2018

Sustainability of sprinkler- irrigated horticulture on sandy soils at Binningup - Swan Coastal Plain, W.A.

Eric Law

CHAPTER 2. LITERATURE REVIEW

The primary focus of this investigation was to determine if seasonal rainfall in Binningup was sufficient to effectively rinse the soil profile of salts and replenish the irrigation source water to sustain horticultural activities. In order to place the data collected in perspective, it is thus necessary to review the literature related to various facets of the research. This review begins with a discussion on irrigated horticulture in Western Australia, its sustainability and the general effects of irrigation upon soil. Next is a discussion on plant water demand, its measurement and the concept of soil water balance. This is followed by a description of soil water dynamics and the current methods of measuring soil water content. The review concludes with a review of soil water salinity, plant tolerance thresholds and leaching.

2.1 Irrigated horticulture in Western Australia

Irrigated horticulture is conducted widely across Western Australia and particularly within the Perth metropolitan, South West, Kimberley and Gascoyne districts. The main growing areas are in the South-West, on the Swan Coastal Plain from Gingin to Busselton, and inland around Manjimup and Albany (Mackay 2014; DAFWA 2015a). In 2013, vegetable production in Western Australia had a farm gate value of approximately $336M within a total industry valued at $909M (DAFWA 2015b). Most vegetables are grown for local consumption but carrots are also exported year round to markets in South East Asia and the Middle East (Phillips 2005).

The sandy soils of the Swan Coastal Plain contain less than 3% clay and 1% organic carbon and are augmented by ploughing in cover crops and vegetable crop remains to increase the humic content. The improved soils are still coarse textured however and have a low moisture holding capacity requiring daily irrigation during the summer growing period (Lantzke 1995; Phillips 2005). This can also result in a high percentage of applied fertiliser being leached below the root zone into groundwater (Prince et al. 2008)

Achieving the correct balance between available crop water, fertiliser use, crop yield and leaching is essential to the sustainability of vegetable production on the sandy soils of the Swan Coastal Plain (O'Malley and Prince 2010). It should be noted however that the coarse nature, low clay content, high hydraulic conductivity and low field capacity of the soils require that near field capacity is maintained in order to achieve optimum yields (Prince et al. 2008). The Mediterranean climate and maritime influence in coastal areas of south-western Australia make growing particular crops, such as potatoes and carrots, possible for 12 months of the year.

Currently well-managed, good quality groundwater supply is available for irrigation purposes (Phillips 2005; Mackay 2014) and unconfined aquifers underlying horticultural properties on the Swan Coastal Plain are the major source of water. Because of this, efficient water use and minimal loss is integral to maintaining vegetable production (O'Malley and Prince 2010).

Source water is available for crop application by sprinkler irrigation during the day or night and in the Binningup–Myalup area, overhead sprinkler irrigation is predominantly used for vegetable production. However, irrigation at night is not considered suitable for sandy soils, as plants do not use the water and it drains rapidly after irrigation (Lantzke 1995; Bavi et al. 2009).

2.1.1 Sustainability of irrigated horticulture

Irrigation is necessary for horticultural production on the Swan Coastal Plain but concerns have arisen about sustainability due to decreasing rainfall patterns, exploitation of water resources and land use competition (Dodd et al. 2010). The primary objective of irrigation is to provide a crop with sufficient and timely amounts of water in order to avoid yield loss (Ayers and Westcot 1985). However, if evaporation is high, losses of up to 45% can occur (Uddin et al. 2014) and, coupled with groundwater salinity above 600 ppm, salts in the applied water may accumulate in the soil.

Fares and Alva (2000) describe industry and best management practices in irrigation which were designed to minimise leaching of water and nutrients below the root zone while maintaining adequate irrigation water within the crops roots. By accurately applying water to meet crop requirements irrigators can achieve high water use efficiency resulting in a reduction in the amount of water flushing through the root zone (Fares and Alva 2000; Money 2000).

However Biswas et al. (2009) reported that salt levels were rising in horticultural crops in many major irrigation districts, even with efficient management and winter leaching following rainfall. Thus increased irrigation efficiency is being sought to conserve water, reduce drainage and to mitigate some of the water pollution associated with irrigated horticulture (Rhoades et al. 1999) and in order to sustain economic viability, irrigators must increase production efficiency (Flowers 2004). However, each location has its limitations; for example, at Binningup, there is surplus water, very high evapotranspiration and marginal, if not limiting, salt levels.

