

## EXECUTIVE SUMMARY

### INTRODUCTION

More than three quarters of the water resources in the Western Cape Province are used for irrigation. The fruit and wine industries of the region are heavily dependent on irrigation. The Breede River valley plays an important role in the economy of the Western Cape and contributes significantly to South Africa's agricultural output. The water in the Breede River is becoming increasingly saline during the summer months, threatening the yield and quality of a variety of crops. The reality, however, is that irrigation farmers are going to have to make do not only with less water but also with water of a poorer quality than that to which they have been accustomed. New water legislation in South Africa has heightened the sense of urgency with which water quality problems need to be addressed, making the publication of this report even more timely.

In 1990 a project entitled *Research on the use of saline water for irrigation purposes and an assessment of crop salt tolerance criteria* was initiated by the University of Stellenbosch under the auspices of the Water Research Commission. Two research sites were established on experiment stations of the Agricultural Research Council. The one, at Stellenbosch, investigated the effect on grapevines of supplementary irrigation with saline water. The other, at Robertson, examined a similar set of salinity treatments when applied as full-scale irrigation to grapevines. In 1993 a second project was initiated, entitled *A pilot study to investigate alternative management options to enhance the use of saline water for irrigation purposes*. This was conducted at Robertson and focused on the use of drip irrigation as an alternative to micro-sprinklers. Both projects were scheduled to terminate in 1995 but were extended for a further three years in order to achieve a more conclusive result. The extension was formalised as a third project

entitled *The effect of saline irrigation water and management options on plant and soil reaction*.

The results of the first project have been published by the Water Research Commission (Moolman *et al.*, 1999). The second pilot study and the third extended study form the subject of the present report, which should be read as a sequel to the one already published. Earlier publication was prevented by the protracted illness and subsequent death of Professor Hulme Moolman.

## OBJECTIVES

The present report addresses a consolidated set of objectives for the second and third projects described above. The objectives of the second (pilot) study were as follows: *To investigate, by means of a pilot study in the Breede River Valley, whether alternative irrigation management strategies can be used to enhance the use of saline water for irrigation purposes.*

The third project included a continuation of the pilot study at Robertson, a modification of treatments in the main study at Robertson and an extension of the Stellenbosch trial in order to obtain data over a sufficiently long period to provide a reliable picture of treatment responses. The objectives were as follows:

- 1 *To establish irrigation water quality guidelines for the management and operation of the Brandvlei Dam and Breede River Valley irrigation scheme. The guidelines will be based on an investigation of the effect of saline water on:*
  - a) *the vegetative and reproductive growth of grapevines (vitis vinifera L),*
  - b) *wine quality, and*
  - c) *soil properties.*
- 2 *To determine the effect of saline water on the evapotranspiration rate and irrigation water requirements of grapevines.*
- 3 *To establish a water and salt balance for the two experimental vineyards that are irrigated with saline water.*

- 4 *To evaluate alternative on-farm management strategies that can be used to enhance the use of saline water for the irrigation of agricultural crops.*
- 5 *To investigate various indices which describe the response of perennial crops to salinity and to establish a methodology by which irrigation water quality can be evaluated for local conditions.*

## METHODS

The location and design of the irrigation experiments are summarised in Table 1. The trials were intensively monitored by sampling and analysis of soil, water and vegetative and reproductive plant parts and by recording yield and other plant response parameters such as transpiration.

**The pilot study:** Initially, two salinity levels (150 and 350 mS m<sup>-1</sup>), two frequencies (replenishing 2 or 25 mm evapotranspiration calculated from weather data) and two methods (surface and subsurface) of drip irrigation were tested, giving eight treatment combinations. These were applied to one block of Columbar and another block of Chenin Blanc vines.

In the second phase of the study (1995-98), high frequency only was employed and the two salinity treatments were changed to (i) canal water followed by 150 mS m<sup>-1</sup> water after veraison and (ii) the same but in reverse order (i.e. saline water first then canal water after veraison). The two application methods (surface and subsurface) were retained (four combinations).

**The Stellenbosch (Nietvoorbij) study:** Supplementary, micro-sprinkler irrigation was applied to Weisser Riesling vines with six salinity treatments (four replications). Water quantity was based on neutron probe measurements in the control (fresh water) treatment and included a leaching fraction of 10 percent. This was extended from the earlier study because the young vineyard had not had sufficient time to exhibit a conclusive response to the treatments.

