sustainability, profitability is another key factor that determines the acceptance and adoption of any new technology or practice by the farmers. The potential benefits of Haloculture, in most cases, can eventually lead to significant improvements in soil and environmental quality and can have significant impacts on living conditions and well-being of the farmers; if not necessarily result in higher incomes to the farmers. Integrated Haloculture production systems, by producing an array of useful economic products, can create new opportunities for income and employment leading to tangible improvements in the economic condition and income of the farmers and investors in a relatively short span of time (Torknejad and Koocheki 2000).

A successful seawater agriculture project called Manzanar Project was started in 1987 in Eritrea. The interesting thing about this Haloculture project was its humanitarian nature. The main humanitarian goal of the project was to offer low-tech solutions to poor resource farmers for eradication of poverty with the help and participation of local villagers (Sato 2009). The agricultural activities in this project were integrated production of mangrove tress for forage and coastline rehabilitation and goat production that was already an important economic activity among the villagers. The environmental and socio-economic impacts of mangrove forests were remarkable, and created ideal habitat for reproduction of several marine species. This in turn, not only provided adequate forage for goat production, but also provided new opportunities for the farmers to raise fish in small, manmade ponds, by collecting fish fingerlings, and made catching fish from mangrove forests as a new economic activity in the local villages (Sato 2009). It seems that the key factors instrumental in the success of Manzanar Project were thorough considerations with respect to the socio-economic needs of the people, local capacity and enhancement of coastal environment for devising the production system.

Successful implementation of Haloculture not only depends on the technical know-how and capital investments, but also on adequate considerations regarding the socio-cultural norms and ethos of local communities expected to benefit. The environmental and social implications of the very famous, integrated seawater agriculture farms from Eritrea and Mexico have been thoroughly evaluated (Bailis and Yu 2012). Eritrea farms were closed in 2003, mainly due to political unrest in that country, and Mexican farms were closed in 2010. In both the cases, positive environmental impacts on marginal and degraded lands were reported. However, ecological and cultural significance of such lands should be taken into considerations as well; otherwise, they may lead to closure of such programs, as was probably the case in Mexico (Bailis and Yu 2012).

It should be mentioned again that Haloculture is practiced in areas and locations, where high salinity of the soil and water make conventional agriculture an unprofitable activity. In socio-economical terms, Haloculture offers income and employment opportunities to combat poverty. The fact that it is a low input activity point to the need for less investment by the farmers. Under proper management, it has high output capability and assured returns to the growers and investors. Torknejad and Koocheki (2000) reported that the total investment per ha over 10 years is \$200 ha⁻¹, while proper management can provide net annual incomes as high as \$200 ha⁻¹. Economic return and profitability of agroforestry for wood production from ten species of halophytic tress in Pakistan, cultivated in highly saline soils (14-41 dS m⁻¹) were all positive and promising (Qureshi et al. 1993). Halophyte production economic return as compared to conventional agronomic crops is presented in Table 1 for Iran. The overall results from Pakistan study (Qureshi et al. 1993) and Table 1, indicate that profitability from halophyte production in saline conditions is comparable to those from conventional agriculture under non-saline conditions. Therefore, Haloculture can offer new sources of income for the resource poor farmers in salt affected areas, and thus enhancement of the living conditions and environmental improvement of the area. Poverty is an important factor and driving force in human induced degradation of the natural resources. Salt affected arid regions, due to shortage of fresh water resources and lack of employment, are usually adversely affected by several social problems. They include poverty, emigration from rural to urban areas for livelihoods, lack of social welfare, lower quality of life and social disorders such as crime, drug addiction and smuggling (Nichols et al. 2013, Ilyas 2015). Haloculture, by harnessing the potential of salt affected areas, will offer job and employment opportunities, investment opportunities for entrepreneurs, better living conditions, improved quality of life and satisfaction to the local communities. In fact, Haloculture can offer a logical and practical solution to poverty eradication in resource poor, less developed areas affected by salinity. Since, environmental degradation is common in such regions due to human and natural activities, Haloculture can be seen as a joint Government-People Collaboration Program to combat environmental degradation. While government can offer technical information and financial support to the local people, encouraging them to participate in environmental protection and rehabilitation activities of economic importance.

4. Conclusions and Recommendations

Haloculture has significant potentials in salt-affected arid regions, in terms of combating desertification, sustainable utilization of saline soil and water resources, sustainable use of agro-biodiversity, creation of employment and income generation opportunities for

Table 1. Comparison of the gross profits between halophyte production in Haloculture and conventional crop production under non-saline conditions.

Type of Production	Conventional Crop	Gross Profit (%)	Halophyte	Gross Profit (%)
Irrigated forage	Barley	46.7	<i>Panicum antidotale</i> (5 year average)	64.5
	Maize	64.1		
Rain fed forage	Barley	24.1	Atriplex (5 year average)	26.3
Irrigated oil seed crop	Sunflower	61.0	<i>Kosteletzkya virginica</i> (5 year average)	48.1
	Soybean (spring)	37.7		
	Soybean (summer)	35.3		
	Canola	55.9		
Agroforestry	Populus (7 years)	1827	Tamarix (4 years)	627

the resource poor farmers, and improving the socio-economic conditions of communities in salt affected areas. However, for its successful implementation in those areas, some capacity building measures are recommended. Education of the policy makers, scientists, publics and farmers about the potential applications and shortcomings of Haloculture is necessary. Extension and demonstration of the applicability, practicality and economic benefits of Haloculture is highly recommended.

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