EXPERIMENTAL IRRIGATION OF VINEYARDS WITH SALINE WATER

by

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A pilot study to investigate alternative management options to enhance the use of saline water for irrigation purposes

and

Establishing effects of saline irrigation water and managerial options on soil properties and plant performance

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The Steering Committees responsible for these projects consisted of the following people (consolidated into one list):

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The University of Stellenbosch, for allowing us to do this research and for assisting with administrative tasks.

Finally, it is fitting that this report be dedicated to the memory of Professor Hulme Moolman who initiated and led this research and who saw to the completion of one report on an earlier phase of the work. Professor Moolman died before it was possible to complete the remaining projects, and we would like to think that some of the more valuable results of the work bear testimony to his sustained enthusiasm which allowed long-term effects to be revealed that would not otherwise have been apparent. His wife Gerida provided him with much needed support during a trying illness while also giving many hours of assistance on the project.

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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^{-1}), 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^{-1} 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 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 mS m^{-1}); the other 5 treatments up to a salinity of 350 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 mS m^{-1}	Deficit replacement + 10% measured with neutron probe in the fresh water treatment	Weekly
		75 mS m^{-1}		
		150 mS m^{-1}		
		250 mS m^{-1}		
		350 mS m^{-1}		
		Fresh to 150 mS m^{-1} change after full bloom		
	High frequency drip (pilot)	*150 mS m^{-1} 350 mS m^{-1}*	*Deficit replacement calculated from Penmann-Van Bavel evapotranspira-tion using an on-site weather station*	*Daily*
	Low frequency drip (pilot)	*150 mS m^{-1} 350 mS m^{-1}*		*Daily*
	Drip : subsurface (pilot)	150 mS m^{-1} then change to fresh water at veraison	Deficit replacement calculated from Penmann-Monteith evapotranspira-tion using an on-site weather station	Daily
		Fresh water then change to 150 mS m^{-1} at veraison		
	Drip: surface (pilot)	150 mS m^{-1} then change to fresh water at veraison		
		Fresh water then change to 150 mS m^{-1} at veraison		
Stellenbosch (supplementary irrigation)	Micro	Fresh water ~40 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 mS m^{-1}		
		150 mS m^{-1}		
		250 mS m^{-1}		
		350 mS m^{-1}		
		500 mS m^{-1}		

SUMMARY OF RESULTS AND CONCLUSIONS

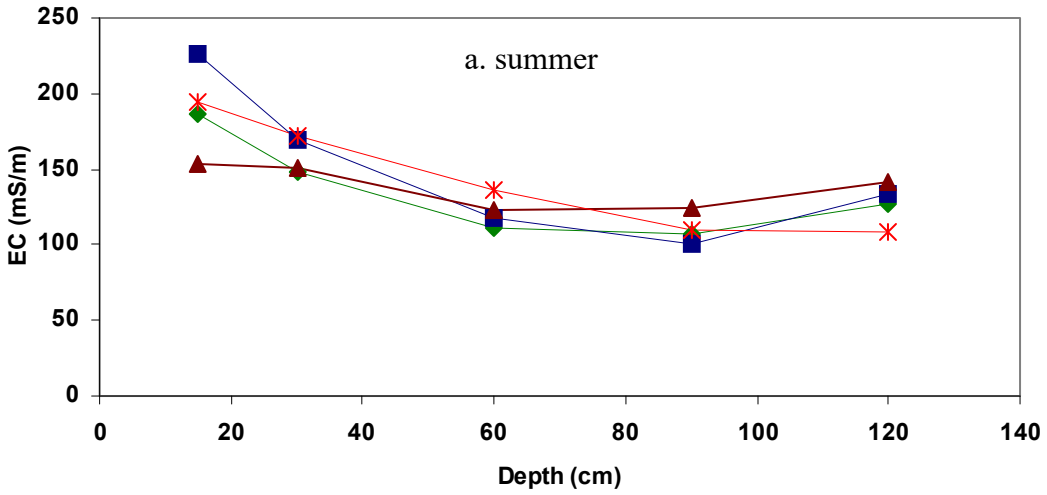
THE ROBERTSON PILOT STUDY (1993-98)

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.



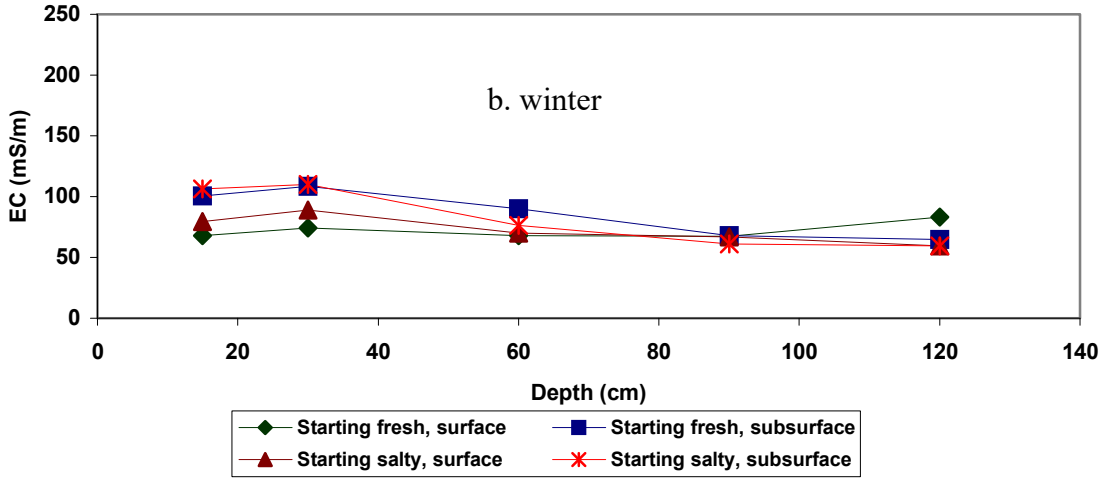


Figure 1. Soil salinity (EC_e) as a function of depth in the Robertson pilot study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the two cultivars over the period 1995-8. The legend refers to the four treatments described in Table 1.

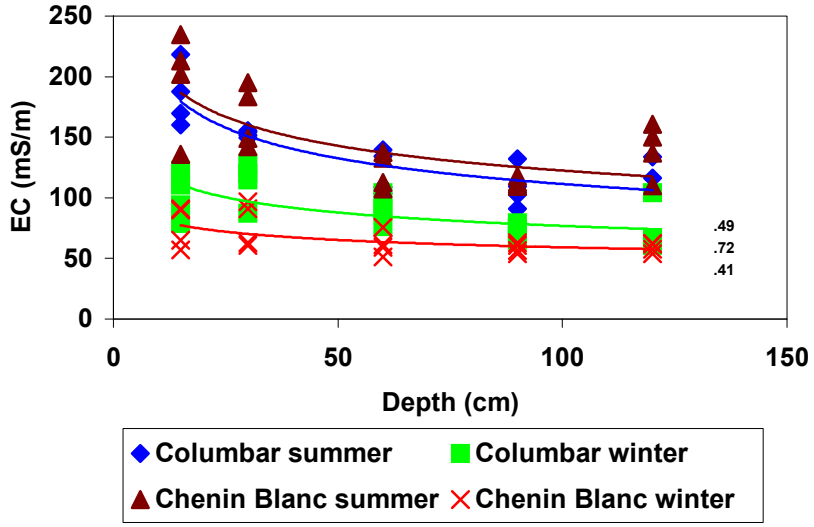


Figure 2. Soil salinity (EC_e) as a function of depth in the Robertson pilot plotted to show the differences between the two cultivars at the end of summer and the end of winter. Points represent treatment means for the period 1995-98.

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 mS m^{-1} or more late in the season only to be reduced back to an EC_e of 50 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.

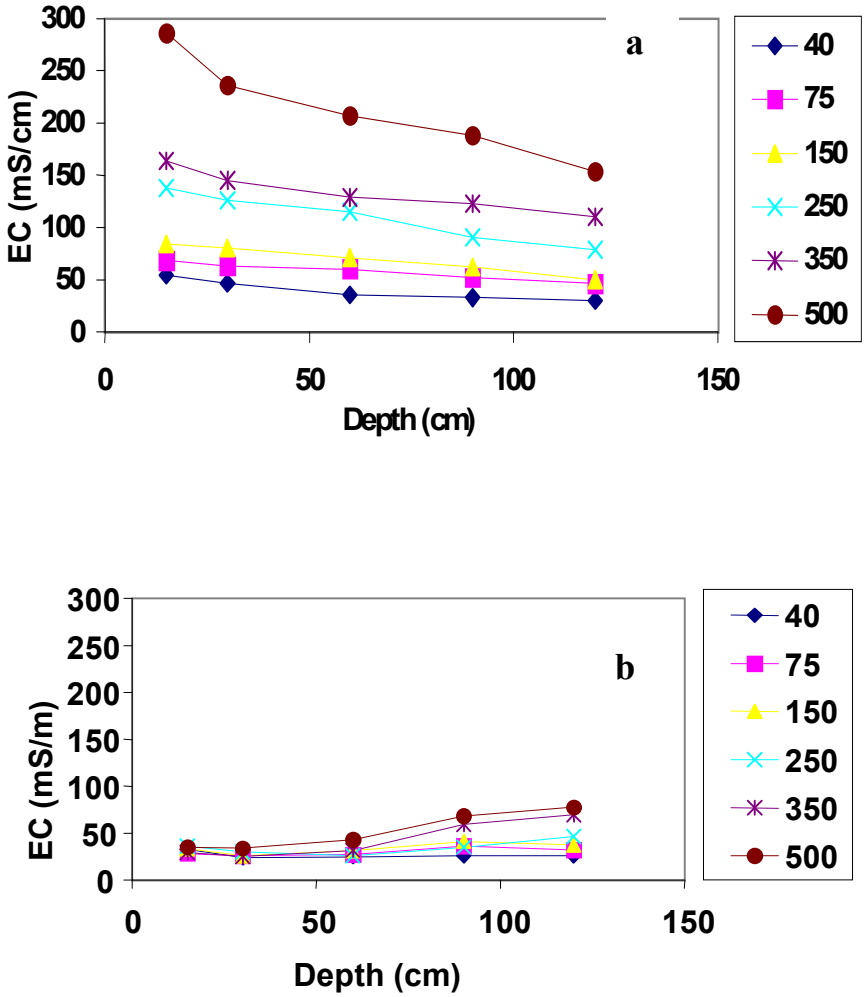


Figure 3. Soil salinity (EC_e) as a function of depth in the Stellenbosch study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the period 1995-98. The legend indicates the salinity of the six micro-sprinkler irrigation treatments described in Table 1.

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 mS m^{-1}) was converted into one involving a switch from fresh (canal) water to 150 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 mS m^{-1} increase in soil salinity (EC_e) beyond a threshold level of 75 mS m^{-1} (Figure 5). Although this contrasts with the decline of 1 percent per 10 mS m^{-1}

beyond a threshold of 150 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.