**The Robertson main study:** The six salinity treatments originally ranged from 30 to 500  $\text{mS m}^{-1}$ . In 1995, the highest salinity treatment was split and replaced by either (a) fresh (canal) water or (b) fresh water up to full bloom and thereafter moderately saline water (150  $\text{mS m}^{-1}$ ); the other 5 treatments up to a salinity of 350  $\text{mS m}^{-1}$  remained the same. Weekly irrigation was based on the water deficit determined by neutron probe readings in the control treatment and included a 20 percent leaching fraction. (Prior to 1995 the irrigation cycle had been two weeks and the leaching fraction 10 percent).

**Table 1: The experimental layout of the whole project since 1995, and (in italics) between 1993 and 1995 for the pilot study at Robertson**

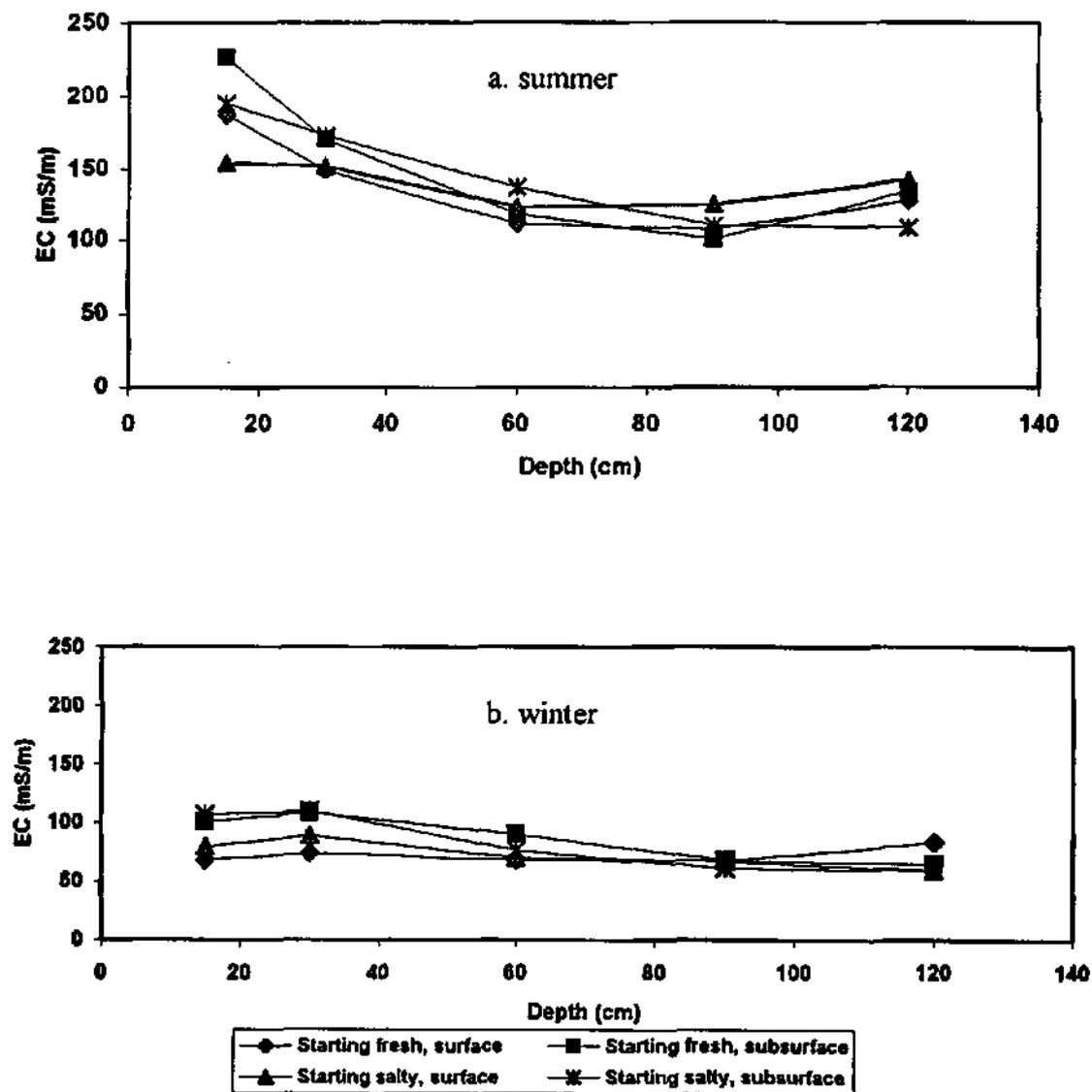
Location and irrigation intensity	Irrigation type	Water quality	Water volume	Irrigation Frequency
Robertson (full scale irrigation)	Micro (main study)	Fresh water ~30 $\text{mS m}^{-1}$	Deficit replacement + 10% measured with neutron probe in the fresh water treatment	Weekly
		75 $\text{mS m}^{-1}$		
		150 $\text{mS m}^{-1}$		
		250 $\text{mS m}^{-1}$		
		350 $\text{mS m}^{-1}$		
		Fresh to 150 $\text{mS m}^{-1}$ change after full bloom		
	High frequency drip (pilot)	150 $\text{mS m}^{-1}$ 350 $\text{mS m}^{-1}$	Deficit replacement calculated from Penmann-Van Bavel evapotranspiration using an on-site weather station	Daily
	Low frequency drip (pilot)	150 $\text{mS m}^{-1}$ 350 $\text{mS m}^{-1}$		Daily
	Drip : subsurface (pilot)	150 $\text{mS m}^{-1}$ then change to fresh water at veraison	Deficit replacement calculated from Penmann-Monteith evapotranspiration using an on-site weather station	Daily
		Fresh water then change to 150 $\text{mS m}^{-1}$ at veraison		
Drip: surface (pilot)	150 $\text{mS m}^{-1}$ then change to fresh water at veraison			
	Fresh water then change to 150 $\text{mS m}^{-1}$ at veraison			
Stellenbosch (supplementary irrigation)	Micro	Fresh water ~40 $\text{mS m}^{-1}$	Deficit replacement + 10% measured with neutron probe in the fresh water treatment	3 to 4 irrigation events only in peak demand period
		75 $\text{mS m}^{-1}$		
		150 $\text{mS m}^{-1}$		
		250 $\text{mS m}^{-1}$		
		350 $\text{mS m}^{-1}$		
		500 $\text{mS m}^{-1}$		