2.2 Effects of irrigation on soil

Infiltration can be affected not just by water quality but physical and chemical characteristics of the soil including exchangeable cations (Ayers and Westcott 1985). Irrigation results in large increases in the amount of water passing through the soil profile which has the potential to accelerate weathering, leach material and change soil structure. Poor quality water can therefore cause critical damage to soil structure (Murray and Grant 2007).

Mechanical stresses can also damage soil structure and these include the impact of water droplets from rain or irrigation, which disrupts soil already weakened by its water content (Lehrsch and Kincaid 2006; Murray and Grant 2007). This results in physical disintegration known as slaking, as well as soil compaction caused by the impact of rain or irrigation water itself (Batey 2009; Shainberg and Letey 1984).

The two main processes determining water movement through a soil are it's infiltration rate and hydraulic conductivity (Shainberg and Letey 1984). If these processes are adversely affected by irrigation water quality there is also the potential to reduce the effectiveness of leaching.

2.2.1 Irrigation water quality

In terms of salinity, a number of factors determine the suitability for irrigation water including the type and amount of salts present, the soil type, plant species and growth stage (Warrence et al. 2002).

Two primary water quality factors that determine how irrigation water will affect soil structure and stability are salinity or electrical conductivity (EC) of the water and sodium adsorption ratio (SAR) given by: $SAR = [Na^+] / \sqrt{([Ca^{2+}] + [Mg^{2+}])}$ where $[Na^+]$, $[Ca^{2+}]$ and $[Mg^{2+}]$ refer, respectively, to the concentrations (in milli-moles/L) of sodium, calcium and magnesium in solution (Ezlit et al. 2010).

Calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) generally comprise almost all of the exchangeable cations in soil. In relation to soil structural stability, SAR is an expression of the balance between the concentration of an undesirable cation sodium (Na) and those of more desirable ones (Ca, Mg; Murray and Grant 2007).

Salinity has a direct physical effect on soil structure generally as a result of high concentrations of sodium, so that the cation exchange capacity of soil irrigated with saline water becomes populated with sodium (Murray and Grant 2007). Tedeschi and Dell'Aquila (2004) noted that irrigation with saline water led to an increase in the percentage of exchangeable sodium and degradation of the soil's physical properties.

2.3 Plant water demand

Determining plant water demand requires the measurement of evapotranspiration (ET), a term used to describe the water loss occurring from the processes of evaporation and transpiration (Critchley et al. 1991). Factors affecting evapotranspiration include solar radiation, air temperature, humidity and wind speed; crop characteristics including crop type, variety and development stage; and management and environmental aspects (Allen et al. 1998).

Evapotranspiration can be measured either directly or determined indirectly from weather data and soil water balance (Zeleke and Wade 2012). Direct measurement requires specific devices and accurate measurements of physical parameters or the soil water balance (Allen et al. 1998). Measurement systems include: lysimeters, eddy covariance, Bowen ratio, water balance, as well sap flow, scintillometry and satellite-based remote sensing and direct modelling (Rana and Katerji 2000; Allen et al. 2011). These methods can be expensive, demanding in terms of accuracy of measurement and require competent personnel (Allen et al. 1998; Sumner and Jacobs 2005). A few are examined below.

2.3.1 Lysimeters

Weighing lysimeters were developed to give a direct measurement of evapotranspiration and consist of a container filled with soil, resting on a scale. The container prevents loss of water to deep percolation or lateral water movement, allowing water losses only through the soil or through the crop planted in the lysimeter (Evett et al. 2009). By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, different parameters in the soil water balance equation can be determined with greater accuracy (Allen et al. 1998).

2.3.2 Energy balance and microclimatological methods

In these methods, only the transfer of heat as sensible heat flux is considered and evapotranspiration (latent heat flux) is calculated as the residual term in the general energy balance equation (Ershadi et al. 2011). Common approaches include the Bowen ratio-energy balance (BREB) which can be obtained independently of weather conditions and requires no information about aerodynamic characteristics (Shi et al. 2008); and eddy covariance, which measures vertical turbulent fluxes in the atmospheric surface layer (ASL) by sensing the properties of eddies as they pass through a measurement level (Allen et al. 1998).