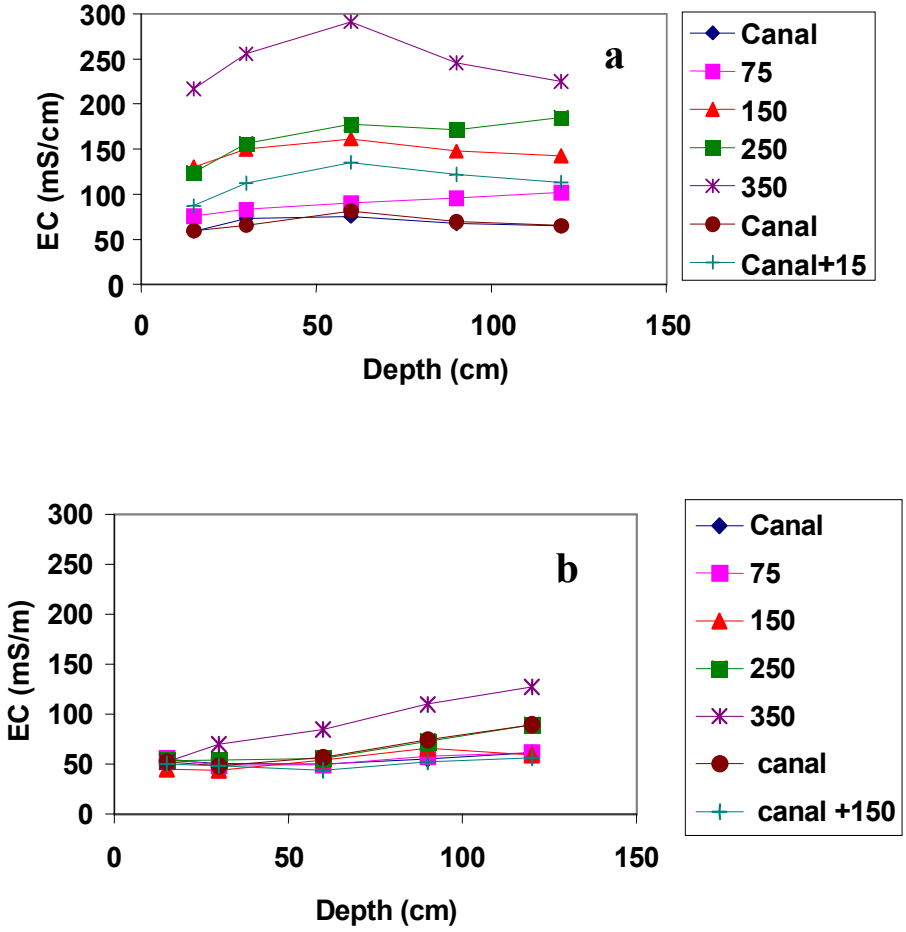


Figure 4. Soil salinity (EC_e) as a function of depth in the Robertson main study (a) at the end of summer and (b) at the end of winter. Points represent mean values for the period 1995-98. The legend indicates the salinity of the seven micro-sprinkler irrigation treatments described in Table 1.

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).

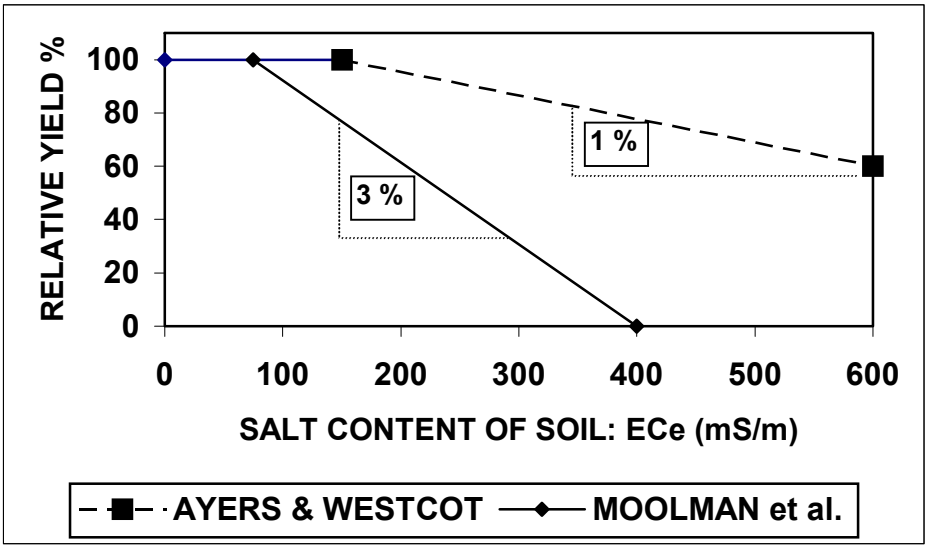


Figure 5. Existing information on the relationship between grape yield and soil salinity.

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.

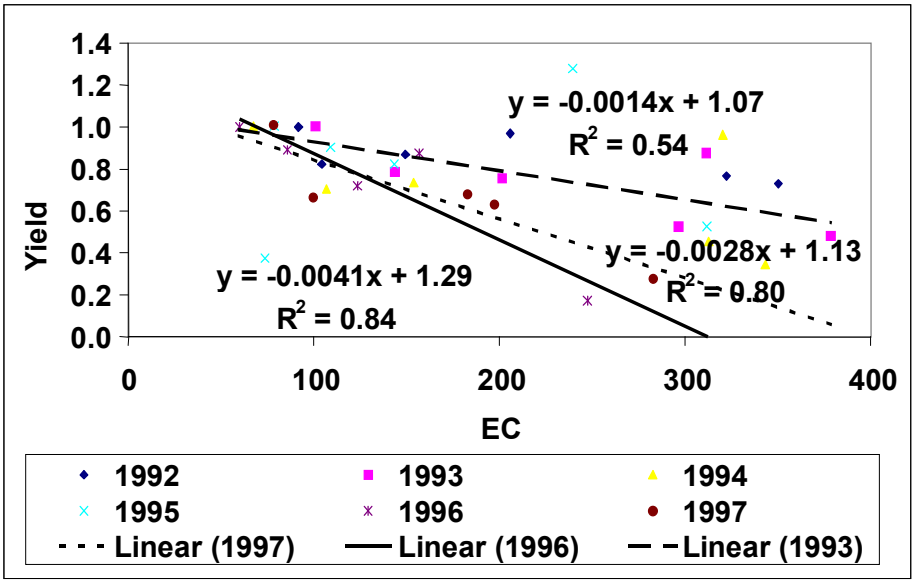


Figure 6. Relationships between relative yield and salinity (EC_e) at Robertson plotted for each year from 1992 to 1997. The data represent seasonal block means.

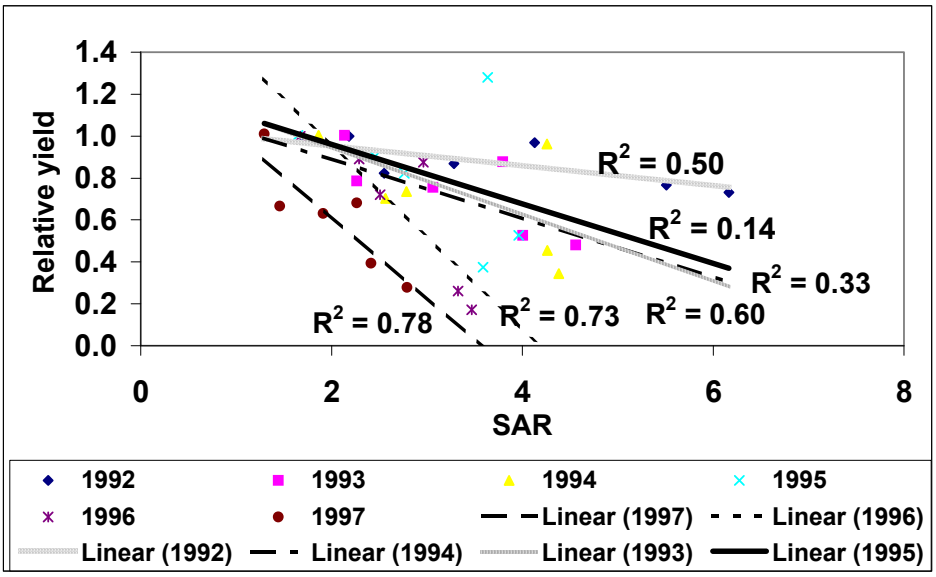


Figure 7. Relationships between relative yield and sodicity (SAR_e) at Robertson plotted for each year from 1992 to 1997. The data represent seasonal block means.

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 $CaCl_2$-NaCl solution used for salinity treatments was equimolar with respect to Na and Ca, which means that SAR actually increases with increasing salinity (EC_i) 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).

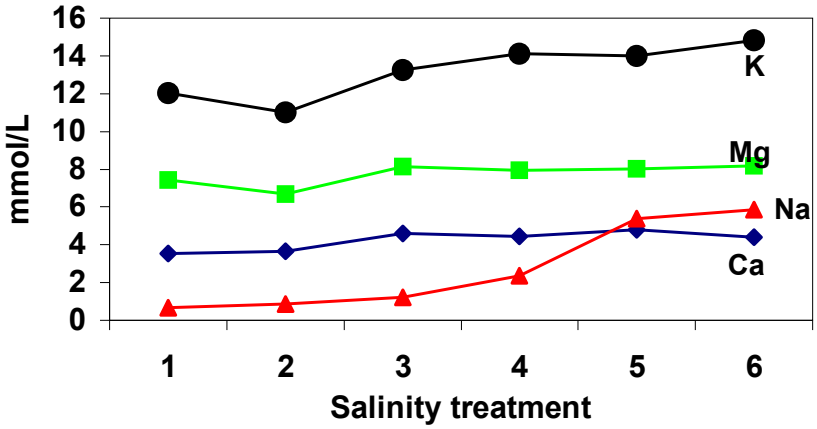


Figure 8. Treatment effect on cation content of the must prepared in 1997 from grapes of the Robertson main trial (treatment numbers are explained in Table 1).

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.

RECOMMENDATIONS

There are two ways in which we think that value could be added to the results of this study. Firstly, the indications of a worsening response by the Robertson vineyard to regular summer doses of saline water (despite leaching of the excess salts during winter) suggest an effect that is related to the breakdown of resistance to salinity by the plant rather than progressive soil degradation. Such an effect could not have been detected had the trial run for only five years instead of eight. There have probably been very few (if any) such long-term experiments on the influence of salinity on woody plants. Unfortunately the Robertson trial was situated in an old vineyard and this was uprooted after the trial. At Stellenbosch, however, the Weisser Riesling vineyard is in its prime and the experimental infrastructure is still in place. It could be worthwhile to renew this experiment and continue the treatments for as long as possible in order quantify the response in terms of relative yield.

The second approach would be to develop a large salinity-oriented data bank from regular surveys of commercial vineyards. This would allow relationships between yield, soil salinity and sodicity, other soil properties and management practices to be studied with different cultivars under different climatic conditions. It would also require a lengthy period and a high degree of co-operation between interested parties. Both these approaches would help us to find out how long a vineyard can put up with saline water even though by current standards, based on short term studies, it might be considered tolerable.

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LIST OF SYMBOLS AND ABREVIATIONS

AET	-	Actual evapotranspiration
c_p	-	Specific heat of air at constant pressure, mb.ºC^{-1}
D	-	Distance
DOS	-	Days of Season starting 1 September
DP	-	Deep percolation past the root zone, (mm)
EC	-	Elecrtical conductivity of water
EC_e	-	Electrical conductivity of a saturated paste extract solution
EC_i	-	Electrical conductivity of irrigation water
EC_{sw}	-	Electrical conductivity of extracted soil water
e_a	-	actual vapour pressure, kPa
e_z^0	-	Saturation vapour pressure, mb at a specific temperature (T), ºC
$e_z^0 - e_z$	-	(=d_a) Vapour pressure deficit, mb, at a specific temperature (T), ºC
$e_{T(p)}^0$	-	Saturated vapour pressure at $T_{(P)}$, ºC for period P
E_I	-	Direct evaporation fraction when irrigating,
E_P	-	Potential evapotranspiration for the specific period (P minutes), (mm).
e_s	-	Saturated vapour pressure, kPa
e_s-e_a	-	Saturated vapour pressure deficit, kPa
ET	-	Evapotranspiration for the interval (P), (mm)
ETo	-	FAO reference evapotranspiration, (mm)
e_z	-	Water vapour pressure, mb at a specific temperature (T), ºC
F	-	Irrigation frequency
FAO	-	Food and Agricultural Organisation of the United Nations (Rome, Italy)
f_w	-	Fraction of total area effectively irrigated
G	-	Soil heat flux density, MJ.m^{-2}.day^{-1}
I	-	Net irrigation applied during the specific period (P), (mm)
ID1	-	Soil water deficit at the end of the previous time interval (P), (mm)
ID2	-	Latest (current) soil water deficit (mm)
I	-	Irrigation
I_E	-	Prescribed irrigation and leaching application efficiency (fraction of the total volume of water used during the interval)
IR	-	Gross volume of water required for the shift, (^{m3})
IR	-	Gross water application on the wetted area during the interval, (mm)
IR	-	Gross irrigation volume, (^{m3})
I_V	-	Gross volume of irrigation water applied during the interval, (^{m3})
K	-	Height at which wind speed was measured / roughness factor for vineyards
K_C	-	Crop factor (coefficent)
LAI	-	Leaf area index
LA_{shoot}	-	Total leaf area per vine shoot

