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

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CHAPTER 6. DISCUSSION

The original scope of this research 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. It was also envisaged that this information would allow horticultural managers to develop an optimal regime of summer irrigation for salt reduction, fertiliser efficiency and crop yield. There were three main objectives:

- To record the behaviour of both rainwater and sprinkler water in the crop soil profile in response to the age of the crop and ambient meteorological conditions
- To record salt accumulation from sprinkler water in the soil profile and determine the intensity and duration of rainfall required to rinse water from the soil profile.
- To determine the replenishment of the aquifer below the crops and conclude whether there was significant accumulation of salt in the upper portions of the aquifer.

The primary results from this investigation have indicated the following:

- Accurate volumes of applied water and rainfall were measured and a known quantity of salt was added to the crop.
- Soil moisture measurements indicated a number of rainfall events occurred sufficient enough to saturate the soil at the 50 cm interval.
- Soil water salinity was measured and indicated that a reduction in salinity occurs after rainfall events that saturate the 50 cm soil profile in summer and winter.
- Average annual rainfall does not affect the quantity of groundwater available for irrigation.
- Salts are returned to the groundwater below the crops; however, groundwater is replenished sufficiently for irrigation purposes.
- Nitrogen as an indicator of groundwater contamination has a negligible effect on irrigation water salinity

And these are discussed in turn below.

6.1 Crop precipitation

It is known, through volumes of water extracted (via pumping capacity and hours), that the horticultural managers aim to apply between 10 and 11 mm of water to the crops each day during summer. However, rain gauge data for the summer investigation period showed that on average, 7.1 mm is received daily at the crop surface. Clearly factors contributing to evaporation are significant in adjusting desired delivery rates. Results from trials conducted on 27/01/2012 noted that evaporation between the sprinkler head and the ground was around 20-25% and this leads both a reduction in volume delivered and a concomitant increase in applied water salinity (Bavi et al. 2009; Uddin et al. 2014). Additionally during summer, water is applied to the crops daily. Whereas in winter, application rates are determined by a combination of crop stage, fertiliser application, rainfall and frost conditions (Table 6-1).

Table 6-1: Summary of P003 and C003 precipitation/irrigation and evaporation.

Investigation and season	Duration (days)	Total crop precipitation/irrigation (mm)	Total rain (mm)	Total applied water (mm)	Mean evaporation
P003 winter	85	597 (7 mm/day)	451 (5.3 mm/day)	146 (1.72 mm/day)	2.25%.
C003 summer	45	379 (8.42 mm/day)	58.8 (1.3 mm/day)	320.2 (7.2 mm/day)	7.75%

While average daily crop precipitation/irrigation was 8.42 mm in winter, compared with 7 mm in summer, it was the difference in evaporation (2.25% versus 7.75% respectively) that accounted for the requirement for additional volumes of applied water. For example, average daily water application received by the crop during P003 was 1.7 mm, very much less than during C003 (7.2 mm).

Rainfall in the year in which this research took place (931 mm) was above the six-year average for this area (802 mm, Figure 6-1.). Thus it would seem that this would need to be taken account of in any irrigation management plan.