2.3.3 Soil water balance

The soil water balance method assesses the incoming and outgoing water flux into the crop root zone over some time period. Irrigation and rainfall add water to the root zone and part may be lost by surface runoff or deep percolation which eventually recharges the water table. Water may also be transported upward by capillary rise from a shallow water table towards the root zone (Allen et al. 1998).

The time and cost associated with direct measurements of evapotranspiration make the use of methods relying on more easily obtainable data more desirable. One such method is the Penman–Monteith equation (PM), which requires measurement of net radiation, soil heat flux, air temperature, relative humidity, wind speed, and other environment-specific variables. Another is pan evaporation (E_p) which requires measurement of daily evaporation from a pan. A third is reference evapotranspiration (ET_0) which can be derived from PM and E_p and requires measurement of incoming solar radiation, air temperature, relative humidity, and wind speed (Sumner and Jacobs 2005).

Empirical equations developed for assessing crop or reference crop evapotranspiration from meteorological data include the Penman-Monteith method which is considered a standard method for evapotranspiration estimation in agriculture (Allen et al. 1998; Zeleke and Wade 2012) and is often used to verify other empirical methods (Chen et al. 2005).

Evapotranspiration estimated from pan evaporation measures the evaporation from an open water surface providing an index of the combined effect of radiation, air temperature, air humidity and wind on evapotranspiration, however differences in the water and cropped surface may produce significant differences in the water loss estimate from an open water surface compared to that of the crop (Allen et al. 1998).

2.4 Soil water dynamics

Maintaining sufficient soil water content and quality is required to support optimum plant growth and product yield (Fares and Alva 2000). The state of water in soil is described in terms of the amount of water and the energy associated with the forces that hold the water in it (Bilskie 2001). Where soil water content is an indication of the amount of water present, soil matric potential determines the availability of water to plant metabolism and is a direct indication of the energy required for plants to obtain water from the soil (Irmak et al. 2006).

Soil water content is expressed as the mass of water in a unit mass of soil (gravimetric) or volume of water in a unit volume of soil (volumetric) (Gardener et al. 2000; Bilskie 2001; Charlesworth 2005). When soils dry, more energy is required to extract available soil water (Charlesworth 2005) and this is measured in kilopascals (kPa, Mullins 2000).

Irmak et al. (2006), describe total soil water potential as ‘the sum of gravitational, osmotic and matric potential where gravitational and osmotic potential are generally not taken into account’. Hydraulic conductivity refers to the ease of water movement through soil, both horizontally and vertically, and it decreases with a decrease in pore size and water content (McCauley 2005). Therefore, the hydraulic conductivity of a soil will vary and be at its greatest when soil is fully saturated (Warrence et al. 2002).

The rate of soil water movement (e.g. Figure 2-1) is therefore determined by its ability to conduct water, evaporative demand, the temperature, and the pressure and salt gradients which change over the course of a day (Jackson 1973).

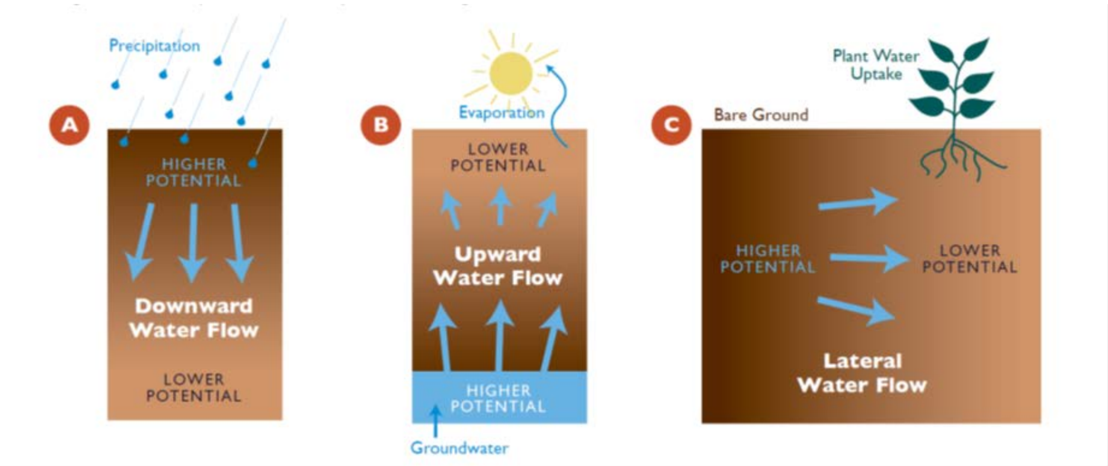

Figure 2-1: Three basic pathways of water movement through the soil profile (Source: McCauley 2005).