LD	-	The leaching demand, (mm)
LRC	-	The calculated amount of leaching (mm)
LRI	-	Leaching due to irrigation, (mm)
LR_P	-	The prescribed leaching as a fraction of I
LRP	-	Leaching due to rain, (mm)
LR_P	-	Prescribed leaching as a fraction of I
LR_P1	-	The leaching for the interval, (mm)
L_V	-	Measured volume of irrigation water applied during the specific period, (^{m3})
M	-	Method of irrigation (surface or sub-surface)
N_{sp}	-	Number of shoots per vine
P	-	Period or smallest increment used in E_p calculations
PET	-	Potential evapotranspitation
P_z	-	Atmospheric pressure, mb
Q	-	Quality of the irrigation water (EC)
Rb	-	Net outgoing radiation
RLD	-	The residual leaching requirement at the end of the latest calculation interval, (mm)
RLD1	-	The residual leaching requirement at the end of the previous calculation interval, (mm)
R_n	-	Net radiation received, in $MJ.m^{-2}.P\ min^{-1}$ (= (1 - α)R_s - R_b, where (1 - α)R_s is the net short-wave radiation received by the vineyard and typically 77% for vines).
R_n	-	Net radiation at crop surface, $MJ.m^{-2}.day^{-1}$
RO	-	Runoff
R_s	-	Solar radiation
RY	-	Relative yield
S_{ap}	-	Total soil area per plant (vine)
SAR	-	Sodium Absorption Ratio
SAR_e	-	SAR of the saturated paste extract
SAR_i	-	SAR of irrigation water
SAR_{sw}	-	SAR of the extracted soil water
SG	-	Specific gravity
T	-	Mean daily air temperature at 2m height. ºC
T_P	-	Average air temperature for specific period P, ºC
u_z	-	Wind speed at 2m height(z), $m.s^{-1}$
XP	-	Rainfall during the interval, (mm)
z	-	Elevation, cm
z_0	-	Roughness length, cm

Δ	-	Slope of saturation vapour pressure-temperature curve, de/dT, $mb.ºC^{-1}$
γ	-	Psychrometric constant, $mb.ºC^{-1}$
α	-	Albedo
σ	-	Stefan Boltzmann constant
λ	-	Latent heat of vaporization, $MJ.kg^{-1}$

ρ	-	Air density, mb
u_z	-	Horizontal wind speed at height z, $km.h^{-1}$
θ_t	-	The maximum allowable soil water deficit (mm).
Δ	-	Slope vapour pressure curve, $kPa.^oC^{-1}$
γ	-	Psychrometric constant, $kPa.^oC^{-1}$
$\theta_t =$	-	Prescribed maximum deficit allowed, (mm)

1. INTRODUCTION

1.1 BACKGROUND

This report covers three projects that commenced at different times during the 1990s. The first of these, entitled *Research on the use of saline water for irrigation purposes and an assessment of crop salt tolerance criteria,* ran from April 1990 to June 1995 and the results were presented in a report to the Water Research Commission (Moolman *et al.,* 1999). In January 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 pilot study also terminated in June 1995 but the results are still to be reported. In July 1995 a third study, entitled *The effect of saline irrigation water and management options on plant and soil reaction* was commissioned to follow up on aspects of the first two studies that required further investigation. This report presents the results of the pilot study in its entirety together with the other follow-up work covered by the third project, which terminated in 1998. The background and general rationale are essentially the same for all three projects which differ merely in terms of their specific objectives. Consequently the normal requirement of providing a full review of the literature and presenting a detailed justification for the work will be dispensed with in the current report, which should be read as a sequel to the earlier one by Moolman *et al*. (1999).

The first and third projects were carried out at two locations on the experimental farms of the Agricultural Research Council's Institute for Oenology and Viticulture at Stellenbosch (Nietvoorbij) and at Robertson. The second project (the pilot study) was conducted on the Robertson farm only. In all cases saline water was applied to grapevines. A key motivation for the pilot study was that it would permit the inclusion of irrigation management alternatives as a criterion for judging the fitness of saline irrigation water for the production of vines. This could lead to a wider extrapolation of the results of the main trial at Robertson and could also lead to a substantial saving of the dilution water released from the Brandvlei Dam in order to counter the build-up of salinity in the Breede River.

1.2 OBJECTIVES

The original objectives of the pilot study (i.e. the second project referred to above) which commenced in 1993 were simply 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, designed to follow-up on the first one from 1995 onwards, 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 original objectives of this third study were stated 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.*

1.3 RESEARCH TEAM

The research team involved in the work leading to the production of this report is essentially the same as that listed by Moolman *et al.* (1999). Professor Moolman's untimely death in 1997 left the project in the hands of Mr WP de Clercq, with the responsibility for completing the contract passing automatically to the department chairperson. There were unavoidable delays in the filling and refilling of this post and there were other staff changes that also affected the project in one way or another. Only since mid-2000 with the appointment of Professor M V Fey as department chair and the slightly earlier arrival of Dr JE Hoffman has there been any real opportunity for the department to meet its commitments. Both individuals made contributions to drafting the final report.

1.4 SCOPE OF THE REPORT

The results are presented in three chapters: Chapter 2 covers the pilot study at Robertson, Chapter 3 deals with the follow-up work on the main trial at Robertson and Chapter 4 presents the results of the trial at Stellenbosch which differs from that at Robertson mainly in terms of the supplementary character of the irrigation. The question of response indices, methods for evaluating irrigation water and management guidelines is then addressed in Chapter 5. A final chapter presents the overall conclusions, explores the extent to which the objectives have been met and makes recommendations based on an appraisal of all three projects.

2 THE PILOT STUDY AT ROBERTSON: THE RESPONSE OF SOIL WATER AND SALINITY STATUS AND OF PLANT GROWTH AND QUALITY TO IRRIGATION WITH SALINE WATER

2.1 PROJECT MOTIVATION

Since this report will cover the pilot study from its inception, the motivation contained in the report by Moolman *et al.* (1999) will be repeated here in modified form with specific reference to the link between the pilot trial and the main trial at Robertson.

The Breede River is of particular importance to the agriculture of the Western Cape. In 1986 a number of factors forced the Department of Water Affairs to attend to the question of the future irrigation supply water quality criteria applicable in the Breede River. This led to the release of document GB/A/88/2 (Soils and Irrigation Research Institute) entitled, "*Hersiene kriteria vir besproeiingswater in die Breërivier*", which was published in January 1988. Because of the paucity of local research on irrigation water quality criteria, this document had to be based on crop salt tolerance data found in the international literature. The authors of this document recommended the following criteria for the total salt content, as indicated by the specific electrical conductivity (EC) of the Breede River irrigation water:

a) For 50% of the irrigation season (by volume), the maximum EC has to be below 70 mS m^{-1}.

b) For 20% of the irrigation season (by volume), the EC may equal, but not exceed 120 mS m^{-1}.

This in effect means that for most of the time the EC of the irrigation water should be less than 70 mS m^{-1}. In order to meet these requirements and because of the rapid increase in the salt content of the Breede River downstream from the Brandvlei Dam, the present operation of the Brandvlei Dam requires a substantial amount of so-called freshening water to be released continuously. This water obviously must be regarded as a loss.

As mentioned by the authors of document GB/A/88/2, the selection of the current irrigation water quality criteria was based on results obtained from international literature. However, among local agricultural scientists it is generally agreed that the conditions under which some of this experimental work was done might not be applicable to local soil and climatic conditions. In the document "*Hersiene kriteria vir besproeiingswater in die Breërivier*" the authors acknowledged that a number of questions regarding irrigation water quality criteria and the effect of salinity on crop production, remain unanswered. They identified the following two research needs:

a) The determination of the salt tolerance of crops cultivated under local conditions (soil, climate and irrigation methodology);

b) Evaluating, under local conditions and varying irrigation management regimes, the existing formulas in use to predict the salt content of soils and the expected concomitant yield decreases.

In order to simultaneously address i) the first research need above, i.e. to determine the salt tolerance of vines (which is the most important crop under irrigation in the Breede River Valley), and ii) to evaluate the operational water quality criteria as stipulated for the Breede River Valley, the Water Research Commission financed a five year project titled "*Research on the use of saline water for irrigation purposes and an assessment of crop salt tolerance criteria*". This five-year project (salt tolerance study) commenced in April 1990 and was conducted by the Department of Soil Science at the University of Stellenbosch.

During the salt tolerance project, vines (*Vitis vinifera L.*) were irrigated using micro sprinklers at two localities, Stellenbosch and Robertson, in a randomised block design using six different water qualities each replicated four times. At each locality, a fixed leaching fraction was used as a constant throughout. Because of the statistical design and other operational constraints imposed by the existing irrigation system, alternative managerial aspects related to the use of saline water for irrigation such as an evaluation of drip- *vs* microsprinkler irrigation, mode of water application (e.g. surface *vs*. subsurface placement of dripper lines) and frequency of application, could not be investigated. However, it was quite possible that the salt tolerance of the crop that was studied, i.e. vines, could be manipulated by using alternative management

strategies. A study of literature indicated that annual crops were being successfully irrigated with saline water using, for example, high frequency subsurface trickle irrigation. In this regard, Phene (1991) reported that tomatoes were irrigated with saline water without any adverse effect by using a high frequency, subsurface irrigation management practice.

The existing vineyard at Robertson included five border rows on each of the northern and southern sides. Because the cultivar (Chenin Blanc) in the southernmost border rows differed from that in the rest of the vineyard (Colombar), they were originally not included in the 6 x 4 randomised block statistical design. However, it was decided that if rigorous statistical criteria were ignored, these ten rows could easily be used to evaluate and demonstrate different irrigation management options. From the above-mentioned information, strong grounds were presented to instrument these ten rows in such a way that the effect of different water qualities, frequency of application and use of dripper lines (including their placement) could be investigated, leading to this report. Furthermore, the project (first phase of the pilot study) was evaluated as being feasible since several benefits could be obtained from the research, namely:

a) it formed a natural extension of the project at Robertson in which the salt tolerance of vines was investigated;

b) a study of this kind would make it possible to also include irrigation management alternatives when judging the fitness for use of saline irrigation water for the production of vines, which in turn could lead to a wider extrapolation of the results of the previous project at Robertson;

c) it would make use of some of the existing infrastructure at the Robertson research site as well as the expertise of the research team of the Department of Soil Science;

d) for two and a half years the pilot study ran concurrently with the salt tolerance project with a concomitant saving on transport and other project expenses;

e) if successful, it might lead to a substantial saving of the dilution water released from the Brandvlei Dam.

The aim of this first phase of the pilot study (1992/95) was to test management options in regard to saline irrigation when surface and subsurface drip irrigation was utilised. The treatments of the first phase included a 150 mS m^{-1} and a 350 mS m^{-1} treatment and each was then divided into surface and subsurface plots as well as high and low frequency treatments. During the follow-up project (1995/98) of the pilot study, EC_i treatments were lowered to fresh water and 150 mS m^{-1}, the different irrigation frequencies were dropped and the aim was focussed more on management of water quality during the season.

2.2 THE RESEARCH INFRASTRUCTURE AT ROBERTSON

2.2.1 General

The research was conducted at Robertson in an experimental vineyard belonging to the Agricultural Research Council. Robertson (33º 46'S, 19º 46'E) is located in the south-western part of South Africa and is situated in the Breede River Valley. The plots used for the pilot study were located at the northern and southern sides of a vineyard where a five-year study (Moolman *et al.,* 1999) was conducted on the effects of saline irrigation water on grapevines.

