ISSN 2277-0836; Volume 2, Issue 2, pp. 33-43; February, 2013.
Journal of Agriculture and Biodiversity Research

Full Length Research

Available Online at http://www.onlineresearchjournals.org/JABR

Application of Biosaline Agriculture Strategies for Sustainable Plant Production in Kuwait

***Bhat NR, Suleiman MK, Lekha VS, Al-Mulla L, Ali SI, George P, and Thomas B**

Kuwait Institute for Scientific Research, P. O. Box 24885, 13109 Safat, Kuwait.

Downloaded 28 December, 2012 Accepted 1 February, 2013

Soil salinization is one of man's oldest and growing environmental concerns, yet it has not been possible to effectively tackle this problem. Only a few commercial crops have the ability to tolerate high salinity levels in the soil or irrigation water. Also, different varieties within the same species respond differently to high salinity and their response varies with the prevailing environmental conditions. In Kuwait, the aridity of the climate and progressive salinization of irrigated lands pose a major challenge to plant production activities. Additionally, the present practice of use of desalinated water to irrigate crop and greenery plants in Kuwait is an expensive option and is unsustainable. For more than 30 years, Kuwait Institute for Scientific Research has been conducting research in biosaline agriculture. KISR has also been making concerted efforts to optimize technologies for promoting sustainable use of available water resources in irrigation. The paper highlights the significant findings of KISR research along with future strategy in this field.

Keywords: Salinization, salt-tolerance, environmental stress, water productivity, water-use efficiency.

INTRODUCTION

Kuwait is a small, flat to gently undulating desert country extending between latitudes 28^0 33' and 30^0 05' N and longitudes 46^0 33' and 48^0 30' E in the north-eastern part of the Arabian Peninsula. It has a surface area of 17,818 km^2 covering the mainland and a number of off-shore islands [1]. The climate is characterized by extremely hot dry summers with long, intense sunshine hours and moderately cool short winters with occasional rain. The average daily maximum temperatures varied from 18.9^{0}C (ten year average from 1996 to 2004) during January to 46.8^{0}C in July [1]. The average daily minimum temperatures during this period ranged from 8.2^{0}C during January to 28.3^{0}C during July with the absolute temperatures dropping to almost zero. The rainfall is minimal; averaging about 115 mm.y^{-1} (fluctuates between 25 and 250 mm), but evaporation is very high, ranging from 3.1 to 21.6 mm.d^{-1}. The total estimated annual evapotranspiration in Kuwait is 2883 mm [2]. Rainfall occurs anytime between mid October and late April. The rainfall sufficient to induce germination of desert annuals normally falls in November. The relative humidity is low, and strong, dry and hot northwesterly winds prevail during most part of summer, particularly in June and July. In a study involving various weather parameters during two periods (1962 – 1998 and 1999 – 2004), Salam and Mazrooei [2] concluded that the average maximum and minimum temperatures were 1.29^{0}C and 1.14^{0}C higher during the 1999-2004 period compared to those during 1962 – 1998 period. The annual rainfall during this period also increased by 18.67 mm, whereas the pan evaporation increased by 0.97 mm d^{-1}. The average wind speed was also increased by 0.21 m.s^{-1} [2]. Using the precipitation (P)/ potential evapotranspiration (PET) ratios, Middleton and Thomas [3] classified the climate of most Gulf Co-operation Council (GCC) countries as hyperarid (P/ PET < 0.05) to arid (P/ PET = 0.05 – 0.2). According to Le Houerou [4], Kuwait and northern part of Saudi Arabia are identified as the arid areas of the GCC.

As the goal of agricultural development in Kuwait during the 20th century was to improve self sufficiency levels, the main focus was on increasing productivity per

*Corresponding Author's E-mail: nbhat@kisr.edu.kw.

unit area of land used in crop production. This was accomplished through over exploitation of natural resources, such as water and plant resources and excessive use of chemical fertilizers and pesticides. This practice did result in a significant increase in crop yields in the short-term, but these yield increases were not sustained in the long-run [5]. It also adversely affected the productive capacity of the arable land and depleted the natural water resources [6]. Therefore, the emphasis of agriculture development in this century will have to be on sustainable, environmentally-friendly use of available land, water and plant resources in agriculture. Like in other countries, the major challenge for the agriculture sector in Kuwait will be to maximize land and water productivity without degrading the environment and natural resource base of the country. Recognizing the shortcomings in the current agricultural practices in the country, KISR initiated biosaline agricultural research in the 1980's and made significant inroads in this field [7]. The paper highlights the major significant outcome of these investigations and presents the future strategy for research in biosaline agriculture in the country.

Land and Water Resources Available for Plant Production in Kuwait

Kuwait's soil is predominantly sandy with low organic matter content and poor moisture- and nutrient holding abilities [8]. Soils of Kuwait vary considerably with respect to their physical and chemical properties. The main soil types are the desert soil covering approximately 74% of the total surface area, desert- regosol intergrade covering approximately 14% of the area, lothosol in 7% of the total area and alluvial in 4% of the total area [8]. Soil salinity in approximately 53% of the country's total area is < 2 $dS.m^{-1}$, whereas 28.3% of the total area has soil salinity between 2.1 and 4.0 $dS.m^{-1}$. The remaining areas (18.7% of the total area) has soil salinity above 4.1%, which is beyond the threshold limit of most cultivated crops. The native soil has low water and nutrient holding capacities. Over 75 % of the total area is used for livestock grazing, while 400,000 ha (200,000 ha each in the south and north of the country) is earmarked for agriculture [8].