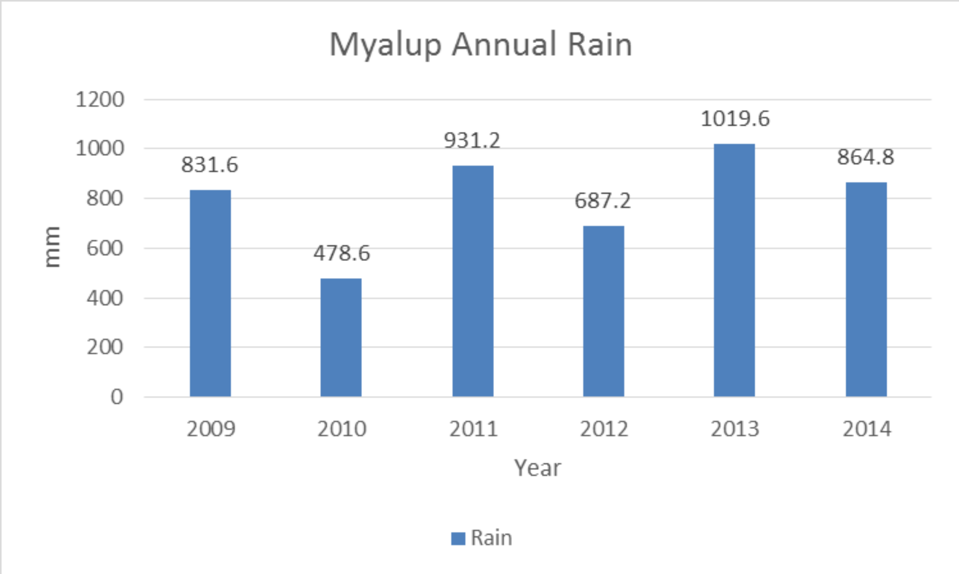

Figure 6-1: Myalup annual rainfall for years 2009–2014.

6.2 Soil moisture

The gravimetric soil moisture enabled the research to standardise the observed soil water salinity measured to greater understand the TDS levels expected at different levels of soil moisture. Gravimetric soil moisture for the winter (P003) investigation was generally high (4.1% to 8.3%). This may be attributable to low evaporation, low temperatures and the 49 days with rain occurring. This also underpins the requirement for small volumes of water to be applied during the winter growing season. This is in contrast with summer, where soil moistures ranged from 3.0% to 7.2% (averages across sampling events at 4.65%, 6.5%, 5.7% and 4.15%).

6.3 Natural rinsing

The primary focus of this investigation was to determine the effectiveness of the rainfall events in winter and summer to leach salts from the soil profile and this was determined by measuring the saturation at and below the root zone (Ayers and Westcot 1985; Monteleone and Libutti 2012). At Binningup this was at the 30 cm and 50 cm soil intervals and is illustrated by the sharp increase and decrease of the curve for the interval on the soil moisture graphs (Figure 5-11, 5-12 and 5-26).

To ensure the sustainability of horticultural activities, salts must be rinsed past the 30 cm interval, the 50 cm interval and through to the underlying superficial aquifer (Barnard et al, 2010; Platts and Grismer 2014). Encouragingly, the three events analysed during winter and one event during the summer indicated that this had occurred. Significant summer rainfall events and summer irrigation have little effect on reducing salinity values as compared with seasonal rainfall experienced in winter, as was observed by Biswas et al. (2009).

6.3.1 Escalating soil moisture

Soil moisture recorded in both winter and summer investigations indicated that there was an escalation in soil moisture in the latter crop stages. No increase in crop precipitation and/or irrigation was recorded to suggest that it was responsible for the escalation. Additionally, no anomalous evaporative conditions were recorded either.

In P003, the escalation occurred on 18/07/2011, 51 days into the investigation, which is approximately when the crop was planted. At C003 the investigation started in a juvenile crop, where small vegetables were already present at the sensor location. An escalation in soil moisture was observed on 16/01/2012, 43 days into the investigation. Evidence of vegetable growth and density increased was observed in both P003 and C003 at these stages and escalation of the crop soil moisture was noticeable for P003 at the 10 cm and 20 cm intervals and in C003 at the 10 cm, 20 cm and 30 cm intervals. It can be concluded that the escalation in crop soil moisture may be attributed to the following:

- **Compaction of the tilled surface soil due to precipitation**. This was evident after heavy rain events in P003, where the tilled rows were observed to appear more compressed (Shainberg and Letey 1984; Imeson and Kwaad 1990; Batey 2009) and where soil appeared to have splashed on to the side of the in situ instruments. This was noticeable in the earlier stages of the investigation when there was an absence of vegetable foliage.

- **Vegetable growth and proximity**. An increase in vegetable growth and proximity was observed which compacted the soil in between, and surrounding, the vegetables (Gregory 2006). The effect of the soil compaction was to increase its water-holding capacity (Hamza and Anderson 2005). Subsequently, a greater proportion of crop precipitation/irrigation water was retained at these intervals

(Figure 5-11, 5-12 and 5-26). As the potatoes were grown further up in the profile, this corresponded with the increased soil moisture in the 10 cm and 20 cm intervals. Likewise, the increase in soil moisture at the 10 cm, 20 cm and 30 cm intervals of the C003 carrot crop corresponds with the depth that the carrots were grown.

- **Proximity of probe sensors to vegetables**. It was observed that the soil moisture probe sensors were close to the surrounding vegetables as the crop matured. This may have had the effect of recording the moisture that was held within the vegetables, as sensors may have a strong correlation with organic material (Fares et al. 2016) and it is known that potatoes contain approximately 70–80% water and carrots 85–90%.