2.2.2 Climate, viticultural features and general instrumentation

The elevation of the experimental farm at Robertson is 156 m above sea level and the climate can be described as semi-arid, with a Mediterranean rainfall pattern. The experimental farm has a long-term (1954-1989) mean annual precipitation of 280 mm per annum (Table 2.01). It should be noted that potential evaporation at all times exceeds the rainfall, especially during summer which means that viticulture is only possible by making use of full-scale irrigation.

The experimental plots formed part of an experimental vineyard, which was established in 1974 and was planted with Colombar and Chenin Blanc, grafted on a 99 Richter rootstock. The vines were trained on a factory trellising system (Burger & Deist, 1981). Between 1976 and 1984 the vineyard was used in an irrigation experiment evaluating the effect of different irrigation systems (flood, sprinkler, micro sprinkler and drip) and soil water regimes on vine performance (Van Zyl, 1984). For the present study, 16 experimental plots divided into two groups were

used. Eight plots were situated on the northern side and eight on the southern side (Figure 2.01).

Table 2.01 Long-term weather data of the Robertson experimental farm, 1954-1989 (Anon. 1989)

Month	Mean Max. Temperature (^{o}C)	Mean Min. Temperature (^{o}C)	Rainfall (mm/month)	Evaporation (mm/d)	Sunshine (h/d)
1	30.7	15.6	12.2	8.4	9.8
2	30.2	15.8	16.1	7.2	9.0
3	28.5	14.4	15.7	5.6	8.0
4	25.4	11.4	30.4	3.7	6.9
5	22.0	8.2	32.5	2.4	6.3
6	19.4	5.9	31.9	1.8	6.1
7	18.9	5.2	26.9	2.0	6.6
8	19.5	6.1	41.8	2.7	6.9
9	21.7	8.1	19.8	4.0	7.2
10	24.6	10.4	21.5	5.7	8.2
11	27.2	12.8	18.4	7.2	8.9
12	29.5	14.5	12.2	8.3	9.6

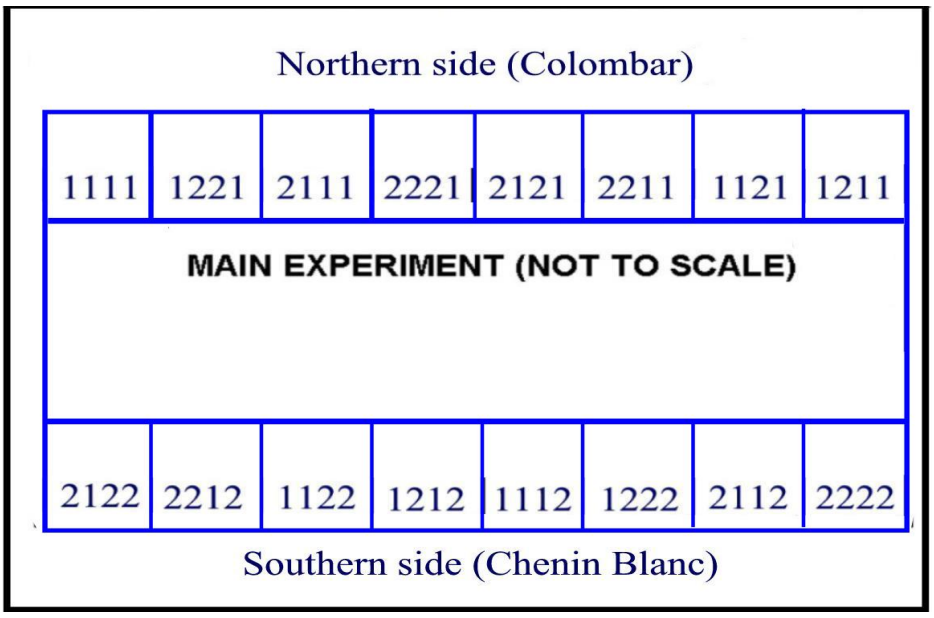


Figure 2.01. Schematic diagram of the experimental vineyard at Robertson showing the 16 plots arranged into two groups of eight each. ***The number at the bottom of each site is the Quality, Frequency, Method and Block***

The borders and original plot sizes of Van Zyl (1984) were retained for the salt tolerance section of the study but were halved where the pilot study was concerned. Each plot consisted of an experimental row bounded by two border rows on either side. The row and plant spacings were 3 m and 1.5 m, respectively. Blocks 1 and 4 had 24 plants per row while blocks 2 and 3 had 23 plants per row. In the experimental row, ten vines were used for research purposes.

The experimental vineyard was also equipped with a class A-evaporation pan and a standard (cumulative recording) rain gauge. From November 1991 until April 1994, the class A-pan and rain gauge were read daily. During the summer of 1992/93 an automatic recording weather station was installed. Wet and dry bulb air temperature, incoming solar radiation, wind speed and rain were recorded on an hourly basis.

2.2.3 Soil properties

Van Zyl (1984) described the soil as a Hutton fine sandy loam, but according to the soil classification system of South Africa (Soil Classification Working Group, 1991) the soil is classified as a Trawal 2210 fine sandy loam (Typic Durochrepts in international soil taxonomy) with a duripan at approximately 1.2 m. Prior to the start of the study (in April 1990), 49 soil samples were taken and analysed for a range of physical and chemical properties. When the samples were taken in April 1990, the plot sizes and boundaries had not been finalised. It was not realised at the time of sampling that if the 15 x 15 m sampling grid that was used in April 1990, was superimposed on the final layout of the experimental design, most of the sampling positions would fall exactly on the border of adjacent plots and therefore sampling extended into the area that was later used for the pilot study. The analytical results could therefore only be summarised in terms of mean values per block (block refers to the replicates of the main study, Figure 3.01). The results are shown in Table 2.02 and primarily give an idea of the east-west variability.

The depth of the duripan (dorbank horizon) below the soil surface was surveyed in 1993 using an automatic recording penetrometer and a 5 m x 11 m sampling grid. The maximum depth that could be recorded with the penetrometer probe was 1.4 m. The depth to the duripan varied between a minimum of 0.8 m and a maximum of >1.4 m. The results are shown as a contour map in Figure 2.02.

Table 2.02 Mean soluble salt content (in terms of the electrical conductivity of a saturated paste extract), extractable cation concentration, cation exchange capacity and clay content with depth for each block (replicates of the main study, combined with the pilot study) of the experimental vineyard at Robertson as determined in April 1990

Block	Depth (m)	ECe* (mSm^{-1})	Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	CEC** (cmol/kg)	Clay (%)
1	0.15	84	11.9	3.5	0.3	10.9	21.3
	0.30	75	12.7	3.6	0.3	11.3	28.5
	0.60	92	14.2	4.6	0.5	12.4	20.7
	0.90	93	15.4	6.1	0.6	14.3	17.1
	1.20	76	13.4	6.4	0.6	12.7	14.2
2	0.15	123	10.5	3.1	0.3	11.1	21.8
	0.30	120	11.6	3.7	0.4	11.5	19.4
	0.60	152	13.6	4.8	0.4	13.1	17.5
	0.90	187	15.0	6.4	0.7	14.2	15.4
	1.20	185	14.0	7.3	0.8	13.5	15.0
3	0.15	84	10.3	3.4	0.3	10.7	20.5
	0.30	79	10.7	3.6	0.3	11.2	25.2
	0.60	93	16.9	4.6	0.4	11.7	26.2
	0.90	122	14.8	6.3	0.6	14.2	18.7
	1.20	146	14.3	6.6	0.6	14.1	16.6
4	0.15	77	12.8	3.7	0.3	11.2	21.1
	0.30	74	12.9	3.9	0.3	10.7	28.6
	0.60	67	13.9	5.3	0.5	12.3	28.0
	0.90	85	14.9	6.9	0.6	13.8	25.7
	1.20	98	14.9	7.9	0.8	14.0	16.2

**ECe = electrical conductivity of a saturated paste extract, **CEC = cation exchange capacity.*

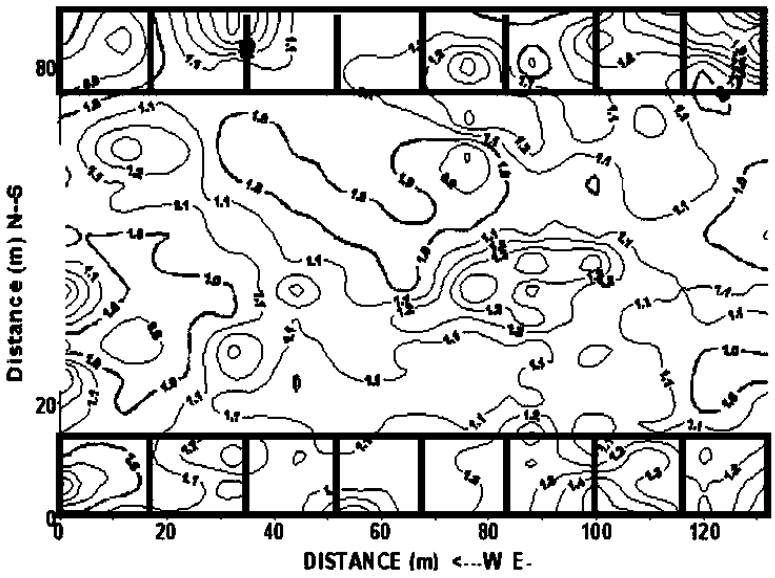


Figure 2.02. Spatial distribution of the depth (meters) to the duripan (below the soil surface) in the Robertson experimental vineyard also showing the position of the pilot study sites.

2.2.4 Salinity and irrigation treatments (1993-95)

The objective of this study was to evaluate alternative management options in order to promote the use of saline irrigation water in the Breede River valley. To reach this goal, three main management options were selected to evaluate their effect on grapevine production:

a) Two qualities in terms of salt concentrations, i.e. 150 (Q1) and 350 mSm^{-1} (Q2) using NaCl and $CaCl_2$ solutions mixed in a 1:1 molar ratio of Na:Ca;

b) Two irrigation frequencies, i.e. low (F1) and high (F2), based on replenishing 25 and 2 mm water respectively, from calculated evapotranspiration (ET).

c) Two irrigation methods, i.e. drip irrigation applied to the soil surface (M1) and subsurface (M2).

Eight combinations of these management options were selected for evaluation with each option having two replications. The combinations were:

i) Q1F1M1, code 111;
ii) Q1F1M2, code 112;
iii) Q1F2M1, code 121;
iv) Q1F2M2, code 122;
v) Q2F1M1, code 211;
vi) Q2F1M2, code 212;
vii) Q2F2M1, code 221;
viii) Q2F2M2, code 222.

The five rows on the northern and southern sides of an existing salt tolerance study were divided into sixteen small plots all together. Two variations of each of the three main management options (factors) appeared four times in the various combinations and were therefore treated as four replications.

Irrigation control (not considering the preparation of the salt solution in a 10 m^3 make-up tank) was fully automated.

In 1994 the steering committee decided to exclude certain procedures from this project in the light of the fact that these procedures would not have contributed to the aims of the study and required an excessive amount of time. These were as follows:

a) Sampling and analysing leaf samples.

b) Monitoring of leaf water potential, stomatal resistance and leaf area index (LAI).

Many problems were experienced with the irrigation management system from the start of the project until the end of the 1993/94 season. This was mainly due to a newly developed management system. The system was planned with full automation in mind but had teething troubles. The main problems experienced were with the irrigation frequency and further investigation revealed that the calculation of evapotranspiration was done incorrectly. Subsequent to 1994/95 the system worked better and sufficient experience in water management was developed for the study to proceed successfully.

2.2.5 Soil water measurement

One neutron access tube was placed 0.2 m from the dripper line at each site. To monitor soil water content and make further refinement to the irrigation program, neutron probe readings were taken at least once per week and daily soil water content was to be monitored with locally manufactured permittivity sensors. Messrs Wessels and Steyn developed the sensors as part of a WRC-financed project. Eight sensors were installed at the Chenin Blanc section of the experiment and the aim was to use the sensors in an uncalibrated mode merely as indicators of water depth (wetting front) in the profile. These instruments failed to be of any value, however, since a soil EC above 75 mS m^{-1} rendered them useless.