**SUMMARY OF RESULTS AND CONCLUSIONS****THE ROBERTSON PILOT STUDY (1993-98)**

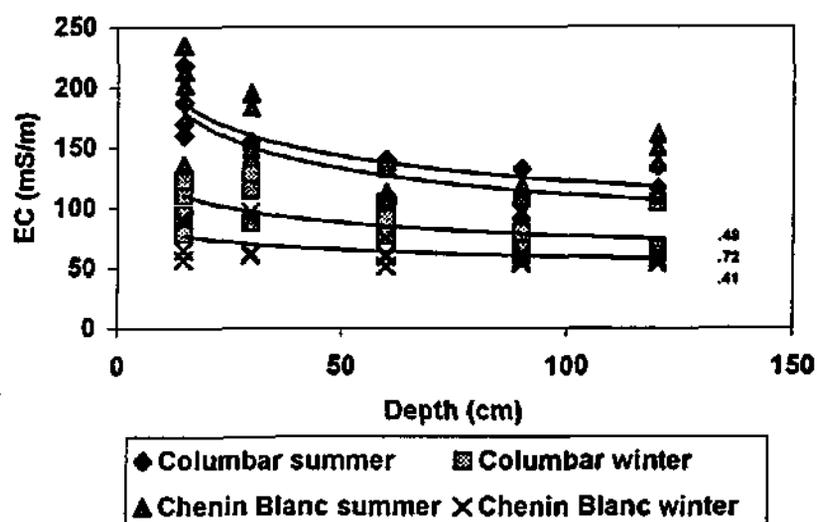
The two sections of the experiment were planted to different cultivars (Colombar and Chenin Blanc). It turned out that the yield of Colombar was generally much lower than that of Chenin Blanc, implying a different response to treatments and therefore a reduction in the number of true replications from four to two. This severely reduced opportunities for establishing statistical significance. The report describes in detail a number of problems with the operation of the irrigation system that effectively compounded the difficulty of drawing sound conclusions from the trial.