Therefore, if the moisture holding capability or bulk density of the crop soil increases with crop maturity, it may reduce the effectiveness of a rain event to leach or dilute crop root zone salts, particularly during low volume, low intensity rain events. Similarly, the volume of rainfall observed to be effective in reducing TDS in the earlier stages of the crop may not be as effective in reducing crop TDS in the later stages.

The ability for horticultural managers to maintain the required soil moisture is therefore increased toward the later stages of crop development and may be beneficial in terms of water use and water efficiency.

6.4 Salinity

It can be concluded that measuring soil water salinity is integral to determining the effectiveness of the rainfall events to rinse the soil profile. Records of salt concentration at each interval pre- and post-rainfall, indicated the downward movement of salts below the crop root zone. Soil water salinity measured at P003 was shown to increase with the development of the crop. This was also observed in C003.

Salts are added to crop soils with each irrigation application (Oster 1994). Therefore, a known quantity of salts is calculated for each investigation period. It was calculated that a total of 0.8 tonnes of salt per hectare was added to P003 during the winter investigation through the application of irrigation water. It is estimated 4.16 tonnes of salt per hectare was added to C003 during the summer investigation.

Note however, that P003 had 451 mm total rainfall and four events that saturated the 50 cm interval. While C003 had 58.8 mm total rainfall in two events that effectively saturated the 50 cm interval. In addition, the TDS concentration of the applied water was shown to increase through evaporation between the sprinkler head and the ground (Lantske et al. 2007).

It was shown in Figure 5-33 that salts applied with irrigation applications from 04/12/2011 to 11/12/2011 and from 11/12/2011 to 20/12/2011 were effectively rinsed with rainfall events that occurred on 07/12/2011 and 12/12/2011 respectively. These events had the effect of reducing salts at all intervals with the exception of the 30 cm interval on the 11/12/2011 where a minor increase (58 ppm) was recorded and a substantial increase was shown at the 50 cm interval (1,974 ppm). These results were recorded after five days of subsequent irrigation applications.

It can be concluded that the rainfall event on 07/01/2012 did not compromise the required volume to leach the salts passed the 50 cm interval, thus leaving an accumulation of the leached salts at this depth. Also a minor increase (30 ppm) was shown to occur at the 20 cm interval on the 20/12/2011 following eight days of applied water after the rainfall event.

A reduction in TDS levels at the 50 cm interval shows that the volume and intensity of the rainfall on 12/12/2011 was sufficient enough to leach the accumulated salts below the 50 cm interval and to the underlying aquifer. The minor increase in the 20 cm interval can be attributed to the salts applied with the subsequent eight days of irrigation water.

6.4.1 Salinity and yield

Soil moisture and gravimetric data show that moisture content varied markedly through the daily watering cycle from as high as 9.5 per cent of dry soil weight which approximates pore space saturation to 4.0 per cent. Assuming that the salt stays in situ, this indicates that the salinity of soil moisture varies substantially in response to percolation and evapotranspiration (Jackson 1973: Villagarcía et al. 2004). Therefore a standard for soil moisture was applied to indicate expected TDS concentrations at a range of soil moisture conditions reflective of those observed during the course of the investigations. These were 4%, 6% and 8 %.

The results indicate that the 100 per cent threshold level is exceeded at all levels at the 4%, 6% and 8% calculated soil moisture for the summer investigation period. At 8 per cent calculated soil moisture, the 50 per cent threshold was exceeded by all intervals at each sampling event with the exception of the 50 cm interval on 04/12/2011, 11/12/2011, 20/12/2011 and the 10 cm interval on 20/12/2011.

These results indicate that rainfall events greater than 30 mm during winter or summer have the ability to saturate the soil profile to depths below the crop root zone and effectively leach or dilute the soil water of accumulated salts.

6.5 Groundwater quality

Groundwater enters the east of the property at a salinity of 200 to 300 ppm (Meagher 2010) and total nitrogen between 0.5 and 1.0 ppm. It generally flows in a westerly direction beneath the property (Rockwater Pty Ltd. 2000). Irrigation water and rainfall percolates through the crop soil which results in the return of irrigation water and associated salts to the groundwater (Lantzke 1997).

