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REVIEW ARTICLE

BIOSALINE AGRICULTURE: PERSPECTIVES FROM OMAN

Asadullah Al-Ajmi[1*], Mushtaque Ahmed[2] and Humphrey Esechie[2]

[1*]*Sultan Qaboos Centre for Developed and Soilless Agriculture , Arabian Gulf University, P.O. Box 26671, Bahrain*
[2]*College of Agricultural & Marine Sciences, PO Box 34, Al-Khod 123, Oman*

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ABSTRACT

Increased salinity in irrigation water due to seawater intrusion has resulted in salinization of large part of agricultural lands in Oman. Government efforts are geared towards restoring water balance to improve groundwater quality with the ultimate aim of leaching the salts from soil profile. Some of these efforts include: controlling digging of new wells and rehabilitation of older wells, construction of recharge dams, reduction of cultivated land, and providing incentives for modern irrigation systems. Research on introduction of salt tolerant crops is also taking place both at Sultan Qaboos University (SQU) and Ministry of Agriculture and Fisheries (MAF) research stations. Efforts have also been made to develop mathematical models to predict soil salinity under Omani conditions from readily available data.

INTRODUCTION

Soil and water salinity are emerging as serious problems of agriculture in many parts of the globe, arid and semi-arid areas being the major victim. Biosaline agriculture is the form of agriculture in which production is obtained from salt affected waste lands (without reclamation) through the use of salt-tolerant plants of economic value by management of salinity in root zone (Hussain et al. 2010). In Oman, the extensive aridity and extreme fresh water deficit does not allow total get rid of salinity. Therefore, the suitable approach is to live with salinity. Soil salinization is a serious problem especially in the Batinah coastal plain. This is the most important agricultural region of Oman encompassing 80,000 ha of cultivated land (Cookson and Lepiece 2001). A study conducted in South Batinah concluded that 50% of the cultivated land could be classified as saline (MAF, 1993). The cause of soil salinity in Batinah can be directly attributed to high levels of salt in irrigation water. Groundwater is used for irrigation and without irrigation, cultivation is not possible as average rainfall is less than 100 mm/yr and potential annual evapo-transpiration is twenty times higher. Saline water intrusion is the result of the farmers abstracting groundwater at rates much higher than annual groundwater recharge. Efforts have been made to combat soil salinity in Batinah.

***Corresponding author e-mail:** asadulla@agu.edu.bh

The success of management of salinity in Oman depends upon how effectively the use of saline water can be minimized and salt accumulation from consistent irrigation with saline water can efficiently be controlled, especially during crop growth (Hussain et al. 2010). Individual as well as comprehensive well-planned government efforts have been made. Government actions, reflecting the recommendations contained in the South Batinah Integrated Study (MAF, 1993) include controlling digging of new wells and rehabilitation of older wells, construction of recharge dams, reduction of cultivated land, and developing incentives for modern irrigation systems. The main effort has been to reduce water abstraction to maintain overall water balance in the aquifers to prevent further saline water intrusion. Government efforts have been made with a view to making farming environmentally sustainable, economically viable and socially sustainable. In the absence of any comprehensive evaluation, it is difficult to say whether government efforts have made any significant gain to combat soil salinity.

The Sultanate of Oman, located in the South East corner of the Arab peninsula, is an arid country with a mean annual rainfall of less than 100 mm. Groundwater is the country's main water resource. The net annual natural recharge to the groundwater is estimated to be around 1260 million cubic meters (MCM). The total water demand is put around 1650 MCM of which 90% is used for agriculture. The deficit of 390 MCM is drawn from the groundwater reserves. (Abdel Rahman and Abdel Majid 1993). In Batinah, the Mean Annual Temperature is 28.6 ^{o}C, Relative Humidity is 58%, Wind Speed is 221 km/day, and Sunshine Hours is 9.7 hours/day. Rainfall is very irregular from year to year and some months can be totally dry. The Batinah Plain is comprised of very thick alluvial, marine and eolian sediments (MAF 1993). The last 40 years have seen tremendous growth of modern irrigated agriculture. Excessive usage of groundwater resulted in seawater intrusion into the coastal aquifers and has caused the problem of soil salinity in many parts of the Batinah plain. According to MAF (1993) study, 50 % of the agricultural area in the South Batinah is slightly to extremely saline (EC_e of > 4 dS/m). Crops grown in this area include date palm, lime, alfalfa, vegetables, fruits, fodder, etc.