No other instruments with the capacity to measure soil water content on an hourly or daily basis existed at that time. Instead, neutron probe readings were taken twice weekly.

2.2.6 The automated irrigation and salt control system (1993-95)

The total irrigated area of the pilot study amounted to 4050 m^2 although in view of the fact that a drip irrigation system was employed full surface wetting was never achieved.

The irrigation system consisted of the following components:

i) The piping. Each plot was supplied from a manifold close to the irrigation control system and due to the different lengths in supply lines careful consideration was given to the use of the correct diameter pipes and valves for pressure control to all sites.

ii) Dripper lines. Pressure controlled drippers were used with a supply rate of 2 mm per hour.

iii) Filter system: An auto-backwash filtering system was used to minimise the risk of emitter blockages.

iv) Salt dosing system. This system consisted of a high pressure pump, a 10 m^3 stock solution tank and electronic control which included sensors and injectors.

v) A computer and integrated weather station. The computer performed the evaluation of weather station data, irrigation data and salinity control, and controlled the irrigation events automatically.

vi) Telephone. The system was linked to a telephone line that enabled remote operation and programming of the system.

Two main supply lines (which made up the two irrigation systems), each containing a water meter and an electrically controlled irrigation valve, were used to irrigate eight plots each. Eight plots were irrigated at a high frequency (each time 2 mm water had been lost through evapotranspiration) on the one system and the other set of eight at a low frequency (after 25 mm water had been lost through evapotranspiration) on the other system. Details are described in Appendix A.

Each main line was split into two pipes where salt solution from the make-up tank (salt dosing line) was injected and automatically controlled to supply irrigation water with an electrical conductivity of 150 or 350 mSm^{-1} (Appendices A and B).

The automatic irrigation system was capable of:

i) determining the starting time and volume of an irrigation period;

ii) starting and stopping the salt dosing;

iii) dosing of saline water and real-time monitoring of the irrigation stream, as well as stopping the irrigation when prescribed requirements were not being met;

iv) automatic collection of the data needed for the above-mentioned functions, as well as the automatic collection of weather data.

Irrigation began when the soil water deficit (which was calculated periodically) reached a prescribed maximum and was stopped after the soil water deficit had been replenished. Records of climatic, irrigation and soil water content data were kept for each period and were filed in an electronic data file.

Salt dosing control was developed with very strict safety measures embedded in the programming of the system. The control of the dosage pump was set in such a way that this pump could only be in operation if the irrigation pump was running. If the salt dosage control system could not ensure effective control of the system for 3 minutes, the salt dosage valves and the irrigation valve of the specific system closed down. If the other irrigation frequency section of the total system was not running simultaneously, shut-down of both the dosage and irrigation pumps would occur. In each case, an alarm was activated to make diagnosis of the system from a remote site possible.

A full description of the calculation of evapotranspiration and soil water deficit for the two phases of this study is given in Appendix C.

2.3 A SUMMARY OF METHODS FOR TREATMENTS APPLIED DURING THE FIRST AND SECOND PHASES OF THE PILOT STUDY

The aim of this section is to remind the reader of the treatments that were used in the first and second phases of the pilot study and also to point out that certain aspects that were neglected in the first phase did receive attention in the second phase.

2.3.1 First phase (1992-95)

The pilot study was aimed at investigating managerial options to enhance the use of saline water for irrigation purposes. Three factors were investigated:

i) Water quality, with salinity levels set at 150 mS m^{-1} (Q1) and 350 mS m^{-1} (Q2).

ii) Irrigation frequency, with low frequency (F1) and high frequency (F2) applications being made when calculated ET had accumulated to 25 mm and 2 mm, respectively.

iii) Method of irrigation, with surface drip (M1) and subsurface drip (M2). For M2 the dripper lines were buried at 0.2 m depth.

The three factors were combined to give eight treatments and each was replicated twice on sixteen plots with eight plots located on the southern- (Colombar) and eight on the northern side (Chenin Blanc cultivar) of the main experiment (Figure 2.01). Drippers were spaced 0.5 m apart and the plant spacing in the vine row was 1.5 m. This implies that each plant was wetted by three drippers.

Important aspects of the construction of the infrastructure will be discussed briefly in the following sections.

2.3.1.1 Installation of irrigation piping

The underground dripper lines were installed at a depth of 0.2 m, directly in the centre of the vine row. The pipes were buried in line with the vines, passing around the trunks. The surface irrigation lines were attached to a wire at a height of 0.3 m above the soil surface. The dripper spacing was 0.5 m throughout. The plant spacing in the

rows was 1.5 m, which meant that each vine was serviced by 3 drippers. It was argued from initial results that a subsurface irrigation depth of 0.2 m was too shallow as the soil surface was constantly wet. It was later found, however, that the problem probably arose from over-irrigation rather than poor drainage.

2.3.1.2 Installation of the irrigation and salinity management systems

The system was developed and installed by Mr WPJ Wessels (of the project team) and Mr H. Steyn (Dept. of Electrical and Electronic Engineering, University of Stellenbosch). The system was computer controlled and simultaneously linked to a weather station. Weather information was sampled on a 15-minute basis and used in the modified Penman-Van Bavel equation. By solving the equation every 15 minutes, reference evapotranspiration was calculated. With this value and relevant crop factors, the soil water deficit was calculated. The method by which the equation was solved and soil water deficit calculated is discussed in the previous section and the in the Appendix. The aim was to irrigate with saline water from the beginning of September to the end of March of the following year. A cover crop was sown in April and from then until the beginning of September winter irrigation was applied to supplement winter rain in leaching the soil. With winter irrigation, the saline water treatments were replaced by fresh (canal) water.

A further problem arose with the way in which the irrigation amount was calculated and transformed from a depth basis to a volume basis. The depth basis was handled by the Penman-Van Bavel equation but it differed between calculations on a 15-minute basis and on an hourly basis. The 15-minute basis was used for the high frequency irrigation and the hourly basis for the low frequency irrigation. Theoretically both values must accumulate, after a period of one week for example, to the same value. This was not the case and consequently affected the irrigation amounts. According to the accumulated data record on the computer, the total evapotranspiration and irrigation values for the period 11 November 1993 to 30 April 1994 were as follows:

15 minute data base (high frequency): ET = 688 mm Irrigation = 559 mm = 839 L

Hourly data base (low frequency): ET = 579 mm Irrigation = 363 mm = 545 L

This was a problem that needed immediate attention. The cause of this was narrowed down to the way in which the system handled the timing of irrigation activation and deactivation. To irrigate 25 mm in the low frequency, the system started and stopped once. For the high frequency system, however, this meant 12.5 start-and-stop events carrying a greater potential for inaccuracy.

The seasonal averages of the salinity treatments applied were as follows:

150 mSm^{-1} Low frequency: 137 mSm^{-1}

150 mSm^{-1} High frequency: 142 mSm^{-1}

350 mSm^{-1} Low frequency: 342 mSm^{-1}

350 mSm^{-1} High frequency: 414 mSm^{-1}

With the change of depth to volume of water (mm to m^3) an area factor was needed. Initially the wetted surface was taken as 4.5 m^2 per vine (i.e. 100%), but as a result of over-irrigation it was changed to 3 m^2 per vine (i.e. 66%) on 22/12/93. It was later also decided to change the wetted surface to 1.5 m^2 and rather to alter the crop factors. The resulting irrigation depth is given in Table 2.03. System ineffectivity was also kept at 0%.

Table 2.03 Summary of 1994/95 climatic and irrigation data

	Irrig mm/wetted area	Irrig mm/plant	ET mm/a	Leaching mm
Low Freq	1197	598	1236	317
High Freq	1247	623	1136	677

2.3.2 Second phase (1995-98)

The four treatments were as follows:

i) Treatment LS1 Four plots were irrigated first with Robertson canal water till veraison, and then with saline water, EC_i = 150 mS m^{-1}, till the end of April, with water applied at a high

frequency (e.g. once per day) with a surface drip irrigation system.

ii) Treatment SL1 Four plots were irrigated first with saline water, EC_i = 150 mS m^{-1}, till veraison, and then with Robertson canal water till the end of April.

iii) Treatment LS2 The same as (i) above, but with a subsurface drip irrigation system.

iv) Treatment SL2 The same as (ii) above, but with a subsurface drip irrigation system.

The allocation of treatments LS1, LS2, SL1 and SL2 of the pilot study to the sixteen plots bordering the main study is shown in Figure 2.03. For statistical purposes, each of the treatments was replicated four times. It is important to note that the replicates were balanced with respect to plots that carried historical effects of either a low frequency irrigation application or a high salinity (EC_i = 350 mS m^{-1}) treatment used in the previous study.

The treatments of the pilot study at Robertson were designed to allow investigation of the following managerial options:

1. The effect of different irrigation systems in alleviating the detrimental effects of saline water on grapevines: comparisons could be made between micro-sprinklers at a medium to low frequency of application (the main study described in Chapter 3), and surface and subsurface drip irrigation at a high frequency of application (pilot study).

2. The effect of salinity exposure at different growth stages on the performance of grapevines. Salinity exposures from bud break till veraison, from full bloom till harvest and from veraison till harvest could be investigated. Before or after each of these stages the vines were irrigated with low salinity water.

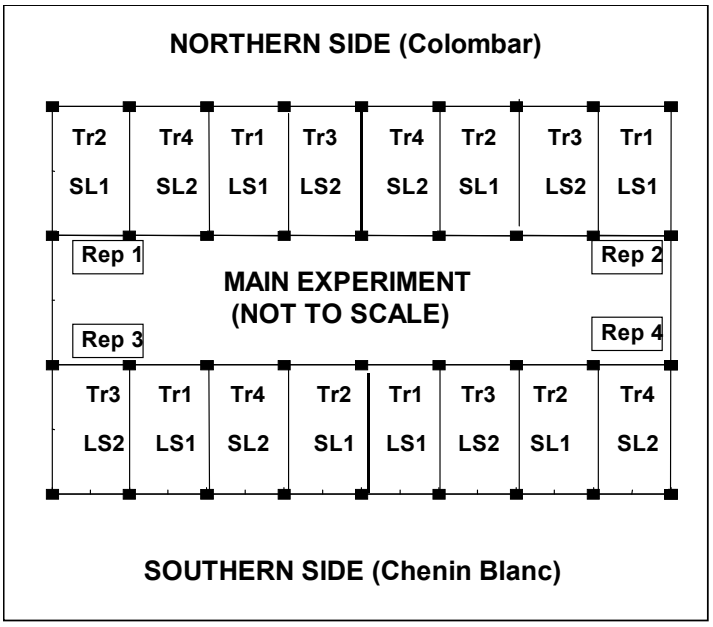


Figure 2.03. Diagram of the sixteen plots and eight treatments (replicated twice) that were used in the pilot study at Robertson from 1995 to 1998 to investigate managerial options to enhance the use of saline water for irrigation purposes. ***The labels in the bottom row (e.g. L,S,1) refer to the new treatments where S=saline water, L=low salinity water, 1=surface and 2=subsurface drip and the sequence of S and L denote the sequence in which saline and low-salinity water alternated during the season.***

2.4 RESULTS OF THE FIRST PHASE OF THE PILOT STUDY (1992-95)

2.4.1 Introduction

As the title of this project indicates, the main aim of the research was to look at management practices that could be used to counter the negative influence of low quality water with a high salt content on grapevines and therefore to promote the use of saline water for irrigation. This pilot study was linked to the original main study (WRC Report No: 303/1/1999; Moolman *et al.,* 1999) in which Colombar grapevines were irrigated with saline water treatments using micro-sprinklers.