The pilot study was designed to keep the soil water level as high as possible without over-irrigation, daily replenishing the amount lost by evaporation on the previous day. As a result of winter irrigation, however, the season appeared to start at too high a soil water level. Because of the irrigation scheduling method employed, the soil water level remained high until late in the season. This changed the expected outcome of the experiment in that there was a net leaching of salt during the first half of the season and a net build-up of salt during the second half of the season. This situation is nevertheless similar to that which might be expected to prevail under normal field conditions in this region.

Figure 1 shows that the seasonal fluctuation in soil profile salinity was much larger than the differences between treatments although in general the subsurface irrigation treatments appeared to produce a greater accumulation of salts at the soil surface. Figure 2 indicates that the accumulation of salts in the summer was much greater on the block planted to the higher yielding Chenin Blanc cultivar, confirming the expected relationship between yield, water consumption and salt accumulation.



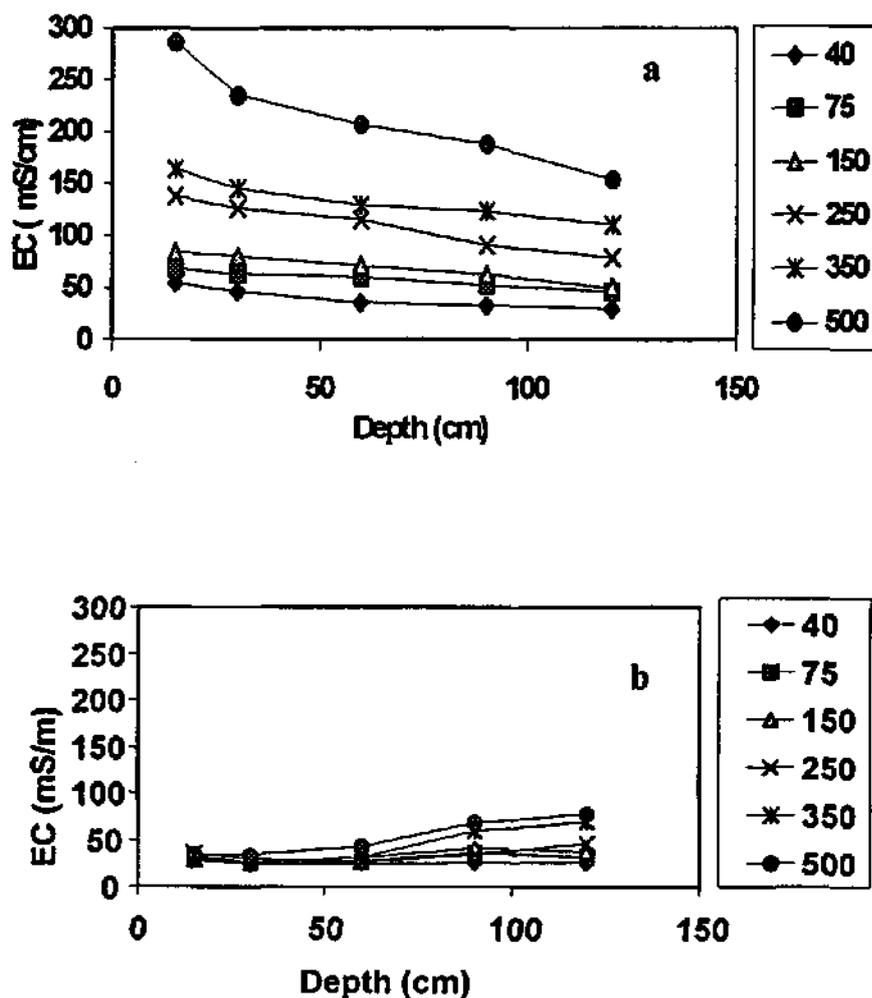
**Figure 1. Soil salinity ( $EC_e$ ) as a function of depth in the Robertson pilot study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the two cultivars over the period 1995-8. The legend refers to the four treatments described in Table 1.**



**Figure 2.** Soil salinity ( $EC_e$ ) as a function of depth in the Robertson pilot plotted to show the differences between the two cultivars at the end of summer and the end of winter. Points represent treatment means for the period 1995-98.