Ground water in Kuwait is mostly saline, except in some freshwater lenses in the northern part and some brackish zones existing in the south and southwest. With the annual average rainfall of 110 – 120 mm and evapotrasnpiration in excess of 2,500 mm, the recharge of aquifers by rainfall is negligible [9]. As a result of continuous increase in extraction of groundwater for irrigation, the quality and quantity of groundwater in the aquifers have been depleted. About 65% of the irrigation water infiltrates back to the aquifers through vadose zone resulting in an increase in the total dissolved salts (TDS) level in the groundwater up to 14,000 $mg.l^{-1}$ [10]. The TDS of the groundwater in the southwest is about 3,000 $mg.l^{-1}$ increasing up to about 10,000 $mg.l^{-1}$ in the northeast [10]. Desalinated seawater is used for irrigation in the urban areas and greenhouse crops [10]. However, the delivered cost of desalinated water is very high (approximately US $ 2.47 compared to US $ 0.35 and US $ 0.18 per m^3 of ground and treated waste water, respectively) and the ground water supplies, which is limited, is fast depleting due to over extraction and negligible natural recharge [11]. Therefore, both desalinated and ground water sources can not provide long-term sustainable solution for meeting the increasing demand for irrigation water in Kuwait. In contrast, the use of sea water and treated waste water, which are available in abundance and are less expensive, is an economically and technically viable option; nevertheless, these sources must be used efficiently to prevent deterioration of available land and water resources [11-13].

Irrigation-induced Salinization of Agricultural Lands

Primary Salinization of soils occurs mainly because of the parent soil material, whereas the secondary salinization and water logging is under the direct influence of irrigation [6]. Kuwait's native soil is non-saline, but the continuous use of saline water with total dissolved salts ranging from 3,000 to 8,000 ppm for irrigation without suitable drainage and irrigation practices has led to salinization of more than 50% of irrigated farm lands [5]. In fact, under Kuwait's harsh environmental conditions, the use of even fresh water in irrigation would eventually lead to salt build up in the soil. The situation has been further complicated by the presence of hard pan (*gatch* layer) at or near the soil surface, over irrigation without sufficient drainage, calcareous nature of the soil, high evaporation from the soil surface, poor fertilizer management and nonuse of mulching [5,6]. Therefore, irrigation-induced salinization of arable land has become a major national concern. In spite of these constraints, the State of Kuwait is supporting crop and greenery plant production activities to achieve a modest level self sufficiency in fresh food products and improve livability of the urban environment. In support of these efforts, the Kuwait Institute for Scientific Research (KISR) developed a twenty year national master plans for agriculture and greenery sectors, which are currently being implemented [13-15].

Management Options under High Salinity and Arid Conditions in Kuwait

In spite of the harsh climate, progressive salinization of farmlands and poor quality water, producers are putting their best efforts to expand its agricultural production base to achieve modest level of crop yields and fulfill peoples' aspirations for fresh food commodities. To produce any crop economically under these peculiar circumstances, producers have to adopt either the engineering (installation of drainage systems, leaching of

Table 1. Daily Water Requirement of Different Plants under Kuwait's Environmental Conditions.

Plant Category	Daily Water Use (liters)
Palms	110 -200
Ornamental Trees	60-100
Afforestation Trees	35-50
Shrubs	20 to 50
Groundcover	12.5 to 25 litres/m^2
Lawn	17.5 to 25 litres/m^2

Source: KISR, 1996.

Table 2. Selection of Crops for Salt-Tolerance*.

Crops**	Lines Tested	Tolerant Lines in Greenhouse Study	Tolerant Lines in the Field Study
Barley	332	76	10
Cabbage	106	15	10
Cauliflower	103	13	10
Garlic	28	26	12
Onion	103	45	10
Others	558	58	22
Total	1,230	220	74

* Response of genotypes to salinity in germination and greenhouse trials was tested using the salinized Hoagland nutrient solution.
** Genotypes (lines) tested were received from various international organizations.

excess salts, improve water-use efficiency and apply water conservation measures) and/or biological (growing of salt and drought tolerant crops and genetic modification to improve salt- and drought tolerance) approach. Where salinity is due to the mismanagement of irrigation, reclamation of saline soils usually takes the form of laying underground drainage system and leaching of salts with fresh water. However, this is an expensive operation and even in other countries, producers are reluctant to invest heavily in such systems [16]. Since fresh water supplies in Kuwait are becoming increasingly expensive, soil is calcareous in nature and, the drainage water cannot be safely re-used, large scale adoption of engineering approach is technically and environmentally not feasible. Therefore, this approach can only be a technological fix and, under arid climates like the one that prevails in Kuwait, is inadequate to sustain economic yields and greenery qualities in the long-term. In contrast, sea water is always available in plenty and could be a valuable asset in cultivating salt-tolerant plants (Table 1).