King and Stark (2005) describe the influence of a soil's water holding capacity on irrigation system design and irrigation scheduling and note that water should be able to be repeatedly applied before crop water stress develops.

2.4.1 Diurnal variation in soil moisture

While water for transpiration is abstracted from the soil, precipitation, irrigation and groundwater variously add water to it. Also, whereas precipitation and irrigation could directly evaporate without adding to soil water, soil water adds to groundwater (via gravimetric drainage) as well as takes from it (via capillary rise) (Moiwo and Tao 2015).

In a soil without vegetation and active rainfall, the soil moisture at the surface has a marked daily variation as it dries during the day and partially rewets at night. The near surface inter-particle space dries and draws moisture from below to be lost in the following cycle, until a stable gradient is established. The daily variation in soil moisture decreases with both depth and decreasing soil temperature (Villagarcía et al. 2004) and plays a significant role in the evaporation of water from soil. Thus atmospheric variables, such as radiation, wind, air temperature and humidity all influence the physical condition of the soil surface and determine the course of evaporation (Jackson 1973).

Importantly, salt concentration in the crop root zone continually changes with moisture change. As the soil dries, the soil solution becomes increasingly concentrated, reducing the plants access to soil water (Allen et al. 1998; Sheldon and Menzies 2004).

Soil moisture in the unsaturated zone near the soil surface also plays a critical role in partitioning rainfall into surface runoff, evaporation and groundwater recharge (Yijian et al. 2009). Evaporation rates will vary with the season soil water content, and movement within the surface zone should be different for the different seasons (Jackson 1973). The soil water within the surface zone can be lost directly to the atmosphere via evaporation and indirectly via transpiration. This continuous process is called evapotranspiration (Moiwo and Tao 2015).

2.5 Measuring soil water content

The measurement of the water content of soil and the unsaturated zone is fundamental to irrigators and to investigations across a broad range of industries. As such, while a range of demands on measurement are required (Gardener et al. 2000), there are two common methods currently utilised, these are thermogravimetric and dielectric (by means of capacitance) and are described below.

2.5.1 Thermogravimetric method

The thermogravimetric method of measurement requires the removal of soil water by evaporation and is achieved by oven drying samples. This method is considered the most established and true direct measurement of soil water content (Smith and Mullins 2000; Charlesworth 2005) and is used as a standard for calibration of alternative soil moisture evaluation techniques (Zazueta and Xin 1994; Walker et al. 2004).

2.5.2 Capacitance probes

Indirect measurement techniques, such as dielectric methods do offer an alternative to the thermogravimetric method but they require careful calibration to convert the sensor response to soil moisture in different soils and temperature conditions (Cosh et al. 2005). Dielectric methods of soil measurement include capacitance techniques which are used to exploit the strong dependence of soil dielectric properties on water content (Smith and Mullins 2000).

Soil water content is determined by its effect on a dielectric constant by measuring the capacitance between two electrodes implanted in the soil (Zazueta and Xin 1994). By using appropriate calibration curves, the dielectric constant measurement can be directly related to soil moisture (Topp et al. 1980; Kennedy et al. 2003).

The dielectric constant is a measure of the capacity of a non-conducting material to transmit electromagnetic waves or pulses. The dielectric of dry soil is much lower than that of water, and small changes in the soils free water have large effects on the electromagnetic properties of the soil water media (Charlesworth 2005).

Where soil moisture is predominantly in the form of free water; for example, in sandy soils, the dielectric constant is directly proportional to the moisture content. The output from the sensor is not linear with water content and is influenced by soil type and soil temperature (Zazueta and Xin 1994).

The development of non-destructive capacitance probes allows continuous monitoring and recording of soil moisture (Villagarcía et al. 2004). Capacitance probes for soil water monitoring have been used broadly in natural resource management, including research on crop yield, watershed management, precision agriculture and irrigation scheduling (Hanson et al. 2004). In horticultural management, using capacitance probes with data-loggers allows near continuous measurement and observation of soil water content, as well short and long-term trends, such as plant daily water use (Starr et al. 2009). Importantly, they allow for the observation of irrigation water and rainfall penetration through the soil profile (Zekri et al. 1999).