### THE STELLENBOSCH TRIAL (1993-8)

The Nietvoorbij trial (Weisser Riesling cultivar) continued to show no significant yield response to supplementary irrigation with saline water. This we attribute to a combination of the smaller salt load, greater rooting depth, better buffering by the soil, younger and more vigorous vines, better drainage and/or greater removal of salt by leaching during winter than in the case of the Robertson trial. Each year the whole soil profile would accumulate salt equivalent to an  $EC_e$  of as much as  $250 \text{ mS m}^{-1}$  or more late in the season only to be reduced back to an  $EC_e$  of  $50 \text{ mS m}^{-1}$  or less by the following spring (Figure 3). During all irrigation events at least a third of the drains flowed after irrigation.



**Figure 3. Soil salinity ( $EC_e$ ) as a function of depth in the Stellenbosch study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the period 1995-98. The legend indicates the salinity of the six micro-sprinkler irrigation treatments described in Table 1.**

Although yields and other indices of plant response did not change significantly with treatment there were signs during the 1996 season of slight leaf damage in the more saline treatments even though chloride and sodium contents did not increase significantly. This was the one season in which saline irrigation was begun earlier (i.e. before the soil water deficit was deemed large enough). Wine quality was not materially altered although the most saline treatment did produce wine that was judged by a panel

of experts to be slightly saltier to the taste. None of the wines possessed the character considered to be typical of Weisser Riesling.

In comparing the most with the least saline irrigation treatments it was found that transpiration from the canopy dropped to half its magnitude and accounted for only about one-third of evapotranspiration instead of about two-thirds in the non-saline treatment (Table 1).

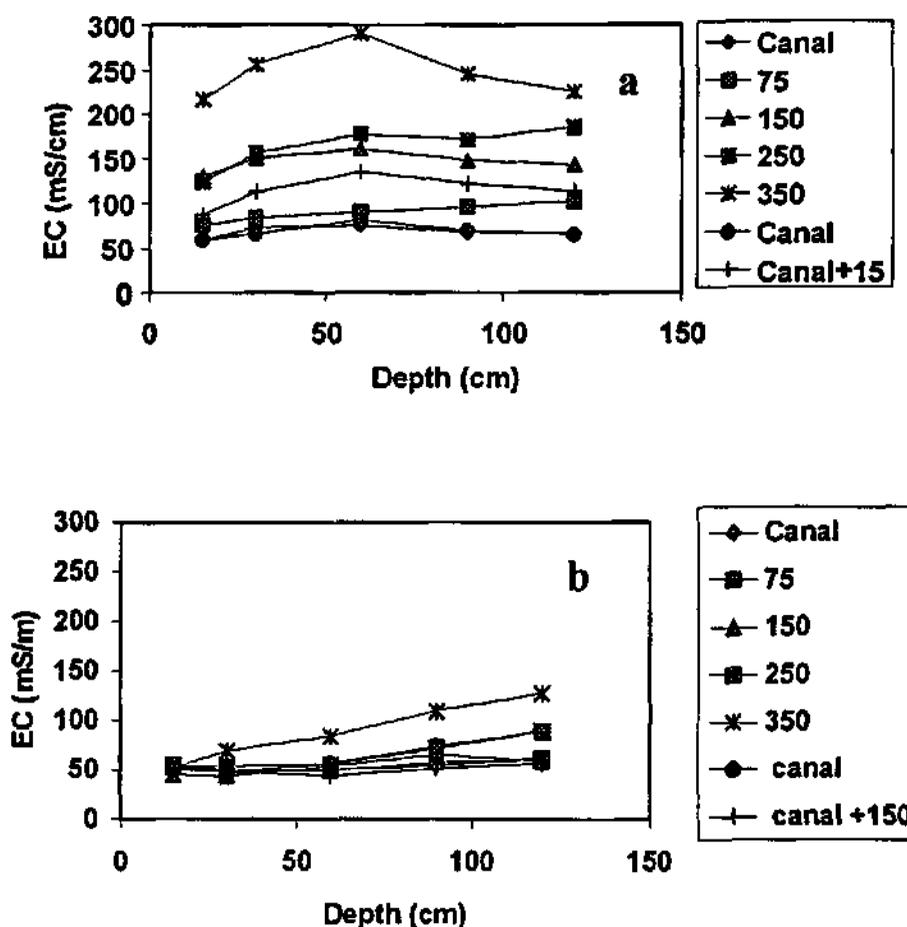
**Table 1** Vine transpiration data in comparison with Penman-Monteith ET and soil water content data at Stellenbosch