Causes of Salinity

High temperature and scanty rainfall are always conducive for accumulation of salts in the soil because the salts cannot be leached down completely. The net water movement in the soil remains upwards during major part of the year. The ground water brings dissolved salts with it, evaporates and leaves these salts on the surface or subsurface. Hence, the chances of development of soils saline remained always very high (Hussain et al. 2010). In the agricultural areas of Oman, high salt content of irrigation waters is another important reason for increase in soil salinity. The major disturbance in the salt balance of the root zone soil commenced with the change in the traditional irrigation system where, surface runoff and flood water from valleys (*Wadis*) was used for surface irrigation of small plots bounded by low dikes, and also for recharging the water reservoir at shallow depths. This practice resulted in removal of salts through leaching. Because of increase in irrigation requirements starting in early 70s, the traditional system was replaced with deeper dug wells equipped with motorized pumps (Qureshi 1995). Excessive pumping caused a rapid intrusion of the sea water in the coastal aquifers, deteriorating the groundwater quality. Continued use of this saline groundwater for irrigation is the most important factor in soil salinization of Batinah Coastal Plain which has the nearly half of cultivated area of Oman.

Extent and Nature of Salt Affected Soils

The area of the salt affected soils from the General Soil Map of Oman (MAF 1990) is estimated to be 35.2% of the total area (11.07 million ha of the total 31.43 million ha). It has also been reported that 77% of the salt affected soils were Gypsi orthids (gypsiferous) (Qureshi 1995). Such soils are conducive to reclamation in terms of structural stability. According to estimates by Hussain (2005), salt affected area within suitable agricultural land as percentage of total suitable agricultural Land is 70.25%. The main cultivated area of the country is located in the northern coastal plain known as the Batinah region. The South Batinah cultivated lands covers a total area of 27,528 ha with the following salinity statistics: non-saline (EC_e of less than 4 dS/m) 50%, slightly saline (EC_e 4-8 dS/m) 11.0%, moderately saline (EC_e 8-16 dS/m) 8.1%, strongly saline (EC_e 16-32 dS/m) 7.6%, very strongly saline (EC_e 32-64 dS/m) 8.3% and extremely saline (> EC_e 64 dS/m) 14.9% (MAF 1993). The soil pH in South Batinah is moderately to strongly alkaline. Calcium followed by magnesium are the main cations saturating the soil exchange complex. Organic carbon content is low, between 1600 and 3000 ppm and nitrogen content is low, between 190 and 270 ppm. The average topsoil calcium carbonate content is about 30%. For North Batinah around 50% of the total cultivated land is irrigated with water of salinity of above 3 dS/m. Approximately 38% is irrigated with water of >5 dS/m salinity (MAF 1997). In Salalah Plain of the southern region, around 60% of the total cultivated land is irrigated with salinity of above 3 dS/m. Approximately 30% is irrigated with water of >5 dS/m salinity (MAF 1992).

Soil salinity research in Oman

Although research work conducted in Oman does not suffice the objective but progressing on right directions. Thus, the investigations of the country coupled with data and information from similar case studies can prove highly useful to manage the problems of soil and water salinity and curtail its magnitude if not controlling fully (Hussain et al. 2010).

Reclamation of Saline Soil Through Leaching

Ahmed *et al.*, (1999) reports the findings from leaching experiments conducted on some Omani soils. Seven samples from two locations in the Batinah coastal area of Oman were analyzed. Repacked soil columns of up to 30 cm in length were used in laboratory experiments to estimate the amount of water required for adequate leaching of salts from the soil profile. Two methods of leaching: continuous ponding and intermittent ponding were investigated. Results show that most of the salt (50-90%) is removed from the soil profile by the application of water equal in amount to the depth of soil to be leached. The results also show that intermittent ponding method of leaching is more efficient than the continuous ponding method of leaching if initial salinity level is high. Soil samples were also collected to find out the salinity status under drip irrigation. It clearly demonstrates that drip irrigation is very effective in removing salts from soil near the emitters although there is a marked accumulation of salts on the soil surface between emitters.