Technically, it is now possible to supplement or completely replace engineering approach with a biological approach. This approach involves selection of salt tolerant varieties or variants and/ or manipulation of conditions. KISR recognized the importance of biosaline agriculture in the 1980's and accordingly, initiated research in this direction [15]. By indicating that certain crops and genotypes exhibit greater tolerance to salinity than others, biosaline agriculture research conducted by KISR have opened up considerable opportunities for improving agricultural production in arid regions [5,6,17-30]. These plants could be used for food, animal fodder, green manure, industrial products and greenery development. However, proper agro-production practices are needed to ensure sustainable and economic productivity in these plants. KISR's biosaline research in the past focused on the following issues:

• Selecting strains and cultivars of commercial crops and ornamental plants for salt-tolerance under multiple stress conditions prevailing in Kuwait.
• Perfecting mass propagation techniques and development of salt-tolerant variants using in-vitro techniques.
• Elucidation of salt tolerance mechanism and identification of novel transcripts in mangroves.
• Initiation of genetic engineering program to develop salt-tolerant lines in economically important crops.
• Optimization of production practices appropriate for biosaline agriculture.

Selection of Crops for Salt Tolerance and Assessment of Screening Techniques

KISR has an ongoing program in which potential plants are continuously introduced from places that have climatic conditions similar to that of Kuwait. These introductions were evaluated for their performance under coastal and inland areas of Kuwait. Parameters used for selecting salt-tolerant lines were germination percentage, days needed for initiation and total germination, seedling growth (height, relative growth rate, and fresh and dry weight), plant condition (degree of leaf necrosis and seedling vigor) and yield. Vigorous seedlings showing good growth and free from severe leaf burn were further evaluated at adult stage [5]. Salinized nutrient solution recommended by United States Department of Agriculture (USDA) Salinity Laboratory was used in the laboratory and greenhouse screening experiments.

Out of a total of 1,230 crop lines screened by KISR, 220 were found to be salt-tolerant in the laboratory and greenhouse experiments [5,6]. Out of these, only 74 were finally selected after the field study (Table 2).

Fruit Crops

Zizyphus Ten improved varieties were evaluated for their ability to withstand high salinity levels in the irrigation water [17]. Experimental plants were irrigated with salinized nutrient solution containing different amounts of dissolved salts (3,200, 6,400 or 12,800 ppm of total dissolved salts). Results showed considerable variation among varieties in their response to salinity with some withstanding 12,800 ppm TDS in the irrigation water

Table 3. Relative Height Growth rate of Five *Zizyphus* Varieties as Affected by Irrigation Water Salinity.

Salinity (ppm)	Bangladesh Selection	Musky	Thailand Selection	Kuwait Selection	UAE Selection
3,200	24	51	195	68	43
6,400	25	114	175	39	48
12,800	8	44	139	25	41

Table 4. Average Plant Height, Average Number of Leaves per Plant and Survival Percentage of Date Palm Cultivars in Different Salinity Treatments.

Cultivars	Salinity Levels (ppm)	Plant Height (cm)	Number of Leaves per Plant	Survival Percentage
Hamad	1,000	63.0	11.0	100
	3,200	42.4	7.9	100
	6,400	27.1	4.6	93
	12,800	D	D	0
Khalas	1,000	95.1	12.5	100
	3,200	74.3	9.0	100
	6,400	65.2	7.1	93
	12,800	42.2	2.2	40
Nabusaif	1,000	78.5	10.3	100
	3,200	43.6	6.6	100
	6,400	36.1	5.0	73
	12,800	D	D	0
Kasab	1,000	77.3	9.9	100
	3,200	52.3	7.3	100
	6,400	36.1	5.6	93
	12,800	D	D	0
Bahari	1,000	76.3	10.0	100
	3,200	48.8	7.7	100
	6,400	33.1	6.2	100
	12,800	D	D	0

D = Dead plants.

without any significant reduction in height growth, while others exhibiting adverse effects above 6,400 ppm. The effects of salinity on the height growth of five most promising varieties are shown in Table 3.

Date Palm

Date palm, an important component of the Arab diet and a priority crop for Kuwait, needs sufficient water of acceptable quality to produce economic yields of good quality fruits [14]. Since under Kuwait's weather conditions, supplemental irrigation will invariably lead to build up of salts in the upper soil layers, KISR's research in this crop focused on the selection of suitable salt-tolerant varieties.

A study was conducted between 2008 and 2010 to determine the response of five tissue-cultured date palm cultivars, namely, Hamad, Nabusaif, Bahri, Khalas, and Kasab to irrigation water salinity of 1.6, 5, 10, or 20 dS/ m. The salinity level of 1.6 dS/m, which corresponds to the salinity of the freshwater, was used as a control. The effects of high salinity on plant survival were manifested at 360 days after planting (DAP). One out of the five cultivar (Khalas) tolerated the highest salinity level. The average height of palms and the number of fronds (leaves) was decreased with increasing salinity levels as time progressed. Overall, results showed that 'Khalas' and 'Nabusaif' were found to be most tolerant and least tolerant cultivars, respectively (Table 4).