2.4.2 Irrigation quantity and quality

2.4.2.1 Soil water status

The time sequence of the average soil water content of the eight treatments from September 1993 to March 1994 is given in Figure 2.04a. The data are expressed as

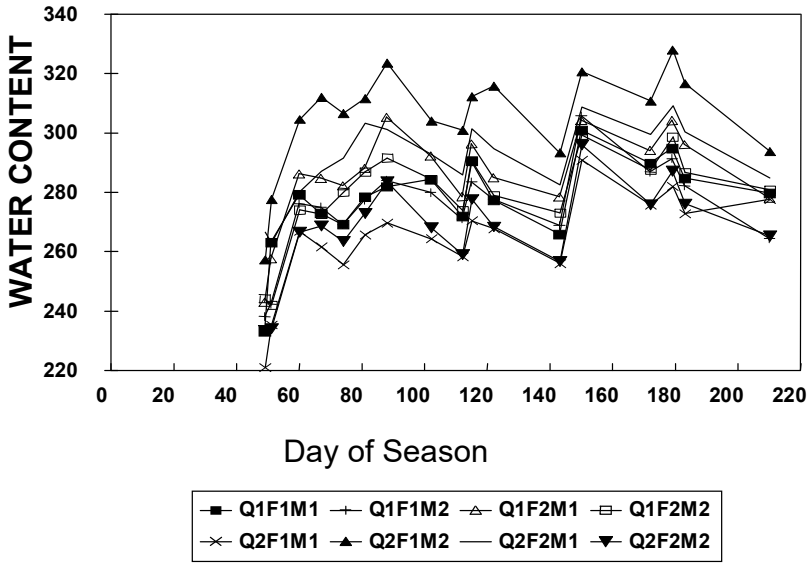
averages per management factor in Figure 2.04b. The initial sharp rise in soil water content around day 50 is due to replenishment of the large deficit that had built up at the time of installing the irrigation system. The soil was then just wetted to the acceptable water content. This value was determined *in situ* during June to August 1993 at an average value of 287 mm/1.05 m. The following remarks can be made in connection with the soil water content (Figure 2.03):

a) The fluctuation in soil water content associated with the high frequency treatment (F2) was more than the specified 2mm. If the management system had worked correctly the soil water status should have been virtually constant, showing only the 2mm fluctuation.

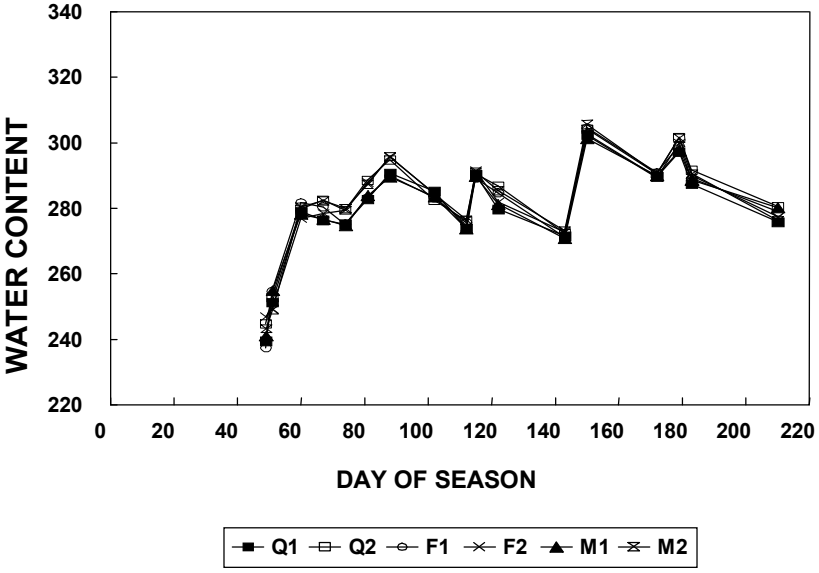
b) From day 60 to day 180 an increase in soil water content was found for all treatments and factors. This indicated over-irrigation. The decrease in water content after day 180 was as a result of pre-harvest termination of irrigation to aid ripening of the grapes.

c) A test of the factor means indicated that the differences between factors are small and non-significant.

Considerable concern existed that the soil volume being wetted by irrigation did not receive enough attention. Also the fact that the surface and subsurface wetting volumes were potentially different was not always taken into account. The volume and the wetted surface played an important role in calculation of the soil water flux. Extra neutron access tubes were consequently installed at a position 0.5 m away from the dripper line. The original set was installed 0.25 m away from the dripper line. This provided an opportunity to study some of the dynamics at the perimeter of the wetted volume and to find out where the extra water went during over-irrigation. It also provided an opportunity to model plant water use more accurately.



(a)



(b)

Figure 2.04. Soil water content over time to a total depth of 1.05 m given as (a) the average per treatment and (b) the average per factor for the period 1st September 1993 to March 1994

Table 2.04 A comparison between ET and averaged soil water content data based on mm per wetted area and mm per plant for the high and low frequencies at Robertson pilot study for the season 1994-95.

Month	Low Freq Irrig mm/wet area	Low Freq Irrig mm/plant	High Freq Irrig mm/wet area	High Freq Irrig mm/plant	Low Freq ET(Pen) mm/wet area	Low Freq ET(Pen) mm/plant	High Freq ET(Pen) mm/wet area	High Freq ET(Pen) mm/plant	Lo PET(Pen) mm	Hi PET(Pen) mm
Aug	239	120	181	91	47	24	109	54	78	181
Sept	187	94	90	45	73	37	79	40	122	132
Oct	101	51	145	72	92	46	96	48	154	160
Nov	93	47	119	59	132	66	142	71	221	236
Dec	122	61	164	82	144	72	143	71	240	238
Jan	134	67	204	102	154	77	127	63	257	211
Feb	130	65	103	51	159	80	116	58	265	194
Mar	89	45	91	45	118	59	89	45	197	148
Apr	86	43	70	35	113	57	84	42	188	141
May	14	7	81	41	203	101	152	76	338	253
Total	**1197**	**598**	**1247**	**623**	**1236**	**618**	**1136**	**568**	**2060**	**1894**
Sep-Apr	944	472	984	492	986	493	876	438	1643	1459
Sep-Apr(Main)	907		907							

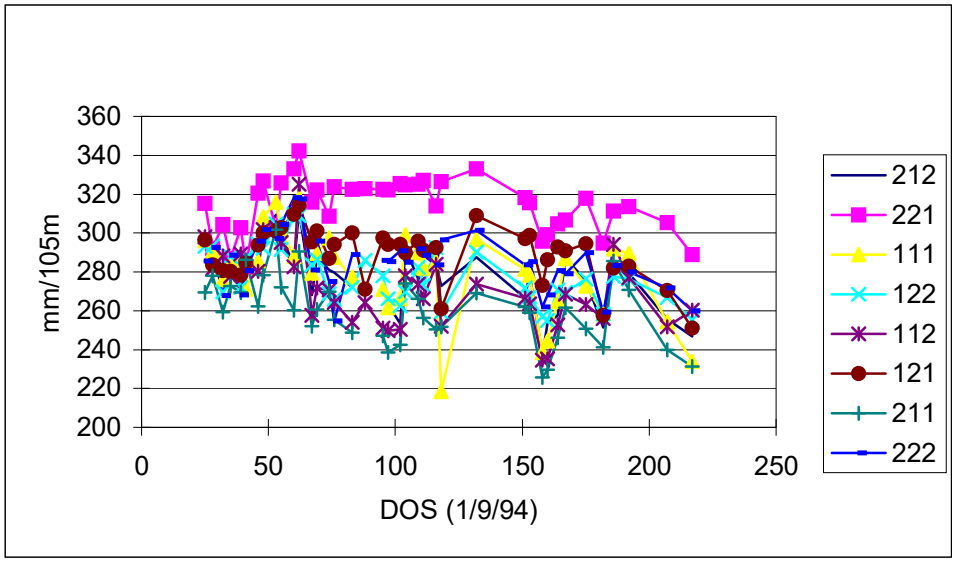
Table 2.05 Container data (mass of the container and EC of the water) for the irrigation season 1994-95 at the Robertson Pilot study.

		Mass water						EC					
Suction		Qual 1	Qual 2	Freq 1	Freq 2	Meth 1	Meth 2	Qual 1	Qual 2	Freq 1	Freq 2	Meth 1	Meth 2
Date	Number	150mS/m	350mS/m	Low	High	Bo	Under	150mS/m	350mS/m	Low	High	Bo	Onder
19/10/94	1	9	8	4	13	8	9	159	315	215	259	251	233
3/11/94	2	19	21	20	19	22	18	167	397	242	323	300	280
13/11/94	3	14	17	18	13	16	15	151	315	231	235	245	233
21/11/94	4	20	23	21	21	23	19	154	354	241	268	261	264
28/11/94	5	24	25	21	28	27	21	151	324	232	244	253	236
4/12/94	6	26	28	23	31	28	25	150	332	249	232	253	243
12/12/94	7	30	31	32	29	29	32	180	316	269	228	235	272
19/12/94	8	24	24	23	26	24	25	162	332	234	260	259	246
03/01/95	9	Full	Full	Full	Full	Full	Full	168	359	257	270	278	263
09/01/95	10	Full	Full	Full	Full	Full	Full	156	344	250	207	218	249
18/1/95	11	23	23	19	26	26	19	154	333	239	247	257	244
2/2/95	12	30	29	31	28	29	29	164	341	238	267	262	256
7/2/95	13	11	9	5	15	8	10	166	363	244	284	279	264
9/2/95	14	18	12	0	5	5	2	99	197	125	170	159	144
18/2/95	15	24	21	24	16	23	20	163	338	244	257	263	253
28/2/95	16	16	14	24	7	16	15	156	338	228	266	259	251
6/3/95	17	29	21	25	12	18	20	93	135	168	59	138	101
13/3/95	18	17	19	21	14	19	17	150	342	237	255	258	248
27/3/95	19	15	13	11	15	13	12	195	382	277	300	298	297
5/4/95	20	19	19	25	12	19	19	147	367	293	221	277	257
21/4/95	21	19	18	22	15	19	18	43	48	48	43	45	46
3/5/95	22	19	17	19	11	17	15	43	44	43	38	37	43
10/5/95	23	7	5	1	6	3	4	49	50	6	49	33	28

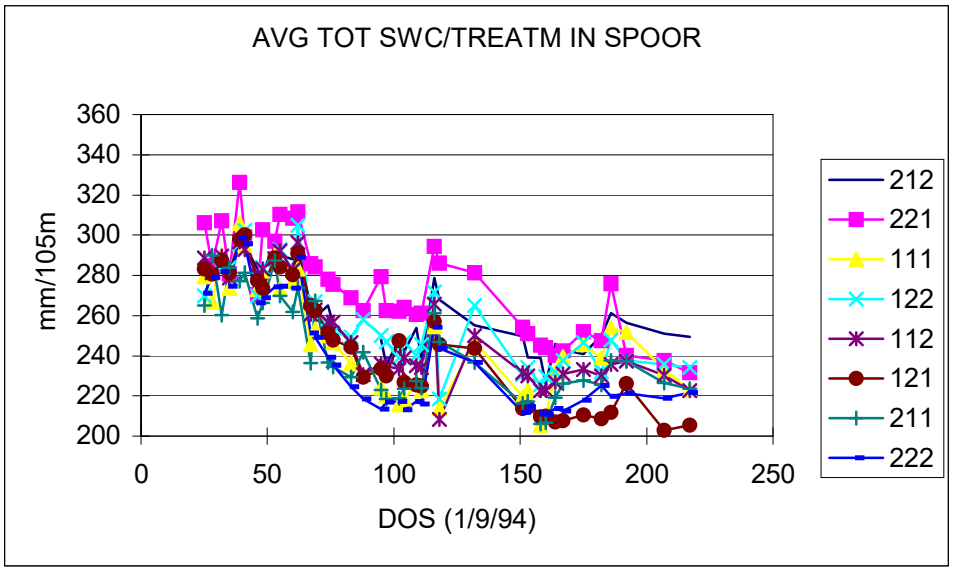
Table 2.04 gives a summary of the irrigation data compared with the Penman-Van Bavel calculated evapotranspiration values for the 1994-95 season. The values show that the low frequency treatment was under-irrigated by 39 mm and the high frequency was over-irrigated by 110 mm during the season, linked to a wetted surface of 3 m^2. Table 2.04 also gives a full account of the comparison of irrigation amounts and calculated ET expressed as mm per wetted area of 3.0 m^2 (4.5 m^2 is full surface) and as mm per vine. Table 2.05 shows the container data, which include the volume and EC of the water that accumulated each week from a 2 liter per hour dripper, attached to the irrigation system at each site. The objective was to obtain a combined irrigation sample each week that would provide an account of the applied salinity, indicate whether the EC control system was on target and also indicate the amount of water applied.