Modeling Soil Salinization in Oman

To manage salinity problems in irrigated areas properly, it is necessary to understand in detail the processes that control the movement of water and salt from the surface to the groundwater table, with particular emphasis on the root zone of irrigated soils. In Oman, however, little work has been carried out in developing models based on local field conditions. Al Ajmi et al., (2002) used historical data set coupled with limited direct field measurements to build a model of soil salinization that is based on sound physical concepts, rather than developing a statistical model, and which is capable of being used with limited data available. The objective was to develop a model to explain the variation between farms in soil water salinity, and thus provide a tool for optimizing management practices to control soil salinization. The management practices of particular interest in this respect were the amount and frequency of irrigation, and the sizes of irrigation basins used in the case of the tree crops. Within the farms studied, there was wide variation in each of these practices, which is likely to be an important factor influencing the observed variation in soil water salinity. A major challenge was that the analysis had to be based on a combination of very inaccurate information about factors such as the amount and frequency of irrigation, because long-term monitoring was impractical. The objective was to study small farms (rather than research stations) where there are no records kept of information such as irrigation scheduling and no monitoring of factors such as irrigation water quality. Direct measurements were limited to data from soil and irrigation water salinity surveys carried out by the South Batinah Integrated Study (MAF 1993) and the measurements that were made during (1998-1999) as part of the study. A model termed IMAGE (irrigation management model) was developed that could make remarkably good predictions of soil water salinity, with 75% of locations being predicted to within 2 dS/m, in the context of absolute values ranging from 1.93 to 51.1 dS/m. Poorly predicted sites were those with large data uncertainties, or factors such as highly permeable soils where there was large within-basin heterogeneity in infiltration and drainage. Sensitivity analyses showed there to be considerable scope for controlling soil water salinity to within acceptable limits through optimizing irrigation scheduling and the size of irrigation basins relative to the size of the tree canopy.

Crop research in Oman

The detrimental effects of salinity have been extensively investigated in several crops in Oman. At Sultan Qaboos University (SQU), the crop developmental stages studied were (1) germination, excluding seedling emergence (2) seedling emergence and growth, including hypocotyls elongation and (3) mature plant growth, including re-growth.

Germination

In a laboratory study initiated to evaluate the effect of salinity and temperature on the germination of alfalfa, it was found that the percentage and rate of germination were severely limited at salinity levels above 12.2 dS/m (Esechie 1993a). The negative effects of salinity on the germination of alfalfa intensified at temperatures above 40 ^{0}C. The optimum temperature range was 20 - 25 ^{0}C. In a related study with sorghum (Esechie 1993b), seed germination was more tolerant to salinity at germination temperatures of 30 – 40 ^{0}C than at 15 – 25 ^{0}C, suggesting that genetic differences exist among crops in their resistance to salinity stress at germination. Esechie (1995), in a study involving Sesbania (*Sesbania sesban*) and Snail Medic (*Medicago scutellata*), suggested that the ability of the seed embryo to accumulate less Cl compared to the seed coat in certain crops may explain the differential resistance to salinity during germination. In this study, Sesbania which had lower embryo Cl concentrations had a higher germination percentage than snail medic with a higher embryo Cl concentrations. At the optimum germination temperatures (30 ^{0}C for sesbania and 20 ^{0}C for snail medic), the salinity levels that reduced germination by 50% were 18.5 and 15.0 dS/m in Sesbania and snail medic, respectively.

Seedling Emergence

Compared to germination studies, relatively little information is available on crop response to salinity stress during seedling emergence. In Sultan Qaboos University Experiment Station, experiments were conducted by Esechie *et al.,* (2002) to investigate seedling emergence in two chickpea (*Cicer arietinum*) species (ILC 482 and Barka local) in response to varied salinity levels and seedling depths. Seeds were sown in potted soil at a depth of 2, 4 or 6 cm. The salinity treatments were 4.6, 8.4 and 12.2 dS/m, with tap water 0.8 dS/m as control. The interaction between salinity treatment and seedling depth was significant. Hypocotyl injury was implicated as a possible cause of poor seedling emergence in chickpea under saline water irrigation. The longer the hypocotyl was in contact with the soil, the more were its chances of being damaged by salinity. This explains the low emergence in seeds sown 6 cm deep, whereas pregerminated seeds had relatively high emergence percentages. The authors, however, did not recommend the use of pregerminated seeds because of the necessity for special planters, but instead suggested that breeding programs involving the exchange of germplasm may be a better means of alleviating this problem. Chickpea cv ILC 482 obtained from ICARDA in Syria, for instance, was found to be more tolerant to salinity at the germination/ emergence stage than Barka local, a cultivar planted by most farmers in the Batinah region in Oman.