In Kennedy et al. (2003), in-situ capacitance probes for measuring soil water content were found to offer three main advantages over other techniques, such as electrical resistance sensors, neutron probes and gravimetric sampling. They are: relatively low in cost compared to other in situ equipment, such as time–domain reflectometry (TDR systems); they require minimal maintenance; and they are relatively easy to install.

2.5.3 Capacitance probes and leaching

By knowing the soil moisture content (θ), irrigators can make timely decisions on starting and stopping water application which optimises water use and crop yield (Hanson et al. 2004). For example, Fares and Alva (2000) demonstrated that soil water monitoring using capacitance probes can also be used to determine drainage below the root zone. Arregui and Quemada (2006) also noted that probes were effective in determining the drainage volumes at depths of up to one metre using daily soil water measurements.

2.6 Soil water salinity

In horticulture, salinity problems occur if salts accumulate in the crop root zone at concentrations that result in a reduction or loss in yield. Plant available water is at its maximum and soil salinity is at its lowest concentration immediately after irrigation (Warrence et al. 2002). Under normal conditions, salts are added to the soil with each irrigation (Oster 1994). The crop removes most of the applied water from the soil to meet its evapotranspiration (ET) demand but leaves most of the salt behind to concentrate in the decreasing volume of soil water (Ayers and Westcot 1985). However in irrigated crops, salts often originate from either a saline, high water table or from salts in the applied water (Ayers and Westcot 1985; Lovell 2006).

A reduction in yield occurs when these salts accumulate in the root zone to such an extent that the crop is unable to extract sufficient water from the saline soil solution. If water uptake by the plant is appreciably reduced, the plant slows its rate of growth (Ayers and Westcot 1985; Schoups et al. 2005). This effect becomes most pronounced during periods of high evapotranspiration demand, such as hot sunny summer days and/or during the peak of the growing season (Warrence et al. 2002).

If there is no movement of water beyond the bottom of the root zone (known as leaching), the salt will accumulate and increase the concentration within the root zone (Oster 1994). Conversely, salt leaching can lead to salt build up in both shallow groundwater below the plant root zone and underlying aquifers (Schoups et al. 2005). Ayers and Westcot (1985) describe how a portion of the added salt must be leached from the root zone before the concentration affects crop yield. This is achieved by applying sufficient water so that a portion percolates through and below the entire root zone, carrying with it a portion of the accumulated salts (e.g. Figure 2-1).

Ezlit et al. (2010) attributed the source of salinity problems primarily to the quality of the irrigation water and the time required to develop an issue can be determined by the concentration of salts in the source water and associated management practices.

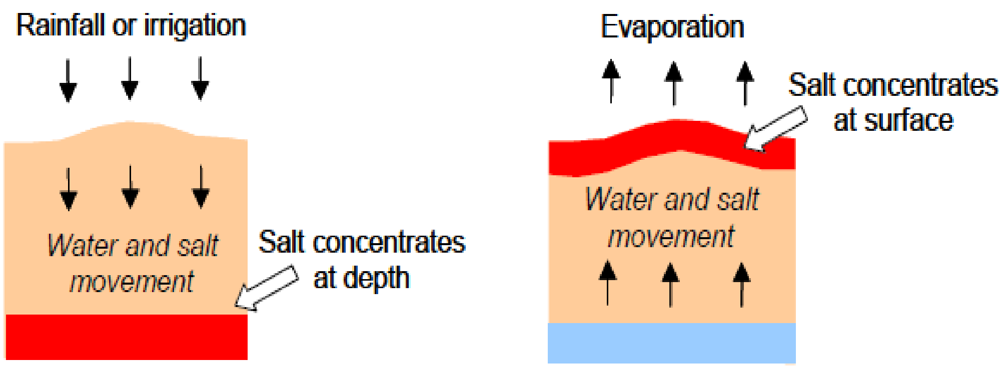

Figure 2-2: Illustration of typical salt distribution in the soil profile under overhead sprinkler application (after Cook et al. 2006).