The seasonal mean soil water contents for the 1994-95 season are shown in Figure 2.05. In Fig. 2.05(a) the treatment averages show a sustained soil water content 0.25m from the drippers over the period up to about day of season (DOS) 170, which was followed by harvest (the season commenced on 1st September). In Fig. 2.05(b) a general decline was evident over the whole period, suggesting that less water reached this 0.5m monitoring distance as the season progressed. Figure 2.06(a) shows a similar graph but for the factors measured at the positions 0.25m away from the dripper line. What is conspicuous here is the better grouping of the results. The same applies to Figure 2.06(b).

Figure 2.07 shows the difference in water content between the two monitoring distances (0.25 and 0.5 m) over the same period, calculated as treatment means (2.07a) or as factor means (2.07b). In both cases the difference increases sharply in the early part of the season and then stabilises after about 100 days.

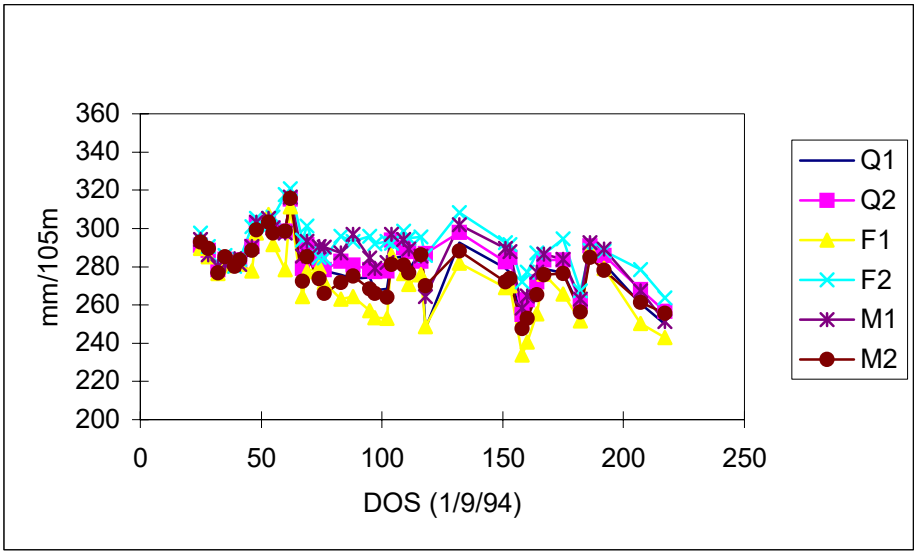


(a)

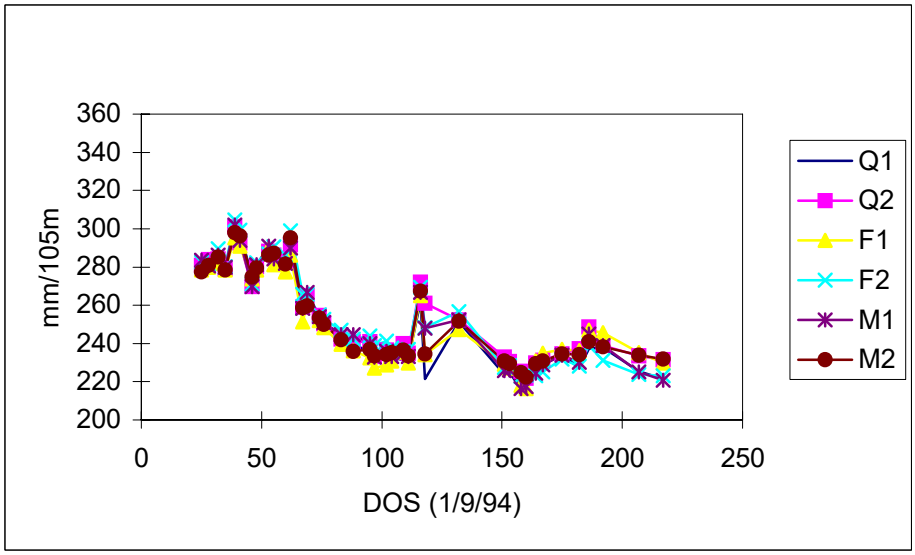


(b)

Figure 2.05. The treatment-averaged soil water content for the 1994-95 season (DOS = Day of season from 1 September) in the Roberson pilot study: (a) measurements made 0.25m away from the dripper line (b) 0.5m away from the dripper line.

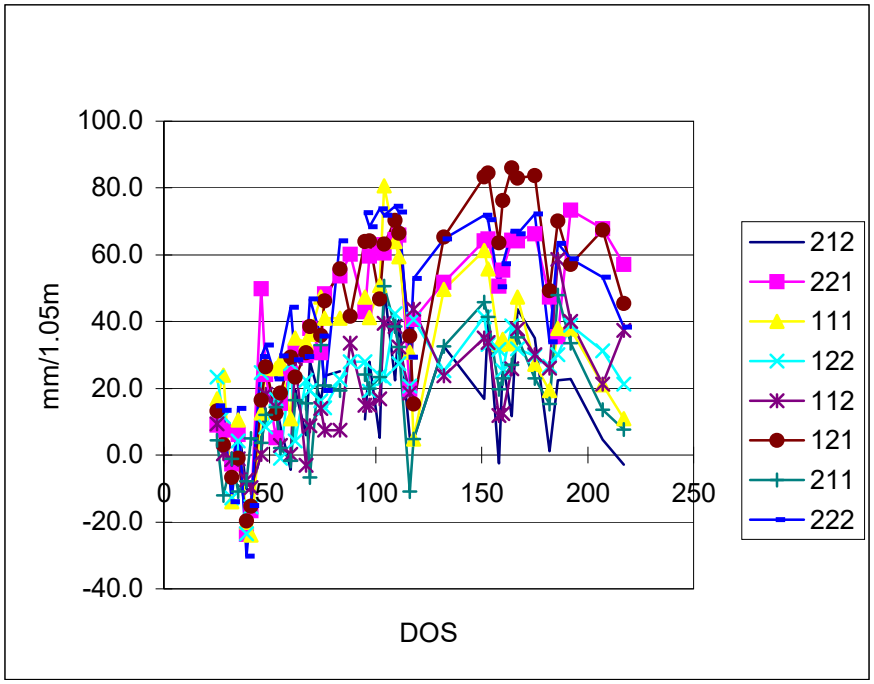


(a)

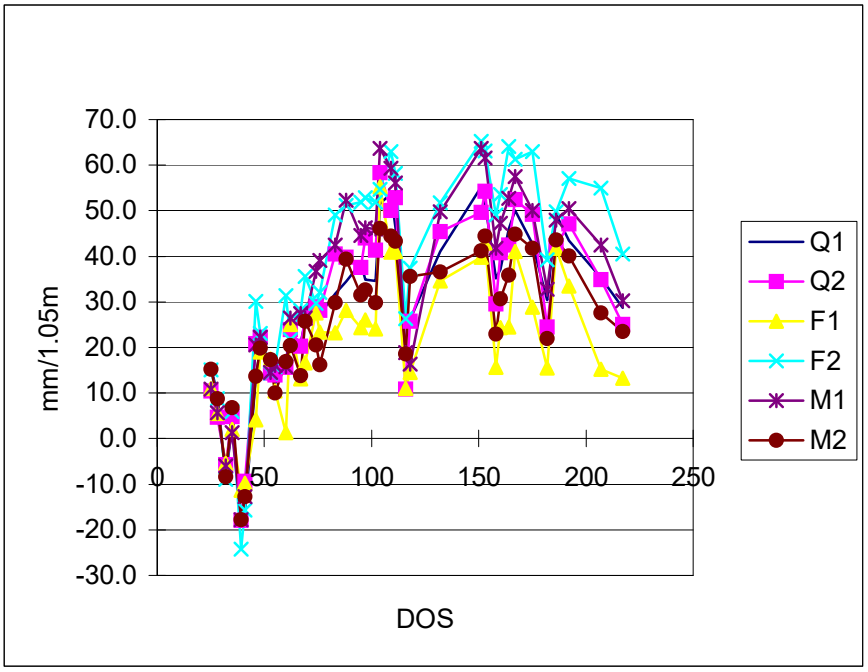


(b)

Figure 2.06. The factor-averaged soil water content (mm/1.05m) in the 1994-95 season (DOS = Day of season from 1 September) in the Roberson pilot study. (a) measurements made 0.25m away from the dripper line (b) 0.5m away from the dripper line.



(a)



(b)

Figure 2.07. Soil water content difference between the two monitoring positions 0.25 and 0.5 m from the drippers plotted in relation to day of season as (a) treatment means and (b) factor means (same data as in Figs. 2.05 and 2.06).

The average differences in soil water content between the two measuring positions, for each treatment and each factor over the 1994-95 season, are given in Table 2.05.

Since the measurements taken at the 0.25m positions were always close to field capacity, the difference between readings of the two positions provides an indication of the dynamics of the lateral distribution of water. Larger differences imply a smaller wetted volume and *vice versa*. These difference values are given in Table 2.06, which shows that factors F2 and M1 resulted in the smallest wetted volume and F1 the largest. Treatments 221, 121 and 222 produced the smallest wetted volume (largest water use) and 212 and 221 the largest (least water use).

Table 2.06 The mean mm/1.05mm difference in soil water content between the two monitoring positions (0.25 and 0.5m away from dripper), calculated as treatment and factor means, for the season 1994-95 in the Robertson pilot study (calculated as: 0.25m-0.5m)

Treatment	Difference	Factor	Difference
212	15.4	Q1	28.2
221	40.4	Q2	29.2
111	31.1	F1	20.8
122	21.1	F2	37.2
112	18.9	M1	33.4
121	43.3	M2	24.9
211	17.3		
222	43.4		

The difference in water use between blocks 1 and 2, i.e. those planted to Colombar and Chenin Blanc, respectively, is shown in Figure 2.08. The water content of both blocks measured at the 0.25 m position (IN) is essentially the same but there is a small difference at the 0.5 m position (OUT). The distribution of soil water with depth is shown in Figure 2.09 from which it is clear that water use by the vines is concentrated in the upper 60 cm of the profile. This is consistent with observations of roots made in the adjacent main study (Moolman *et al*., 1999).

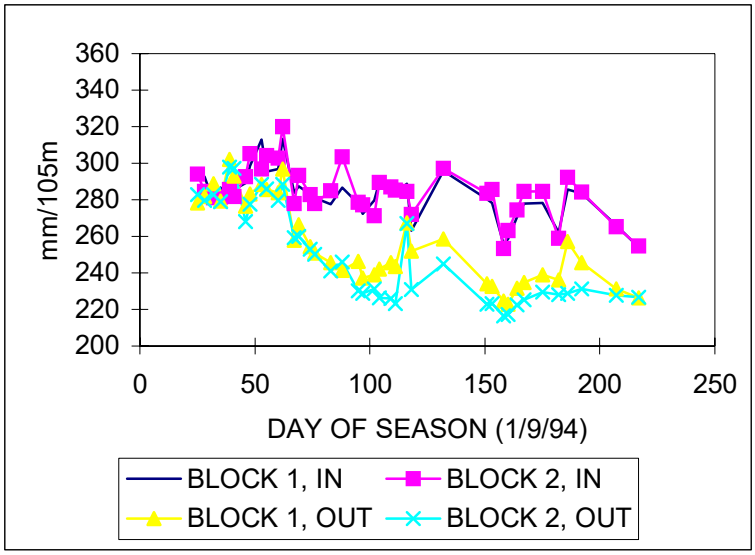


Figure 2.08. Mean soil water content of each block (Colombar(1) and Chenin Blanc(2)) in the Robertson pilot study (1994/95) measured 0.25m (IN) and 0.5m (OUT) from the dripper line.