Water use parameter		Fresh water	Saline water
T (mm/day):	before irrigation	4.4	2.2
	after irrigation	3.6	2.0
T as % of ET:	before irrigation	60.4	29.9
	after irrigation	65.5	36.4
Soil water (mm/m):	before irrigation	187	170
	after irrigation	238	236

### THE ROBERTSON MAIN TRIAL (1992-8)

The Robertson main trial continued to provide the most valuable information of the whole project and the decision to extend the duration of this trial by three years was vindicated. In 1995 the most saline treatment (originally  $500 \text{ mS m}^{-1}$ ) was converted into one involving a switch from fresh (canal) water to  $150 \text{ mS m}^{-1}$  water or *vice versa* after the veraison stage. Although this provided some useful information on the draw-down of soil salinity (Figure 4) the most useful results came from the general crop yield response to saline irrigation.

The data of Moolman *et al.* (1999) suggested a general decline of 3 percent relative yield for every  $10 \text{ mS m}^{-1}$  increase in soil salinity ( $\text{EC}_e$ ) beyond a threshold level of  $75 \text{ mS m}^{-1}$  (Figure 5). Although this contrasts with the decline of 1 percent per  $10 \text{ mS m}^{-1}$  beyond a threshold of  $150 \text{ mS m}^{-1}$  proposed by Ayers and Westcot (1985), it was based on calculated means from a data set with considerable variation about the mean values and consequently needed to be re-examined critically now that data were available from additional seasons.



**Figure 4. Soil salinity ( $EC_e$ ) as a function of depth in the Robertson main study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the period 1995-98. The legend indicates the salinity of the seven micro-sprinkler irrigation treatments described in Table 1.**

Of special interest was the fact that yield correlated equally well with sodicity (expressed as the sodium adsorption ratio, SAR) as it did with salinity (expressed as electrical conductivity of the saturated paste extract,  $EC_e$ , and usually calculated as a mean for the profile and for samples taken at different stages in the season).

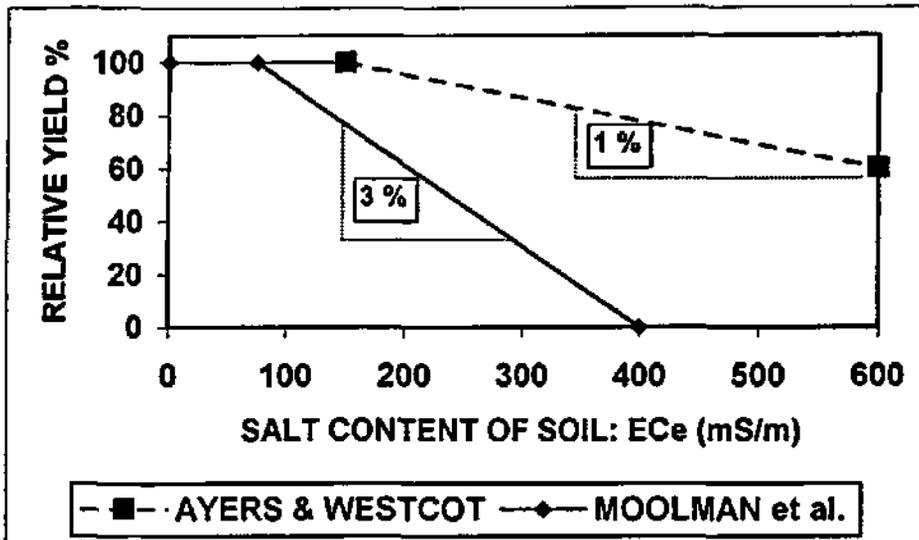


Figure 5. Existing information on the relationship between grape yield and soil salinity.

The data in Figures 6 and 7 summarise the changes in the relationship between relative yield and either salinity or sodicity as the experiment progressed.