Olive

Ten improved olive varieties were irrigated with salinized nutrient solution containing 1000, 3,200, 6,400 or 12,800 ppm of TDS to ascertain their salt-tolerance under Kuwait's environmental conditions [18]. Three cultivars (Barnea, Picual and Frantoio) that tolerated 12,800 ppm of TDS were identified as highly tolerant; five cultivars (Arbequina, Corotina, Istanbuli, Koroneiki and Picual) that tolerated 6,400 ppm of TDS as moderately tolerant and the remaining three cultivars (Black Italian, Frantoio, Leccino and UC13A6) that were adversely affected at 3,200 ppm of TDS as susceptible to irrigation water salinity [Table 5].

Vegetables

Tomato, Cucumber and Eggplant

A number of fresh vegetables are produced commercially in Kuwait. Soil and irrigation water salinities severely limit their production on a commercial scale. Recognizing the significance of identifying sources of genetic variability for salt-tolerance, KISR screened several hundred genotypes of tomato, cucumber, eggplant, cauliflower, onion and garlic using both conventional (salt-box) and tissue culture techniques [5,20,21].

Forage Crops

Kuwait's native vegetation is of enormous scientific value because it represents a transition between semidesert and desert vegetation, highly vulnerable to human induced changes [22,23]. It also offers valuable gene pool and plant material for drought and salt-tolerance research. The native plant biodiversity in Kuwait and other Arabian Peninsula countries is being rapidly depleted due to harsh weather conditions and increased anthropogenic pressures. The palatable species are usually overgrazed and are at the verge of extinction [22,24]. Omar et al., [25,26] identified five native communities [*Nitraria retusa* (Forrssk.) Aschers., *Tamarix aucheriana* (Decne.) baum (Athl), *Zygophyllum qatarens* Hadidi (harim), *Halocnemum strobiliaceum* (Pall.) M.B. (Thullayth) and *Seidlitzia rosmarinus* Ehrenb. Ex. Bge. (Shinan, Ushnan)] and a number of species [*Aeluropus lagopoides* (L.) Trin. Ex. Thwaites (Ikrish), *A. littoralis* (Goauan) Parl. (Sheraib, Ikrish), *Frankenia pulverulenta* L. (Mulaih, Abuthurayb), *Bienertia cycloptera* Bunge (Golleman), *Mesembryanthemum nodiflorum* L. (Qasool)] associated with them to be highly tolerant to salinity and water logging. These species have good potential as forage for camel and sheep.

Ornamental Plants

Greenery Plants

Response of several ornamental plants irrigated with water of varying salinity levels (1,000, 1600 or 3,200 ppm total dissolved salts) was studied in coastal site that was characterized by extremely hot summers, low humidity, high velocity winds laden with salt particles, and saline water table [27,28]. Plants such as *Allamanda cathartica*, *Duranta goldiana*, *Peltophorum ferruginea*, *Ficus pumila* and *Thespesia populnea,* were found to be highly tolerant to salinity Table 6. Growth in several other species was affected only slightly by the highest (3,200 ppm TDS) salinity level [28].

Mangroves

Mangroves are the most prominent salt-tolerant plant of the inter-tidal region in several tropical countries. They provide a suitable habitat for a variety of marine organisms ranging from bacteria and fungi to fish, shrimp, birds and mammals. Mangrove trees produce large quantities of detritus that serve as food web in the near-shore areas and increase marine productivity. Kuwait has 290 km long coastline, 57% of which is the intertidal mudflats [29,30]. In view of the positive correlation between abundance of mangroves and health of marine ecosystem, KISR introduced different ecotypes of *Avicennia marina*, *Ceriops tagal* and *Rhizophora mucronata* and, established technical and environmental feasibility for their growing in Kuwait [30]. Through concerted research efforts, KISR also optimized mass propagation techniques and silvicultural practices for establishing large-scale mangrove plantations along Kuwait's coastline [30].

Salicornia

Salicornia is a halophytic fodder crop capable of growing under arid conditions and can tolerate sea water irrigation. The ecotype, SOS-7 was introduced from Mexico and evaluated for biomass production under Kuwait's growing conditions [31]. Fifteen tons of biomass was produced per ha which was comparable to its maximum productivity in Mexico. The feeding studies suggested that *Salicornia* can substitute up to 25% the total daily feed intake by sheep without any adverse effects on their performance.

Development of Salt-tolerance through Tissue Culture

Date Palm

KISR successfully established protocol for micropropagation through induction of embryos from callus, in-vitro germination of embryo and formation of adventitious embryonic plantlets and their acclimatization to produce large number of plants of superior cultivars [32,33,34]. Genetic integrity of tissue cultured date palms under field conditions were confirmed using the micro-satellite (ISSR) and randomly amplified polymorphic DNA (RAPD) analysis [35].

Table 5. Survival Percentage of Olive Cultivars in Different Salinity Treatments After Days from the Start of the Treatments.

Cultivars	Salinity Levels (ppm)	Survival Percentage	Average Plant Height (cm)	Average Stem Dia (mm)	Average Number of Branches
Arbequina	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
Barnea	1,000	0	Dead	Dead	Dead
	3,200	67	136	11	8.5
	6,400	67	159	11	12.5
	12,800	0	Dead	Dead	Dead
Black Italian	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
Corotina	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
	1,000				
Frantoio	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
	1,000	0	Dead	Dead	Dead
Istanbuli	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
Koroneiki	1,000	100	170	7	17
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
Leccino	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead

Table 5. Cont.