Mature Plant Growth and Re-growth

The data presented by Maas and Hoffman (1977) have shown that forage yield from alfalfa decreased by 7.3% for each dS/m increase above 2.0 dS/m in the soil solution. Therefore, at 9.0 dS/m salinity level, not uncommon in the Batinah Coastal region in Oman, 50% yield depressions are expected. In a later study, Esechie *et al.,* (1998) observed that alfalfa exposed to salinity during growth produced less dry matter, less nodules (quantity and quality), and fixed less nitrogen (estimated by acetylene reduction activity) than those growing under nonsaline environments. Omani *Rhizobium* isolate (*Buraimi*) was more tolerant to salinity than the strains imported from Brazil. Application of N-free nutrient solutions tended to cushion the adverse effect of salinity. The results from the regrowth followed the same trend as those from the primary growth. In a related experiment, shoot and root growth, as well as root: shoot ratios were inhibited by increased salinity, inhibition being more severe in the shoot than the root (Esechie *et al.,* 2002). Addition of nitrate-N or ammonium-N reduced the deleterious effects of salinity, but their effectiveness did not follow a consistent pattern. Ammonium-N was superior to nitrate-N in counteracting the adverse effects of salinity in the first cut (primary growth), but in the regrowth nitrate-N was more effective. The authors suggested that further experimentation was needed to explain this differential response.

The possibility that the inhibition of leaf growth in alfalfa growing under salinity conditions may be associated with a reduction in ion concentration in the leaf was investigated by Esechie and Rodriguez (1998). Their results show that salinization significantly reduced the fresh weights of the roots, stem and leaves as well as the concentration of N, K. Ca and Mg in the leaf tissue. With the exception of Cu concentration, which was enhanced by salinity, all the micronutrients (B, Zn, Mn and Fe) had reduced concentration the leaves of salinized alfalfa. The application of an external nutrient solution, especially the full strength solution, produced an increase in leaf growth and leaf nutrient element concentration. On the basis of these results, it was concluded that reduced leaf nutrient concentration may be one of the primary causes of the inhibition of leaf growth that is characteristic of alfalfa growing under salinity stress.

In a saline environment, plants take up excessive amounts of Na at the expense of K and Ca. In a field-simulated study, Esechie *et al.,* (1998) concluded that the imbalance in ion compartmentation (Mg vs Ca, for instance) in alfalfa plant parts may be an important factor in the nutrient deficiency symptoms exhibited by alfalfa growing under salinity stress. They observed that an increase in Na content generally decreased the K content, suggesting an antagonism between Na and K. Esechie *et al.,* (2002), in a recent study, found that the cationic sums in alfalfa petioles were constant when alfalfa was subjected to salinity treatments of 0.0 – 6.4 dS/m and 8.2 – 12.2 dS/m. Based on these results they concluded that the *cationic constancy* rule proposed by Bear and Prince in 1945 may have a potential in identifying the salinity levels that may seriously affect the normal growth and yield of alfalfa.

Use of saline oil production water for agriculture

Large quantities of water are usually produced in conjunction with oil production in Oman. Because this water is saline and heavily contaminated with oil, it is not suitable for domestic or agricultural uses. A short-duration comparative study on the effects of using treated oily-water and fresh water on soil physical properties has been performed (Al-Haddabi *et al.,* 2003). It was found from this study that the use of treated oily-water caused a sodicity problem, which has adverse effects on the soil physical properties of the soil such as infiltration rate, saturated hydraulic conductivity and pore size distribution. The reduction in the saturated hydraulic conductivity reached up to 43% of the initial value. The volume of large pores was reduced whereas the volume of small pores increased when treated oily-water was used. These results suggest that disposal of treated oily-water through irrigation and land spreading will be difficult. Impact on soil properties after long-term exposure to such waters needs to be investigated.

A short-term study using production water on plants was also conducted. Rhodes grass, Alfalfa, and Barley were used. The chlorophyll reading and dry weight of stems and roots per plant were used as growth indicators. After seeds were planted, all the plots were irrigated with tap water for 28 days, then treated production water for 35 days, tap water for 5 days and then 25 days with treated production water. The control plots continued to be irrigated using tap water. Generally, the chlorophyll readings were slightly higher in the tap water control plots, but there was no significant difference. Concerning the dry weight of stems and roots, no significant differences were seen as well, and no stunted growth or diverse impact resulting from salts in the treated water was observed.

Learning from others, a comparative analysis of salinity management in Oman and Australia

There are similarities between the salinity situation in Oman and Australia. Agricultural practices have resulted in soil salinity, salinity has caused severe hardships for farmers, and the process has been relatively rapid (very fertile land becoming saline within a span of 10-20 years). However, there are also dissimilarities. These include physical drivers (elevated groundwater level is the main reason for salinity in Australia whereas in Oman it is due to application of saline groundwater) as well as social elements. The latter include the small size of Omani farms compared to Australian farms, and large differences with regards to application of modern technology in farming, economic and educational levels of farmers. The presence of large number of non-Arabic speaking expatriate farm workers in Oman is also different to rural Australia (which tends to have fairly homogeneous social groups), and has important implications for communication and technology transfer.