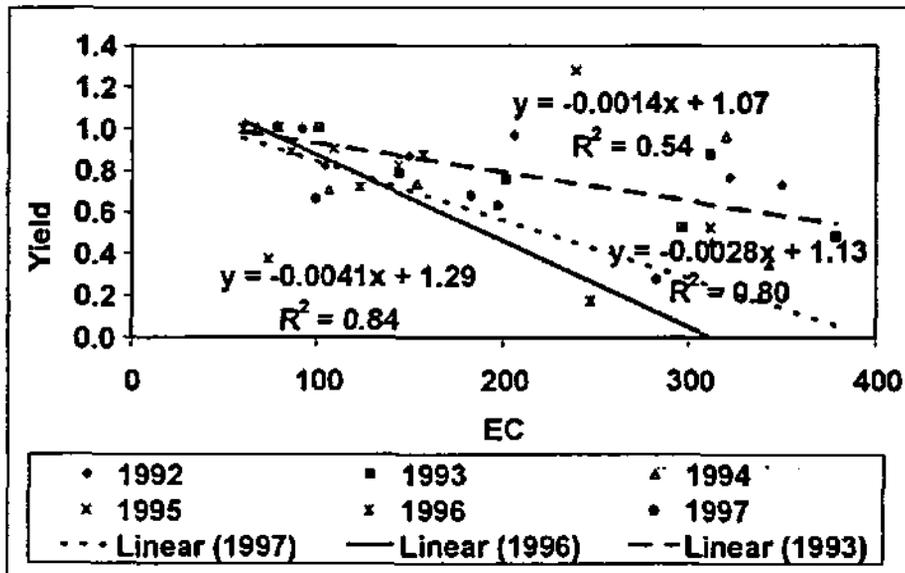
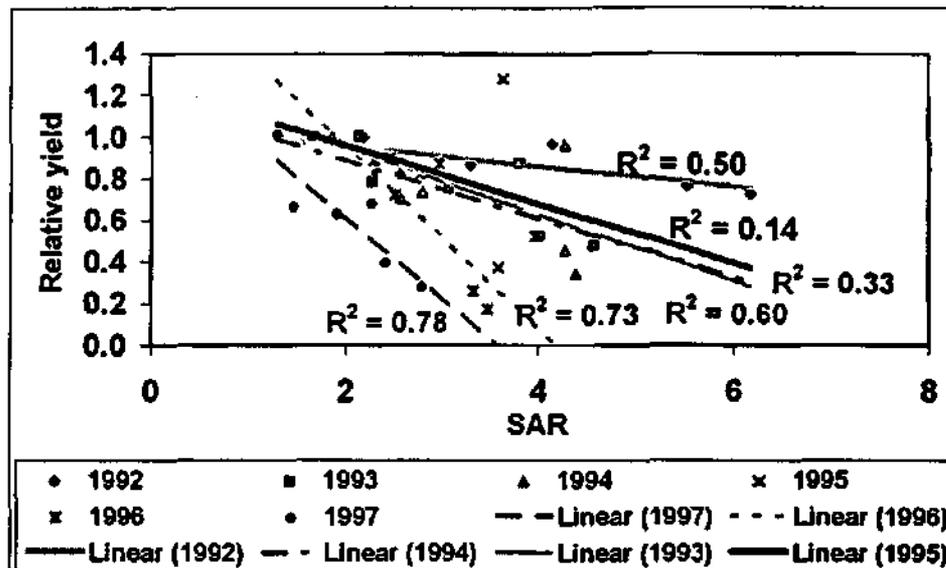


Figure 6. Relationships between relative yield and salinity (EC<sub>e</sub>) at Robertson plotted for each year from 1992 to 1997. The data represent seasonal block means.



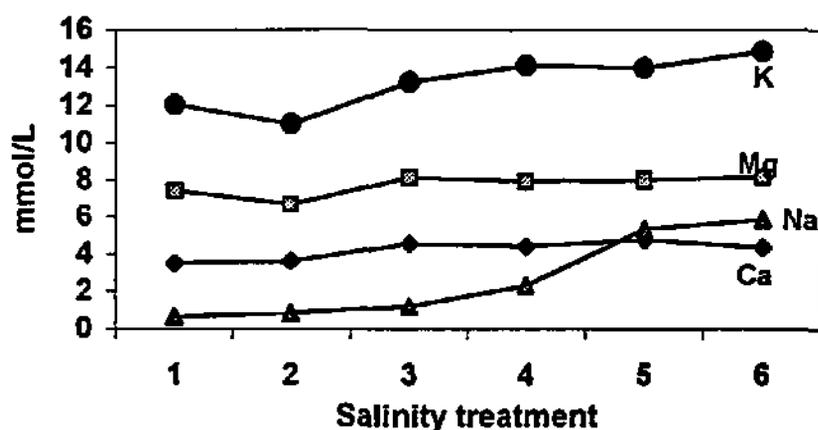
**Figure 7.** Relationships between relative yield and sodicity (SAR<sub>e</sub>) at Robertson plotted for each year from 1992 to 1997. The data represent seasonal block means.

