Chapter 6
Spray Irrigation

Abstract Irrigated agriculture is the largest consumer of the world's water resources. A decline in the availability of fresh water is driving the use of waters with increasing salinity to be used for irrigation. The irrigation of salt tolerant plants, or halophytes, is a way of addressing this issue and freeing up fresh water for other uses. In the context of brine disposal, spray irrigation is the practice of using concentrate for irrigation of crops, lawns, and other vegetation. The major requirement of this process is that the salinity of the water is acceptable for use on the desired plant. Depending on the salinity of the concentrate, it may be used as is, or diluted with less saline water to bring the concentration of salt to a range where it is acceptable to use on halophytes and salt tolerant non-halophytes. As each plant species has a different salinity tolerance, the amount of concentrate that can be applied depends on the species of plant, the characteristics and salinity of the soil and concentrate that is to be used.

Keywords Conventional crop irrigation · Costs · Crop yield · Environmental concerns · Halophyte irrigation

6.1 Crop Irrigation

Dryland salinity is causing a decline in the productivity of land used for conventional agriculture. In spite of this, there is a range of halophytes and salt-tolerant non-halophytes that are capable of being used as crops in these salt-affected areas. Due to the lower salinity of concentrate from nanofiltration, microfiltration and ultrafiltration processes, spray irrigation is a more viable disposal option for these than for reverse osmosis processes. The successful use of membrane concentrate for crop irrigation requires the selection of appropriate vegetation. Either conventional crops or halophytes can be irrigated with membrane concentrate.

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Areas best suited to irrigation with concentrate are those with level ground and warm climates. Nearby potable aquifers, unsuitable soil conditions and local regulations may altogether prevent spray irrigation at certain sites (Mickley 2009). Unfortunately the potential for spray irrigation as a method of managing concentrate is restricted, as large amounts of land are needed, and the geology must be suitable to prevent the accumulation of salt in the soil and the leaching of salt into underground sources of freshwater.

6.1.1 Halophyte Crop Irrigation

A growing number of studies have begun to focus on the use of concentrate from reverse osmosis plants for the irrigation of halophytes (Jordan et al. 2009; Riley et al. 1997; Soliz et al. 2011). Halophytes have possible uses as forages, oilseeds and biofuels (Glenn et al. 1991, 1998; Hendricks and Bushnell 2008; Rogers et al. 2005; Swingle et al. 1996) but more research is required to see these uses reach their full potential. Moreover, the characterisation of water consumption and growth of halophytes is required to be able to develop sustainable water management strategies (Jordan et al. 2009). Aronson (1989) has created a database listing 1560 known halophytes, but it is estimated that 5000–6000 halophyte species exist (Le Houerou 1993).

Halophytes may be grown in salt-affected areas, but to do this effectively, species need to be developed that are adaptable to various soil conditions, salinity and waterlogging stress levels, climates and livestock management systems (Rogers et al. 2005). For the successful use of halophytes as irrigated crops, the following conditions should be met (Glenn et al. 1999):

- Halophytes need to have a high yield potential
- The irrigation requirements of halophytes should be similar to that of conventional crops, and the irrigation must not damage the soil
- Halophyte products should be substitutable for conventional crop products
- High salinity agriculture needs to be able to be integrated with existing agricultural infrastructure

Research into the development of halophytes has largely focused on their use as animal fodder. Swingle et al. (1996) have demonstrated that halophytes can be incorporated into livestock feed without producing health problems or negatively affecting the carcass quality. When using halophytes as fodder, it is recommended that the use of halophyte forage accounts for no more than 50% of an animal's diet so that the loss of energy content in the salt-containing forage can be balanced by an increase in consumption (Swingle et al. 1996; Glenn et al. 1999). Substituting halophytes for a portion of animal fodder has also been found to decrease feed efficiency and increase animal water consumption. Although the fresh water requirements of animals may increase, this amount can easily be offset by the irrigation water saved when using desalination concentrate.

6.1.2 Conventional Crop Irrigation

The application of salt water for the irrigation of conventional crops has been the subject of a number of studies (Glenn et al. 1999; Grattan 2004; Grattan et al. 2004; Grieve et al. 2004; Skaggs et al. 2006a, b). However, there exists less potential for the irrigation of conventional crops with membrane concentrate when compared with halophytes. This is particularly a result of the limited range of conventional crop species that are tolerant to salt. Those which are most salt tolerant include sugarbeet, cotton, barley, date palms and some varieties of wheatgrass (Maas 1985). Saline irrigation waters and the presence of salt in the soil hinder the ability of most plants to absorb water, and most crops require irrigation with water containing a salt concentration of less than 7000 mg/L. Only the most tolerant are generally able to exceed this concentration (Rhoades et al. 1992). The irrigation of conventional crops will therefore usually require some degree of dilution, based on the salinity of the concentrate.

The yield of a crop irrigated with saline water is related to its salinity tolerance, such that once the threshold of tolerance is exceeded, the yield will decline. The following relationship derived by Mass and Hoffman (1977) shows this decrease in yield as soil salinity exceeds the threshold salinity for a species of plant:

$$Y_R = 100 - B(EC_e - A) \qquad (6.1)$$

where Y_R is the relative yield of the crop, EC_e is the soil salinity (dS/m), A is the plant's salinity threshold (dS/m), the point after which the expected yield begins to decrease, and B is the decline in yield per unit decrease in salinity. Comprehensive data tables including the salinity threshold and decline in yield for a wide range of plant species can be found elsewhere (Maas 1985, 1990; Maas and Hoffman 1977). The values of salinity used for the calculation of the yield are based on water with high concentrations of sodium chloride, as opposed to other ions that may be present in concentrate. The calculated relative yield should be considered as an estimate only, as factors such as climate and soil conditions affect the threshold limit and decline in yield. A number of plant species are also less tolerant to salinity during germination, or throughout the emergence and seedling stages. Note that the amount of salt that is present in the root zone may alter the time a crop takes to reach maturity (Shannon et al. 1994).