The Land and Water Management Plan concept applied in Australia could be a useful model for managing soil salinity in Oman if it is adjusted to meet local requirements for socio-economic and cultural reasons (Hoey et al., 2002). In such plans, scientific assessments and modeling, linked to socio-economic considerations, are the basis for developing salinity management strategies for long-term environmental sustainability. Partnership between government and private enterprise underpins these plans.

Lessons learned in Australia with regards to development and implementation of Land and Water Management Plans could bring large benefits to the farmers in Batinah. 'Technology transfer' and scientific exchange would be a valuable first step in this process. This is not to say that the land and water management process has all the answers by any means. The process of development and implementation of the plans in Australia was relatively long, and testament to the difficulties encountered. However, it is certainly worth investigating as to whether such an approach is indeed suitable for Oman.

Future directions

Research

As has been reported earlier in this paper, variation in salinity tolerance exists not only between crop species but also among cultivars of any given species. Therefore, possibilities exist for traditional breeding programs where selection for salt tolerance among species can be made. Success in these breeding programs must involve an extensive collection of wild native species. Additionally, the level of desired improvement in a chosen crop as well as the criteria for selection must be well defined. Many breeders are, however, reluctant to use wild germplasm because it takes a long time and many backcrossing cycles to remove the undesirable traits that are linked with the desirable traits.

Although traditional breeding approaches have been reasonably successful in other parts of the world, we propose that this be integrated with physiological research. In a recent study, Al-Hinai *et al.,* (2003) used random amplified polymorphic (RAPD) DNA analysis to study genetic diversity in several alfalfa cultivars from different parts of Oman. With appropriate DNA markers, this research could be used to tag the physiological components of salinity tolerance. We propose that RAPD and perhaps RFLP (restriction fragment-length polymorphisms) be integrated into breeding programs for the genetic improvement in salinity tolerance in crops in Oman.

Among the Chenopodiaceae, mainly *Atriplex, Salicornia* and *Kochia,* there exist several species with remarkable adaptation to drought and salinity. Some of these crops are used for forage. Research on *Atriplex* has been carried out on a limited scale at the Ministry of Agriculture and Fisheries (MAF) in Oman. We propose that a collaborative research program involving Sultan Qaboos University (SQU) and MAF be developed where large scale adaptability trials of these crops could be done. In Egypt, several species in the genus *Juncus* have been shown to be salt tolerant (Zahran *et al.,* 1979). They are fiber-producing, and have the potential for cultivation on salt-affected nonproductive lands. Research on this crop for possible introduction to the saline farmlands at the Batinah Coastal Region in Oman is recommended.

Extension

Leaching of salts in the rhizosphere is probably the most effective method of alleviating the impact of salinity on crops. The Sultanate of Oman is not endowed with much water resources, therefore this method is not feasible. In lieu of this, Extension Officers should encourage farmers to grow crops that are relatively salt-tolerant. Carrot (*Daucus carota* L.), for instance does not tolerate salinity, so the extension officer should discourage farmers in salt-affected farmlands from growing this crop. Forage oats, rye and barley are tolerant to salinity and the cultivation of these crops as annual forage crops should be encouraged, especially at the Batinah Region. Seed should be supplied to farmers free or at highly subsidized rates. Farmers should be informed about the advantages and disadvantages of sprinkler, flooding and drip irrigation systems.

Training & Education

Extensive research programs on salinity have been carried out at Sultan Qaboos University over the years. There is a need for a closer interaction between SQU and MAF so that extension workers can take advantage of the research results and protocol in SQU. Several Omani graduates are doing postgraduate degrees on aspects of salinity at SQU and many more will join the program in the near future. Opportunities for training also exist for graduate students from other countries. Conferences and workshops on salinity should be held more regularly at SQU.

CONCLUSION

Soil salinity is a serious threat to Omani agriculture. Livelihood of large number of farmers is at stake if the problem is not confronted head-on. Water management practices have been the major focus in terms of management of this problem. Biosaline agriculture in terms of development and introduction of new crops and salt-tolerant varieties of existing crops should be given priority along with the water focused solutions. On-going research and government initiatives need to be strengthened to make any significant improvement in the salinity situation in Oman.

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