Picual	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead
UC13A6	1,000	0	Dead	Dead	Dead
	3,200	0	Dead	Dead	Dead
	6,400	0	Dead	Dead	Dead
	12,800	0	Dead	Dead	Dead

Table 6. Relative Height Growth Rate of Selected Ornamental Plants in Different Salinity Treatments.

Salinity Levels	**Relative Height Growth Rates (%) in 12 Months**				
	Peltophorum ferruginum	***Thespesia populnea***	***Ficus pumila***	***Duranta goldiana***	***Allamanda cathartica***
1,000 ppm	25*	13	41	186	65
1600 ppm	41	38	63	178	25
3,200 ppm	46	20	79	177	45

Using the cell and tissue culture techniques, attempts also were made to develop salt-tolerant somaclonal variants in date palm [36]. The technique involved the induction of embryogenic callus of four commercial varieties (Barhi, Majdhool, Nabout-seif, Iklas) and one male variety Boyer and transferring the cultures to a medium containing 12,000 ppm of TDS to select salt-tolerant variants. Emryogenic callus from Nabout-seif variety tolerated up to 9,000 pp of TDS, whereas that from the male Boyer cultivar survived in 12,000 ppm TDS. The somatic embryogenic calli selected from the NaCl supplemented medium were multiplied in Murashige-Skoog medium containing same concentrations of salts. The plantlets regenerated from these calli were transferred to rooting medium for initiating roots, after which they were transferred to soil medium for hardening and field evaluation [37].

Greenhouse Vegetables:

In-vitro studies were conducted in tomato, egg plant and cucumber for large-scale screening and selection of seeds in vitro, generation of plants from callus through embryogenesis (eggplant and cucumber) or organogenesis (tomato) and screening of tissue cultures lines using brackish water stress [21,38]. Development of salt-tolerant lines through cell and tissue culture in tomato was successful; however, attempts to do the same in cucumber were not successful. Use of salt box techniques led to the identification of four salt-tolerant lines in egg plant.

Potato:

Cultures of 23 potato cultivars were initiated in-vitro using certified seeds and screened for their salt-tolerance. None of these varieties showed tolerance to high salinity; however, three salt tolerant clones were developed through tissue culture techniques. These variants tolerated up to 12,000 ppm of TDS [39]. Further studies to produce microtubers from these clones using in-vitro techniques for field testing are underway [40,41,42].

Native and Greenery Plants

In Kuwait and other Arabian Peninsula countries, rangeland biodiversity and livestock production exist in delicate balance. Widespread salinization of desert areas and continuous removal of native vegetation by livestock and humans have led to severe depletion of biodiversity. For mass multiplication of salt-tolerant lines, tissue culture techniques have been developed for some native plants and mangrove [43-46].

Genetic Manipulation of Plants for Salt Tolerance

Conventional plant breeding and engineering (physical conditioning of saline soil) approaches have proved inadequate to completely overcome salinity related problems. It is believed that saline water and harsh

Table 7. Total Quantity of Irrigation Applied to Various Date Palm Cultivars under Different Treatments during First Year of Planting (2010).

Treatments	Amount of Irrigation Applied (Liters/ Plant)		
	Kasab	Al-Hamad	Khalas
Polymer (Agrihope @ 0.4%) plus bark mulch	920	970	930
Polymer (Agrihope @ 0.4%) plus date palm leaf (fronds) mulch	910	910	930
Polymer (Agrihope @ 0.4%) only	1,030	1,080	1,050
Bark mulch only	1,110	1,110	950
Date palm leaf mulch only	1,040	1,080	940
Control (no polymer or mulch)	1,110	1,190	1,170

climate of arid and semiarid region can be turned into assets rather than deterrents for plant production if the techniques of genetic engineering and micropropagation are properly applied to develop seawater based agriculture system. One of the ways to develop such as system is through genetic manipulation of commercial plants to equip them with salt-tolerance conferring genes to be able for them to survive and produce economic yields under highly saline environments.

The first step in designing and developing salt-tolerant crops is the elucidation of biochemical and molecular basis of salt tolerance in halophytes. This requires a suitable experimental system, such as mangrove (*Avicennia marina*) as it possesses mechanisms for both salt tolerance and avoidance [46]. This is followed by identification of salt-stress induced proteins and genes, cloning of full-length salt-tolerant genes from halophyte system and subsequent functional analysis of the cloned genes in salt-sensitive plants.

Studies conducted at KISR strongly suggested a good degree of correlation between salt-tolerance and oxidative stress [47]. By comparing the activities of a number of antioxidative enzymes, most notably the superoxide desmutase (SOD) in using the mangrove (*Avicennia marina*) system, a core set of salt related transcripts were identified through differential mRNA analyses [48]. A number of these novel transcripts were found functionally homologous with genes encoding important molecules such as antioxidative enzymes (Mn-SOD encoding transcript, genes encoding aquaporin proteins, ATPases, NADH dehydrogenase and genes encoding sodium transport proteins. These transcripts (cDNAs) were used to generate and isolate corresponding full length genes conferring salt tolerance in mangroves. Over expression of mangrove Mn-SOD and transporter genes were found to be responsible for conferring salt tolerance in mangroves. Therefore, efforts are now being made to use these novel genes to genetically program salt sensitive plants.