Figure 6.1 is a plot of relative crop yield versus soil salinity, and shows the regions for classifying crops based on their salinity tolerance. The crop yield for barley is indicated by the dashed line, with its crop yield indicating that it is tolerant to soil salinity.

When irrigating crops with saline water, a number of management techniques can be employed to help offset the potential loss of yield. Meiri and Plaut (1985) describe a number of strategies to manage crops under saline conditions, including:

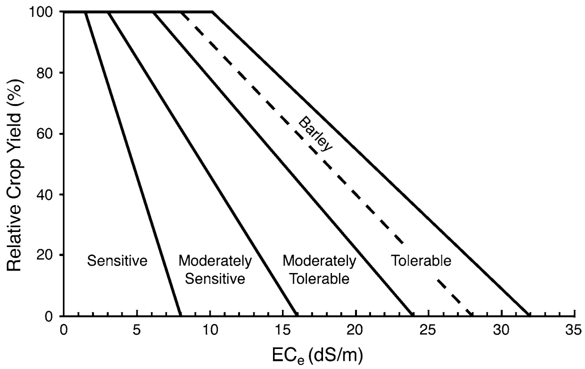

Fig. 6.1 Classifications of crop tolerance based on relative crop yield versus soil salinity. The tolerance of barley is shown by the dashed line. Adapted from Maas (1985) and Maas and Hoffman (1977)

Controlling Root Zone Salinity

The salinity of the root zone can be controlled through numerous means, including adjusting the leaching fraction, adjusting the soil surface contour and seedling planting position, optimising the irrigation interval, using water of varying salinity at different growth stages, and blending water with different salinities. Waters with different salinities may be blended prior to irrigation or applied directly to crops and allowed to mix in the soil.

Optimising of Row Spacing

The field yield of a crop is determined by the yield of each plant, as well as each plant's density or stand (plants per unit area). Optimisation of the row spacing can increase the stand without negatively affecting the plant yield, hence increasing the field yield (Keren et al. 1983).

Reducing the Salinity Damage of the Plant

Reducing the damage caused by salinity will result in an improved crop yield. This can be done through changes in crop management or environmental conditions. Specifically, changes in irrigation method (Maas 1985), climate (Hoffman and Jobes 1978; Hoffman and Rawlins 1971; Magistad et al. 1943) and ambient CO_2 concentration (Schwarz and Gale 1984) have been shown to affect the growth of crops in saline conditions.

6.2 Costs

Typical costs for spray irrigation include the pretreatment of concentrate, equipment required for the storage, blending and distribution of water, land preparation (including drainage systems) and the cost of land. Large tracts of lands are usually required to dispose of the concentrate, especially considering any increase in concentrate volume due to dilution (Mickley 2009). Spray irrigation is therefore best suited to smaller desalination plants with low volumes of concentrate. Unless additional concentrate management schemes are implemented, plants with concentrate volumes of greater than 0.4 million gallons per day (MGD) are usually considered unsuitable (Mickley 2009). High leaching fractions can also lead to greater water requirements and greater pumping costs.

6.3 Environmental Concerns

Anthropogenic salinity is largely due to poor irrigation management. As the use of concentrate for spray irrigation allows for the potential build up of salt in the soil and contamination of groundwater, adequate irrigation management is essential to prevent further increases in salinity.

Increases in soil salinity can hinder the growth of plants by limiting their uptake of nutrients (Grattan and Grieve 1992). The major cations that affect saline soils are Na^+, Ca^{2+}, Mg^{2+}, as well K^+, while the major anions are Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-. When the soil has a high pH, CO_3^{2-} is also present. The nutrients which plants require most are Ca^{2+}, Mg^{2+} and K^+. However, the uptake of K^+ and Ca^{2+} is hindered by the presence of excess Na^+, and an increased concentration of Ca^{2+} in the soil can lead to a deficiency of Mg^{2+} (Grattan and Grieve 1992).

Accumulation of salt in the root zone can be prevented by allowing a certain amount of water to percolate through the root zone. This is known as the leaching requirement, and is defined as the leaching fraction, LF, such that:

$$LF = \frac{\text{amount of water that passes through the root zone}}{\text{amount of irrigation water applied}} \tag{6.2}$$

This can also be expressed in terms of the surface depth of water, or the volume of water per unit surface area. The excess water that passes through is used to carry excess salts that can hinder growth. From the above equation, it can be seen that the greater the leaching fraction, the lower the salinity in the root zone but the greater the irrigation water requirement. Therefore, as the salinity of the concentrate increases, more water must be applied to remove the extra salt. The amount of salt that leaves the root zone may be greater than, equal to or less than the amount of salt in the irrigation water applied, based on precipitation and dissolution reactions of salts (Oster and Rhoades 1990). Several steady state and transient models exist for the estimation of leaching requirement. These can be found elsewhere (Corwin et al. 1990, 2007; Letey et al. 1985; Rhoades 1974; Rhoades and Merrill 1976; Richards 1954; Šimůnek and Suarez 1994).

Irrigation drainage from saline water must not leach into underlying potable aquifers. To do this, the site that is selected for irrigation should have a deep soil profile and should not be in a flood plain. These measures, along with irrigation management to minimise deep leaching and preferential flow, can help to prevent the contamination of potable aquifers (Riley et al. 1997).

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