This aspect was not addressed by Moolman *et al.* (1999) who concentrated on salinity (and to some extent chloride level) as the indices of soil response to saline irrigation that would be most appropriate for use as predictors of crop yield. Indeed we found a high degree of covariance between EC, SAR and Cl, suggesting that it would be premature to blame any one of these factors individually for the adverse effect of irrigated salts on the crop. It should also be noted that the CaCl<sub>2</sub>-NaCl solution used for salinity treatments was equimolar with respect to Na and Ca, which means that SAR actually increases with increasing salinity (EC<sub>i</sub>) in all these trials.

A pattern seems to have emerged from these newer results, which could not have been picked up during the initial trial period, suggesting that, irrespective of whether the inhibitory effect of the saline irrigation treatments on yield is an osmotic one, a toxic one (Na and/or Cl), or both, the threshold level remains the same over a number of seasons of irrigation but the sensitivity of the crop to levels beyond the threshold increases with the number of seasons of exposure. This is reminiscent of an allergic type of response which suggests that, instead of there being one particular cultivar-specific response function, the response pattern changes with time and the effect of the saline/sodic/chloridic water is cumulative on the vines (i.e. not only through a build-up in

the soil). This might explain why the overall yield of the main trial at Robertson showed a progressive decline, since even the control treatment made use of slightly saline canal water on a site that already was moderately saline. This result may have very important management implications because it suggests that even moderately acceptable water by current standards may, in the longer-term and not necessarily because of soil deterioration, have a cumulative, debilitating effect leading to premature failure of the vineyard.

The wine quality at Robertson was also judged to have a salty taste when made from the most saline treatment but all wines lacked the typical character of the cultivar. When chemically analysed in 1997, the must showed a marked upturn in sodium content in response to the two most saline treatments (Figure 8).



**Figure 8.** Treatment effect on cation content of the must prepared in 1997 from grapes of the Robertson main trial (treatment numbers are explained in Table 1).

### MEETING THE RESEARCH OBJECTIVES

In this section the objectives as originally stated will be repeated and the extent to which they were met will then be indicated.

*1. To investigate, by means of a pilot study in the Breede River Valley, whether alternative irrigation management strategies can be used to enhance the use of saline water for irrigation purposes.* The pilot study experimental design did not allow definite

conclusions to be drawn about yield-salinity relationships. Topsoil salinisation is more pronounced with drip irrigation, however, and even more so when the drippers are buried.

*2. To establish irrigation water quality guidelines for the management and operation of the Brandvlei Dam and Breede River Valley irrigation scheme. The guidelines will be based on an investigation of the effect of saline water on: a) the vegetative and reproductive growth of grapevines (*Vitis vinifera* L), b) wine quality and c) soil properties.* This objective has been partially met in that the EC requirements for sustainable viticulture are probably even more stringent than previously thought. Vineyard longevity with 75-100 mS/m water will probably be reduced.

*3. To determine the effect of saline water on the evapotranspiration rate and irrigation water requirements of grapevines.* This objective was met to some extent in the Stellenbosch trial although soil water and transpiration data did not match satisfactorily which means that calculation of salinity-modified water requirement would not be reliable.

*4. To establish a water and salt balance for the two experimental vineyards that are irrigated with saline water.* Water and salt balances can be established from data in this report. However, the use of control (low salinity) plot measurements of water use for determining irrigation requirement means that high salinity treatments were over-irrigated leading to misleading figures in terms of water use modification by saline irrigation.

*5. To evaluate alternative on-farm management strategies that can be used to enhance the use of saline water for the irrigation of agricultural crops.* See objective 1.

*6. To investigate various indices which describe the response of perennial crops to salinity and to establish a methodology by which irrigation water quality can be evaluated for local conditions.* This has proved to be the most informative part of the project with Na, Cl and EC being co-variant, and soil values being less important than water values in terms of relating to plant response. Chloride could well be the key factor in affecting the deterioration in relative yield with time, but sodicity and osmotic effects cannot be ignored.