2.6.1 Salinity effects

As noted above, salts accumulate in water and soils due to evaporation, transpiration and mineral dissolution. Salt in soil water reduces water availability by increasing the force the plant must exert to extract water, which induces water stress (Cook et al. 2006) and this additional force is referred to as the osmotic effect or osmotic potential. The osmotic effect is a natural process where water, passing through a semi permeable membrane, moves from a solution of low concentration to one with a higher salt level (Lantzke et al. 2007). The high concentration of salt in the soil water makes it harder for roots to absorb water from it, reducing the rate of water uptake by plants, even when there is sufficient water available (Ayers and Westcot 1985; Warrence et al. 2002). Growth is subsequently slowed and yields reduced. This effect is progressive and increases in proportion to the salinity (Flowers and Yeo 1989; Lovell 2006).

Toxicity problems will occur if certain constituents – predominantly sodium (Na^{+}) and chloride (Cl^{-}) ions - in the soil or soil water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields (Ayers and Westcot 1985; Grattan and Grieve 1999). Damage may result when these ions are taken up, either by the roots or by direct contact on the leaves. Ions absorbed by the roots are transported to the leaves where they accumulate during transpiration (Ayers and Westcot 1985; Lantzke et al. 2007). Under normal conditions, the roots of most plants exclude these salts during water uptake which concomitantly contributes to an increased concentration in the soil (Mass and Hoffman 1977).

Typical sodium toxicity symptoms are leaf burn, scorch and dead tissue along the outside edges of leaves, in contrast to the symptoms of chloride toxicity which normally occur initially at the extreme leaf tip (Lantzske et al. 2007). In addition, high concentrations of sodium in irrigation water can also induce plant calcium and potassium deficiencies in soils low in these nutrients.

In general, the effect of salinity is to reduce a plant's growth rate, resulting in smaller leaves, shorter stature and sometimes fewer leaves (Shannon and Grieve 1999). Although salinity affects plants in many ways physiologically, adverse symptoms rarely occur except under extreme salinisation (Maas and Hoffmann 1977). The severity of salinity response can be affected by environmental interactions, such as relative humidity, temperature and radiation (Shannon et al. 1994).

2.6.2 Measuring salinity

Salinity is the presence of soluble salts in the soil solution which may be naturally occurring or derived from rainfall, mineral fertilisers or irrigation water (Rhoades et al. 1999; Lovell 2006). More specifically, 'salinity' usually describes the concentration of dissolved minerals measured as a unit of volume or weight (Rhoades et al. 1999).

In irrigation, salinity is generally described as total salts, irrespective of the constituents involved (Ezlit et al. 2010). The salinity of crop soil water is often reported as total salt concentration or total dissolved solids (TDS) which are the total amount of mobile charged ions, such as minerals, salts or metals dissolved in a given volume of water (Grattan 2002). This can be determined by evaporation of a known volume of water to dryness and weighing the quantity of dissolved material contained in that amount (Rhoades et al. 1999). TDS is expressed in parts per million (ppm) (Grattan 2002).

Another salinity measurement is electrical conductivity (EC) which is a numerical expression of the ability of a medium to carry an electrical current (Rhoades et al. 1999). Because the conductivity and total salt concentration of an aqueous solution are closely related, EC is commonly used as an expression of the TDS of an aqueous sample. EC measurements are based on the fact that the electrical current transmitted between two electrodes increases with an increase in soluble ionic salts, and vice versa (Grattan 2002). The basic unit of EC is the siemens per metre (S/m). In horticulture, EC is generally very low, so decisiemens is commonly used (dS/m).

Common methods for measuring soil water salinity include saturated paste extracts and soil suspension (Maas and Hoffman 1977; Shannon and Grieve 1999), such as:

- EC1:5 – the electrical conductivity of a 1:5 soil water suspension, used routinely in analyses.
- ECse – the electrical conductivity of the soil saturation extract, used for predicting plant response – commonly predicted from 1:5 and soil properties, or it can be measured directly (Maas and Hoffman 1977).

The EC1:5 soil water suspension method is the electrical conductivity of a 1:5 soil water suspension, which is used routinely in analyses (Rayment and Higginson 1992; Lovell 2006). In an Australian context, the ratio of 1:5 was established in response to difficulties when using the traditional saturation extract mixing method with heavy textured soils.

EC1:5 gives a different result than a saturated extract and tends to underestimate the electrical conductivity of sandy soils compared with clay soils (Rayment and Higginson 1992). This method, however, is relatively quick and inexpensive and is therefore appropriate for field tests. Field test results will differ from laboratory results because soil drying, shaking and settling times are not standardised in the field. However they are generally quite adequate for practical salinity appraisal purposes (Rhoades et al. 1999).