Irrigation Water Management

The use of hydrophilic polymers and surface mulch can greatly reduce plant water requirements and subsequent salt build up in the soil. KSIR scientists evaluated five hydrophilic polymers (Aquasorb, Agrihope, Broadleaf P_4 Hydrogel, or Hydrosource) at different concentrations and three mulches (bark and gravel or compost) either alone or in combination for reducing irrigation water requirements and improve water-use efficiency in a number of ornamental plants [49]. As shown in Tables 7 – 9, soil incorporation of Agrihope @ 0.4% with or without application of 5 cm thick layer of bark mulch to surface reduced the plant water requirement between 20 and 36.4% as well as decreased salt buildup in the surface soil [49].

Future strategy for Biosaline Research at KISR

Significant achievements have been made in addressing some of the key issues in biosaline agriculture in Kuwait. Nevertheless, lot needs to be done to ensure economic and sustainable utilization of saline water in agricultural production. Therefore, future research in this field would need to focus on the following aspects:

• Augmentation of physical and biological approaches for optimizing bio saline agriculture production systems.
• Exploration and exploitation of naturally occurring salt-tolerant plants and halophytes in Kuwait.
• Implementation of an integrated approach to utilization of saline irrigation water and marginal land of Kuwait for increased production.

Table 8. Volume of Water Applied to Ornamental Plants (*Conocarpus lancifolius* and *Zizuyphus spina-christi*) in Various Polymer and Mulch Treatment Combinations under Urban Conditions.

Treatments*	Total amount of water applied/ plant during the 12 month period (liters)
No Mulch and No Polymer	16,500
Polymer Only	13,500
Gravel Mulch only	15,000
Organic Mulch Only	12,000
Polymer Plus Organic Mulch	10,500
Polymer Plus Gravel Mulch	12,000
SEM[x]	901.4

*Polymer (Agrihope) was mixed backfilling soil containing soil, Sphagnum peat moss and perlite (2:1:1 v/v) @ 0.4% by weight.
[x]SEM = Standard Error of Mean.

Table 9. Amount of Irrigation Water Applied to Lawn Grasses Grown in Polymer-amended and Control Soils.

	Amount of Water Applied (l/ Day)	
Treatment	***Pasphalum viginatum***	***Zoysia japonica***
Polymer-amended soil	6.875	9.100
Control	9.175	12.850

• Applications of Plant Growth-Promoting Rhizobacteria (PGPR) to soil.

CONCLUSIONS

For developing sustainable agriculture in Kuwait, it is important to conserve land, water and native biodiversity resources. KISR research has proven that there is a good potential for developing salt-tolerant crop lines through both conventional and non-conventional approaches. Furthermore, techniques that enhance water and land productivity (mulching, recirculation of irrigation water) are important in improving water-use efficiency in plant production. The outcome of KISR research has facilitated the development of sustainable biosaline agriculture in Kuwait.

Acknowledgement

The authors would like thank the managements of Kuwait Institute for Scientific Research for supporting biosaline research at KISR.

REFERENCES

[1] Annual Statistical Abstract. Ministry of Planning. Statistics and Information Sector. 2006; Kuwait.

[2] Salam AM, Al-Mazrooei S. Crop water and irrigation water requirements of date palm (Phoenix dactylifera) in the loamy sands of Kuwait. Acta Horticult, 2007; 736: 309-315.

[3] Middleton N, Thomas D. World Atlas of Desertification. United Nations Environment Program/ Arnold, 1997; pp. 182.

[4] Le Houerou HN. 1996. Climate change, drought and desertification. J Arid Environ, 1996; 34:133-185.

[5] Abdal M, Bhat NR, Al-Ghawas S, Albaho M, Ferrin J, Ghloum D. Selection of crops for salinity. Kuwait Institute for Scientific Research, 2002; Report No. KISR 6744, Kuwait.

[6] Bhat NR, Al-Menaie H, Abdal, M., Suleiman, M. K., Christopher, A., Ferrin. J. Selection of crops/ lines for sustainable utilization of land and water resources in Kuwait. Paper Presented in the Gulf Conference on Environment and Sustainability, December 3 – 5, 2005; Kuwait.

[7] Omar S, Abdal M, Sharma J. Conceptual and strategic framework for plant biosaline and biothermal program development in Kuwait. Kuwait Institute for Scientific Research, 1987; pp 45.

[8] Kuwait Institute for Scientific Research. Soil survey for the State of Kuwait. Volume II: Reconnaissance Survey. (Australia: AACM International), 1999.

[9] Al-Senafi M, Abraham J. Vulnerability of groundwater resources from agricultural activities in southern Kuwait. Agric Water Manage, 2004; 64: 1 – 15.

[10] Al-Senafi M, Al-Fahad K. Petrography of calcretes and their effects

on the hydrology of Kuwait. Group aquifer. In: Mohamed AMO, Al-Hosani KI (Eds.), Geotechnical, geoenvironmental Engineering and management in aridlands. Proceedings of the conference on Geoengineering in aridlands. November 4 – 7, 2000; UAE University, Al-Ain, UAE, pp 481 – 484.