This is demonstrated by the occasional increases in nitrogen and TDS at W1 which is central to the cropped area (Figure 3-1) and therefore represents a good indicator of groundwater quality underlying the property. TDS levels at W1 were observed to range from 832 to 906 ppm.

While W3 TDS levels were similar to W1, TDS at W2 was 200–300 ppm higher (~1,200 ppm). The reason for this variation in TDS may be explained by the effect of the previous land uses on the Coastal Limestone and the reaction of the groundwater to heterogeneous characteristics within the formation, however these factors were not within the scope of the research.

Nitrogen recorded at W1, W2, and W3 as an indicator of groundwater contamination from fertiliser applied to crops during the growing season did not increase the TDS of the groundwater supply.

TDS levels monitored at W1 remained stable, despite recirculation of the irrigation water and the salts found to be accumulating in the soil profile during the summer growing period. The return of salts to the groundwater did not register unsustainable levels, suggesting that there was adequate mixing of the returned irrigation water and the underlying source water. This is confirmed by past TDS records (Meagher 2010) which show that levels remained stable during the past 10 years of horticultural operations. It can therefore be concluded that the current horticultural practice is sustainable in the long term.

CHAPTER 7. CONCLUSION

At Binningup–Myalup, the near-surface superficial aquifer contains a greater volume than that required for sprinkler-irrigated vegetable crops. However, the combination of high TDS, good drainage and high evapotranspiration cause the soil water salinity to be limiting to yield. Additionally, the practice of maintaining irrigation water at the crop root zone, while preventing leaching of fertilisers, allows salts to accumulate to levels prohibitive to sustainable yield during summer months. Evaporation of applied water between the sprinkler and the crop was recorded to be up to 25% in summer months resulting in a reduced volume of applied water and increased salinity. It was also observed that the target of 10–11 mm of applied water was often not achieved.

The physical characteristics of the soil overlying the property enabled 100% infiltration and a combination of crop precipitation/irrigation and soil moisture measured during the winter and summer investigations found that rainfall events in excess of 30 mm were sufficient to saturate the soil profile to depths of up to 50 cm for the duration of the investigation. These rainfall events provide a natural mechanism to transport solutes below the crop root zone during the growing periods. A change in crop soil moisture characteristics was also observed during the crop cycle and soil moisture escalated in the top 20–30 cm of the soil profile during the latter stages of potato and carrot crop development.

It was shown that levels of soil water salinity during a winter potato crop were below the recommended 100% yield threshold value. Thus with these greater volumes of rain and low evaporation, the accumulation of salts in the crop root zone pose no concerns for horticultural managers during the winter growing season.

However, root zone soil water salinity measured on a summer carrot crop were found to exceed the recommended 50% yield threshold value at four routine sampling events during the course of the growing period. Furthermore, the TDS concentrations at a calculated soil moisture content of 8% were also found to exceed the recommended 50% yield threshold values. Therefore, during the summer growing season, it is recommended to maintain crop soil moisture at levels greater than 8% to prevent major yield reduction or crop loss.

Rainfall events analysed during this research were found to rinse the crop soils of accumulated salts applied during irrigation. It must be noted that crops grown during the winter period and subject to rainfall events above 30 mm are not affected by accumulating salts. It is also recommended that crops grown in the summer period should be located on areas of the property that have remained bare during the winter months. This would ensure that the soils have been rinsed of salts from previous crops and associated irrigation.

Data collected from this research indicates that crops grown in the summer months require at least one rainfall event >30 mm to reduce the effect of accumulating crop salts applied by overhead sprinkler irrigation. For example, the exceedance of the 50% yield threshold value at 8% calculated soil moisture indicates that summer crops may not be sustainable without further intervention or alternative irrigation strategies such as applying appropriate volumes of irrigation water. Although this was outside of the scope of the current study it may prove fruitful for future investigations.

To conclude; this research evaluated the effect of annual rainfall against intensity and frequency of rainfall events in determining the sustainability of horticulture in relation to sprinkler irrigation water, salinity increase and weather regime. Results indicated that it is the occurrence of high-volume, short-duration rainfall events that enhance salt rinsing, as opposed to consistent low volume application by rain or reticulation. During intense rainfall events, excess water results in reducing soil salinity by rinsing the salts accumulated past the crop root zone and into the underlying superficial aquifer. Thus, it is not whether winter rainfall is above or below average that regulates residual soil water salinity, rather the intensity and frequency in which it occurs.