2.6.3 Salinity tolerance thresholds

A plant’s salt tolerance is its inherent ability to withstand the effects of high salts in the root zone or on the plant’s leaves without a significant adverse effect (Shannon and Grieve 1999). Not all plants respond to salinity in the same way and some crops can produce acceptable yields at a much greater soil salinity than others. (Ayers and Westcot 1985). Impacts on crop production can be described in terms of ‘percentage yield loss’ (Harvey and Strudwick 2009). Studies conducted by Biswas and colleagues (2009) to measure the effect of increasing soil salinity on crop yield, reported that yields appeared to remain constant up to a certain salinity value known as the ‘threshold’ and then begin to reduce.

Table 2-1 below provides a list of threshold values in Primary Industry and Resources South Australia (PIRSA 2006) expressed as the electrical conductivity of soil water (ECsw) for maximum production of horticultural crops and expected yield reductions from higher salinity levels.

Table 2-1: Soil water salinity thresholds for horticultural crops (PIRSA 2007).

Crop	Soil water salinity threshold (ECsw) in dS/m		
	0% yield loss	25% yield loss	50% yield
Orange	3.4	6.6	9.6
Grapefruit	3.4	6.6	9.6
Lemon	3.4	6.6	9.6
Apricot	3.2	5.2	7.4
Peach	3.4	5.8	8.2
Carrot	2.0	5.8	9.2
Onion	2.4	5.6	8.6
Potato	3.4	7.6	11.8
Tomato	5.0	10.0	15.0

2.7 Leaching

As noted above, leaching salts for the prevention of excessive salt accumulation in irrigated soils is essential for sustainable crop production (Barnard et al. 2010). It is achieved by applying sufficient water so that some of it percolates through and below the entire root zone carrying with it a quantity of the accumulated salts (Ayers and Westcot 1985; Monteleone and Libutti 2012).

Salt removal by leaching must equal or exceed the salt added by the applied water or the salts will accumulate at the root zone, eventually reaching concentrations prohibitive to crop yield. The amount of additional water needed to do this effectively is termed the 'leaching requirement' or 'fraction' (Ayers and Westcot 1985; Rhoades et al. 1999). Identifying the crop leaching requirement varies as to the irrigation method, crop type, geology and climatic condition (Ayers and Westcot 1976; Cardon et al. 2007).

There are, however, limitations to leaching. With high evaporative conditions, it is difficult for irrigators to supply the required crop water and leaching water during the summer. Ayers and Westcot (1976) noted that effective leaching should be carried out at pre-planting, as most crops are more susceptible to salt damage during germination or in the seedling stages.

Leaching can also be conducted on a limited basis at times during the growing season when a grower may have high quality water available (Cardon et al. 2007). Alternatively in situations where a grower has numerous water sources of varying quality, leaching can be achieved through planned events at times when salinity is known to cause stress for a given crop (Lantzke and Calder 2004; Cardon et al. 2007).

Comparing the leaching requirement to irrigation efficiency is critical for sustainable irrigation practices and Meyer and Bowmer (2004) note that many growers are attuned to the balance in the application of water. Sustainability, therefore, requires the ability to consider a variety of factors, including soil geology, groundwater and climatic conditions.

2.7.1 Rainfall – natural leaching

Rainfall is considered the primary source of water for horticulture and agriculture globally (Dastane 1978) and it generally has salinity less than that of applied water. In irrigated soils, root zone salinity largely depends on a number of factors, including but not limited to, annual rainfall (Cook et al. 2006; Platts and Grismer 2014). Monteleone and Libutti (2012) evaluated the capability of yearly rainfall to leach salts accumulated in the soil during the previous spring–summer irrigation season in Mediterranean climates. While the research was conducted under simulated conditions, it concluded that annual cultivation of a spring–summer irrigated crop without any additional leaching (including rainfall) leads to a saline build up.

Platts and Grismer (2014) concluded that rainfall was critical for sustainable irrigation and found that effective leaching of crop root zone salinity occurs during the winter rainy season, when ET rates are generally low. Dastane (1978) explains by way of illustration (Figure 2-3), that a certain fraction of rainfall lost beyond the root zone is considered essential for the rinsing of salts, especially in arid and semi-arid regions.