[11] Suleiman MK, Abdal M. Water availability for greening of Kuwait. Limnologia - Ecol Manage Inland Waters, 2001; 32: 322 – 328.

[12] Abdal M, Rilley JJ. Halophyte Salicornia (SOS-7) evaluation and development: Phase I (AG-60). in: Leith L, Al-Masoom, AA (Eds.), Towards the Rational Use of High Salinity Tolerant Plants. The Netherlands: Kluwer Academic Publishers, 1993.

[13] Kuwait Institute for Scientific Research. Master Plan for the development of Kuwait's agriculture sector. (1995 - 2015). Kuwait Institute for Scientific Research, 1995; Report No. KISR 4615, Kuwait.

[14] Kuwait Institute for Scientific Research. National Greenery Plan. Kuwait Institute for Scientific Research, 1996; Report No. KISR 4938, Kuwait.

[15] Omar SA, Al-Awadi N. Contributions of Kuwait Institute for Scientific Research to biosaline agriculture. In: Taha FK, Ismail S, Jaradat A (Eds.), Prospects of Saline Agriculture in the Arabian Peninsula, Massachusetts, USA: Amherst Scientific Publishers, 2004; pp. 413-425.

[16] International Atomic Energy Agency. Productive use of saline lands. International Atomic Energy Agency, Food and Agriculture Organization, Rome, Italy, 2004.

[17] Bhat NR, Suleiman MK, Bellen R, Al-Zalzaleh M. Evaluation and improvement in Zizyphus for landscape beautification in Kuwait. Kuwait Institute for Scientific Research, 2004a; Report No. KISR 7284, Kuwait.

[18] Bhat NR, Suleiman MK, Al-Menaie H, D'Cruz G, Christopher A, Bellen R, Thomas B, Isath Ali S, Lekha VS, George P, Al-Zalzaleh M. Selection of olive varieties for greenery and fruit production in Kuwait: Phase I. Kuwait Institute for Scientific Research, 2008; Report No. KISR 8991, Kuwait.

[19] Sudershan C. Introduction of a multipurpose palm, Phoenix pusilla, in Kuwait. Palms, 2004; 48:191 – 196.

[20] Sharma JN, AboEl-Nil M, Ibrahim H. Selection of genes or germplasm suitable for salt tolerance breeding (in three vegetables) for Kuwait. In: Al-Ferieh F, Khalid F, Zehery SH, Al-Own S, Muzaffar M (Eds.), Research and Development KISR Project Abstracts, Kuwait Institute for Scientific Research, 1989.

[21] Abdal M, Suleiman, MK, Vegetables production in greenhouse using brackish water. Acta Horticulturae, 2003; 609: 269-273.

[22] Omar SAS, Bhat NR. Alternation in Rhanterium epapposum plant community in Kuwait and restoration measures. Int J Environ Stud, 2008; 65: 139 – 155.

[23] Omar SAS, Al Mutawa Y, Zaman S. Vegetation of Kuwait. Kuwait Institute for Scientific Research, 2007; pp. 161.

[24] Peacock JM, Dakheel A, Ferguson ME, Al-Hadrami G, Saleh A, McCann IR. Sustainable use of salt affected soils with indigenous desert and other forages in the Arabian Peninsula. In: Taha FK, Ismail S, Jaradat A (Eds.) Prospects of Saline Agriculture in the Arabian Peninsula. Massachusetts, USA: Amherst Scientific Publishers, 2004; pp. 535 -547.
\

[25] Omar SAS, Misak RF, Shahid SA. Sabkhat and halophytes in Kuwait. In: Barth and Boer, B. (Eds.) Sabkha Ecosystems (Netherlands: Kluwer Academic Publishers), 2002; pp 71 – 81.

[26] Omar S, Shahid S, Abo-Rezq H. Potential forage shrubs and grasses for revegetating Bubyan Island. In: Taha FK, Ismail S, Jaradat A (Eds.), Prospects of Saline Agriculture in the Arabian Peninsula. (Massachusetts, USA: Amherst Scientific Publishers), 2004; pp. 367 - 376.

[27] Taha FK, Bhat NR. Selection of ornamental and landscape plants for the implementation of the National Greenery Plan of Kuwait. In: Al-Awadhi N, Taha FK (Eds.) New Technologies for Soil Reclamation and Desert Greenery, (Massachusetts, USA: Amherst Scientific Publishers) 2002; pp. 27-44.

[28] Suleiman MK, Bhat NR, Al-Mulla L, Christopher A, George J. Evaluation and screening of ornamental plants for salinity tolerance. Eur J Sci Res, 2006; 15: 165-172.

[29] Bhat NR, Shahid SA, Suleiman MK. Avicennia marina establishment and growth under the arid climate of Kuwait. Arid Land Res Manage, 2004a; 18: 127-139.

[30] Bhat NR, Shahid SS, Al-Zalzaleh H, Taha FK, Mankara H, Al-Qattan H. Establishment of mangrove plantations for protection and enrichment of Kuwait's coastline: Priorities, procedures and problems. In: Taha FK, Ismail S, Jaradat A (Eds.) Prospects of Saline Agriculture in the Arabian Peninsula. (Massachusetts, USA: Amherst Scientific Publishers), 2004b: pp. 97-110.