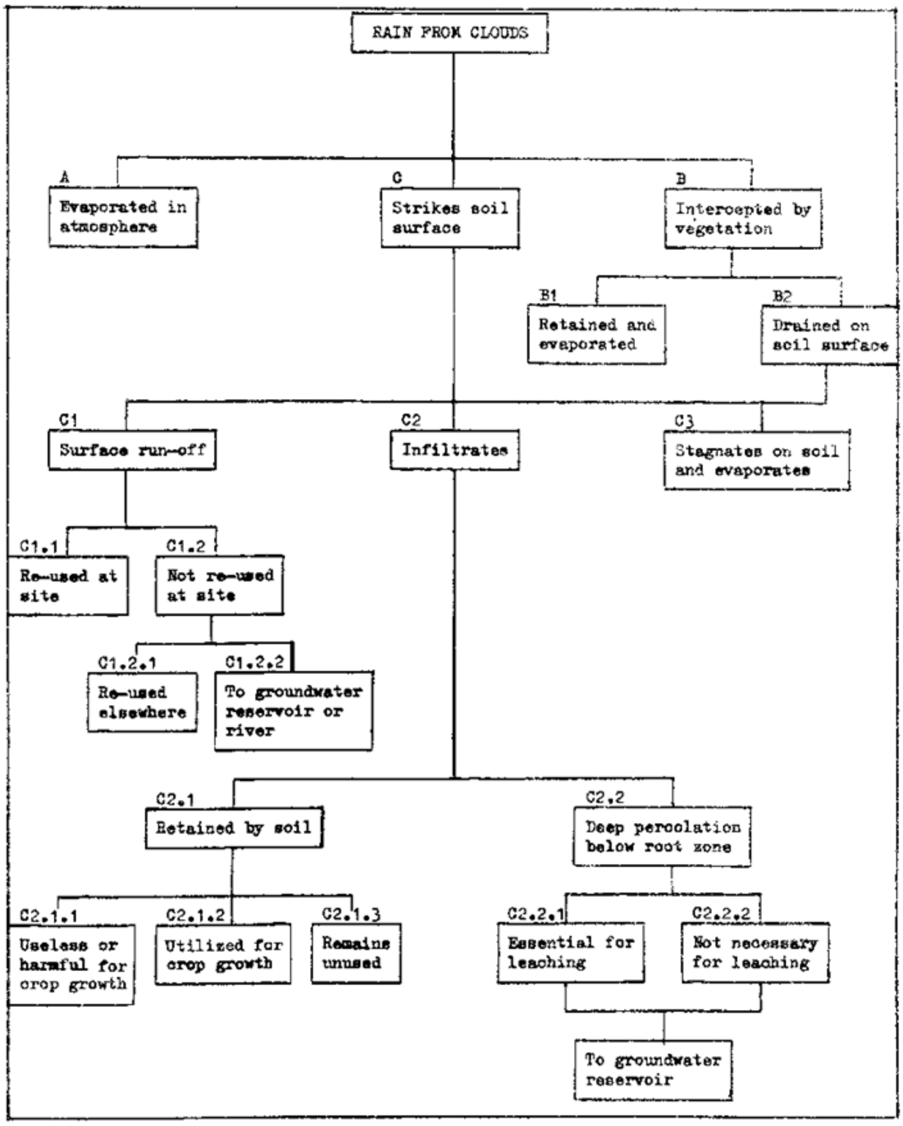

Figure 2-3: The pathway of rainfall (Source: Dastane 1978).

2.8 Conclusions

Sustainable irrigated horticulture relies on maintaining sufficient soil water content at the crop root zone. However, salts are known to accumulate within the soils as a result of irrigators managing soil water and limiting the drainage of applied water past the crop root.

Thermogravimetric and dielectric methods are used to obtain accurate soil water content measurements. The use of multisensory capacitance probes is sufficient to monitor and measure soil water content. The capacitance probes are capable of providing qualitative data which can determine the movement of applied water and rainfall through the soil profile.

Soil salinity is known to be prohibitive to crop yield at high concentrations. Soil salinity can be measured in field and is known to be greatest during periods of high ET demand. Soil salinity can be effectively managed by leaching, which requires the application of surplus water volumes. While ET is low, winter rainfall can be effective in rinsing salts accumulated from summer irrigated crops, especially in Mediterranean climates.