[31] Abdal M, Sharma JN, Rilley JJ. Halophyte Salicornia (SOS-7) evaluation and development, Phase I (AG – 60). Kuwait Institute for Scientific Research, 1990; Technical Report.

[32] Sudershan C, Abo El-Nil M, Al-Baiz A. Direct somatic embryogenesis and plantlet formation from the leaf ex-plants of Phoenix dactylifera L. cultivar Barhee. J Swamy Bot, Cl, 1993; 10: 37-43.

[33] Sudershan C, AboEl-Nil M, Al-Baiz A. Occurrence of direct somatic embryogenesis on the sword leaf of in vitro plantlets of Phoenix dactylifera L. cultivar barhee. Curr Sci, 1993; 65: 887–888.

[34] Sudershan C, AboEl-Nil M. Axillary shoot production in micropropagated date palm (Phoenix dactylifera). Curr Sci, 2004; 86: 771–773.

[35] Saleem M. Application of AFLP and RAPD technology to determine trueness-to-type of tissue culture derived date palm. In: Al-Ferieh F, Khalid F, Zehery SH, Al-Own S, Muzaffar M (Eds.) Research and Development KISR project Abstracts 1973 – 1996. Kuwait Institute for Scientific Research, 1998; pp. 364.

[36] Al-Ahmad S, Saleem M, Al-Baijan, Haider I. Evaluation of genetic integrity of the KISR-tissue cultured date palms (Phoenix dactylifera L.) under field conditions. Annual Report. Kuwait Foundation for the Advancement of Sciences, 2006; pp. 64 – 65.

[37] AboEl-Nil M. Development of salt tolerant date palm cultivars via tissue culture technology – Phase I: Induction and selection. Annual Report. Kuwait Foundation for the Advancement of Sciences, 2006; pp. 76.

[38] AboEl-Nil M, Al-Sbah L. Selection of genes or germplasm suitable for salt tolerance breeding (in three vegetable) for Kuwait. In: Al-Ferieh F, Khalid F, Zehery SH, Al-Own S, Muzaffar M (Eds.), Research and Development KISR Project Abstracts, Kuwait Institute for Scientific Research, 1993; pp. 330 – 331.

[39] Sudershan C, Manuel J, Al-Ajeel A, Hussain J, Al-Mulhem S. In-vitro screening and development of salt tolerant potato via plant cell and tissue culture technology. Annual Report. Kuwait Foundation for the Advancement of Sciences, 2006; pp. 82.

[40] Sudershan C, Manuel J, Al-Ajeel, A, Hussain J, Al-Mulhem S. Pilot scale production of seed potato via tissue culture. Annual Report. Kuwait Foundation for the Advancement of Sciences, 2006; pp. 48 – 49.

[41] Sudershan C. Seed potato production in Kuwait via tissue culture: Refinement of technology for the minituber production. In: Proceedings of 6th Triennial Congress of the African Potato Association April 5 – 10, 2004, Agadir, Moracco.

[42] Sudershan C, Manuel J, Al-Ajeel A, Hussain J, Al-Melhem S. A simple and large scale potato microtuber production via single node culture technology. Journal of Swamy Botany Cl, 2007; 24: 71 -76.

[43] Sudershan C, AboEl-Nil M, Al-Ajeel A. In-vitro tissue culture and differentiation of Avicennia marina. in: N. R. Bhat, F. K. Taha and A. Al-Nasser (Eds.) Mangrove ecosystems: Natural distribution, biology and management. Kuwait Institute for Scientific Research, 2001; pp. 99-106.

[44] Sudershan C, AboEl-Nil M, Hussain J. Tissue culture propagation technology for the conservation and propagation of certain native plants. J Arid Environ, 2003; 54: 133–147.

[45] Sudershan C, AboEl-Nil M, Hussain J. Somatic Embryogenesis of Ochradenus baccatus. J Swamy Bot, Cl, 1999; 16: 51 -54.

[46] Saleem M, Al-Shayji Y, Al-Salameen F, Al-Ahmad S, Al-Baijan D. Development of salt-tolerant plants – Phase II: Characterization and analyses of salt-induced genes of mangrove plant. Annual Report. Kuwait Foundation for the Advancement of Sciences, 2006; pp 73.

[47] Saleem M, Al-Shayji Y, Sudershan C, Al-Ahmad A, Al-Baijan D, Al-Salameen F. Antioxidant Response to salinity in callus tissue of mangrove Avicennia marina (Forsk.) Vierh. in: Al-Shayji Y, Siddu JS, Saleem M, Guerinik K (Eds.) Biotechnology Applications for the Arid Regions. Kuwait Institute for Scientific Research, 2002; pp. 123–134.

[48] Suleiman MK, Bhat NR, Sharma AJ, Bellen RR, Al-Zalzaleh MA. Determination of irrigation stress and mulching effects on selected proven introduced shrubs and groundcovers. Kuwait Institute for Scientific Research, 2002; Report No. KISR 6601, Kuwait.

[49] Bhat NR, Suleiman MK, Al-Menaie H, Al-Ali EH, Al-Mulla L, Al-Zalzaleh M, Bellen R. Use of hydrophilic polymers and mulches for water conservation in greenery projects in Kuwait. Kuwait Institute for Scientific Research, 2006b; Report No. KISR 8034, Kuwait.