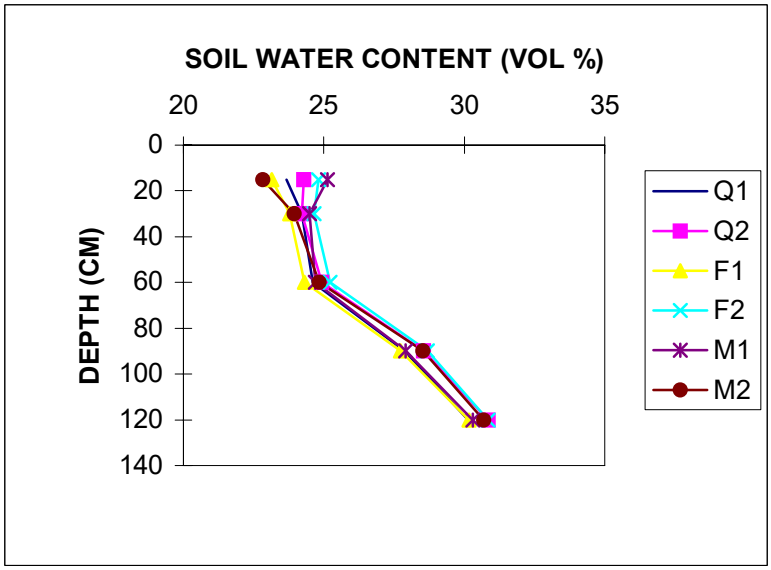
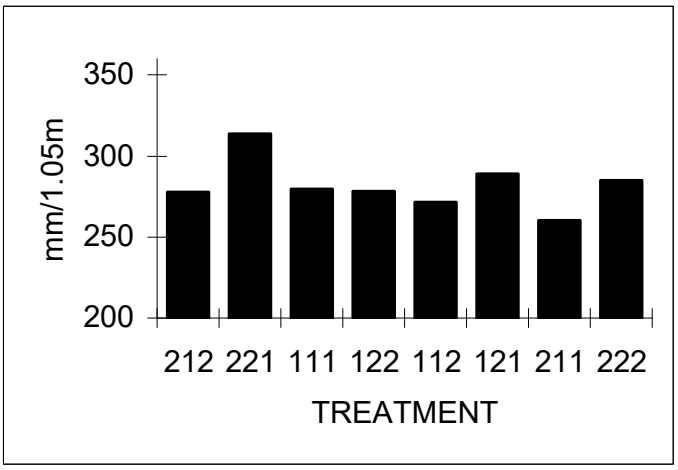
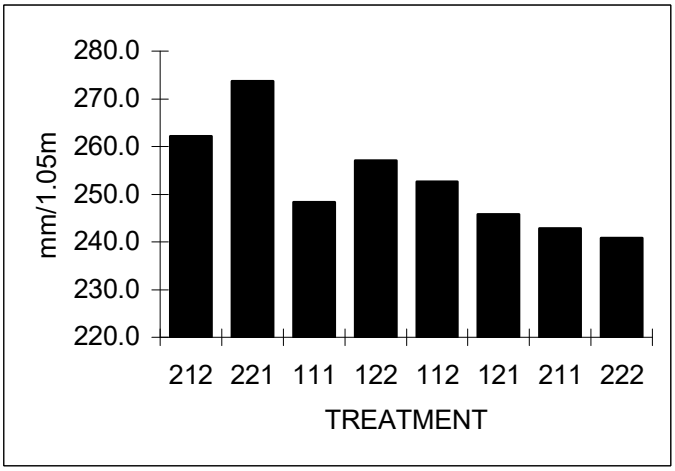


Figure 2.09. Seasonal mean soil water content (average value for the two monitoring distances from the dripper) as a function of depth in relation to each factor (mean of both blocks) in the Robertson Pilot study.



(a)



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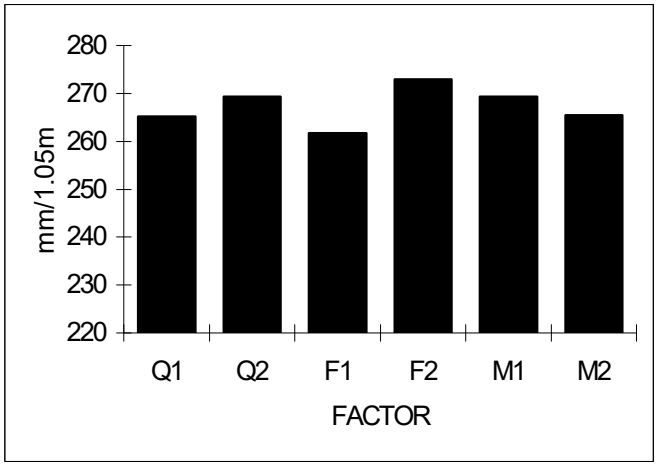


(c)

Figure 2.10. Average soil water content for the 1994-95 season (a) in relation to treatment 0.25 m away from dripper line, (b) in relation to treatment 0.5m away from dripper line and (c) in relation to each factor at both monitoring positions.

Responses to treatments were clearly much greater at the more remote monitoring position. Figure 2.11 shows the general decline in soil water content in relation to each factor, averaged for all monitoring points, as the 1994/95 season progressed.

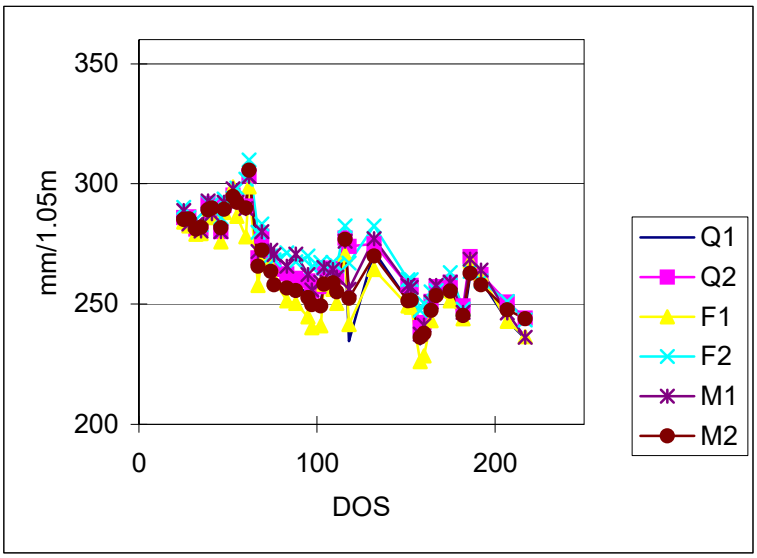


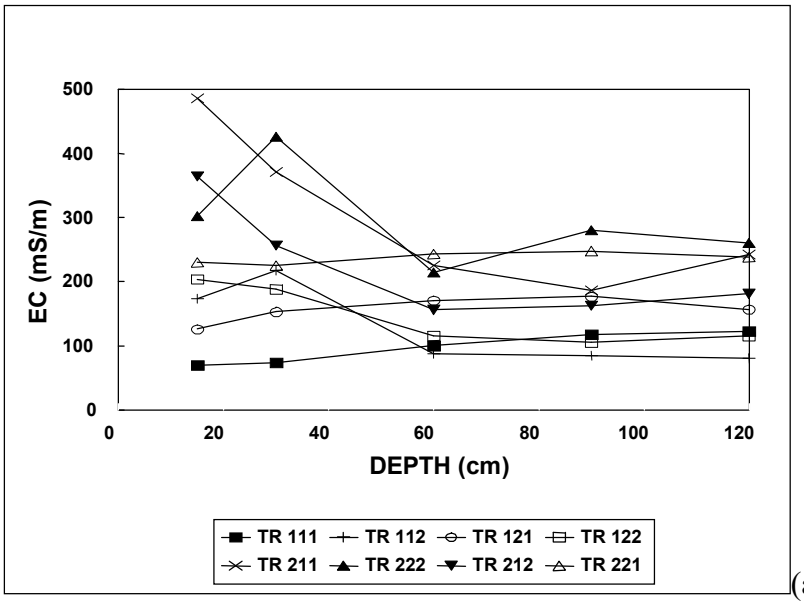
Figure 2.11. The total soil water content (factor means) over time (first day of season was 1 September) for combined row and inter row measurements in the Robertson pilot study for the 1994/95 season.

The fact that the size of the wetted volume shrunk over the season implies that the soil water content was possibly kept at too high a level. In all of these graphs it is evident that Frequency 2 caused the wettest soil water conditions and so did treatment 221. The driest soil water conditions were observed in response to Frequency 1 and, in the case of the 0.25 m monitoring position, to treatment 211. Treatment 222 produced the driest conditions overall.

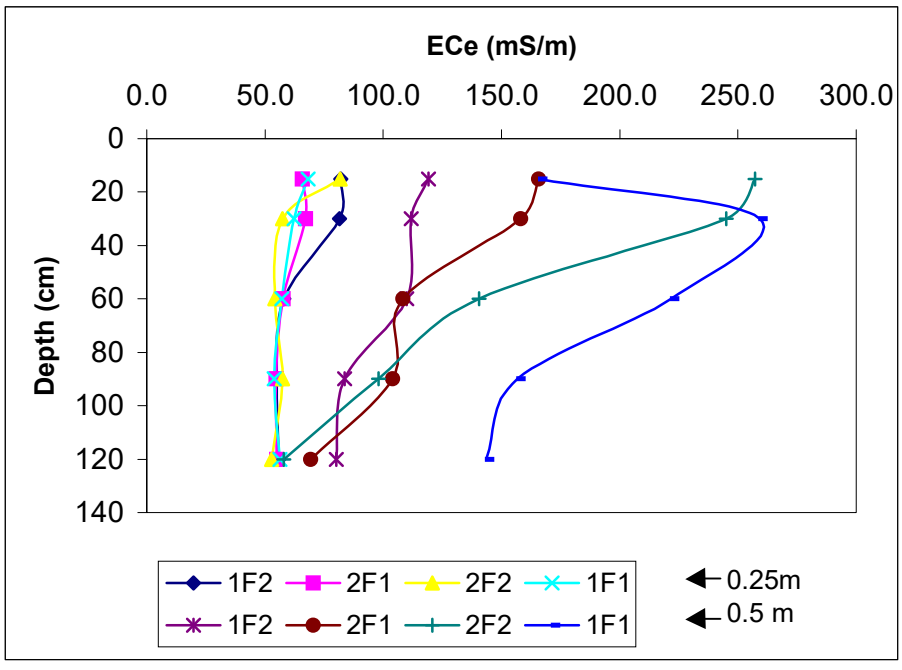
2.4.2.2 Soil salinity and sodicity

Suction cup samplers were used from January 1994 on each of the southern sites, i.e. the Chenin Blanc section of the experiment. The first soil samples were taken in October 1993 before the start of the first saline irrigation at depths of 0-15, 15-30, 30-60, 60-90 and 90-120 cm, and 10 to 15 cm away from the dripper lines. This was repeated in April 1994, September 1994 and April 1995. From all sets of soil samples, saturated paste extracts were made. They were analysed for electrical conductivity (EC_e) and for anions using ion chromatography and for cations by flame emission or

atomic absorption spectrometry. The data for salinity (EC_e) and sodicity (sodium adsorption ratio, SAR_e) will be concentrated on rather than those for individual ions. The EC_e variation with depth measured in April 1994 and September 1994 is shown in Figure 2.12 a and b. The latter shows a large amount of salt still present in the profile after winter irrigation.



(a)



(b)

Figure 2.12. Depth distribution of soil salinity in relation to eight treatments measured in (a) April 1994 and (b) September 1994. In (b) the data represent frequency means presented separately for the two

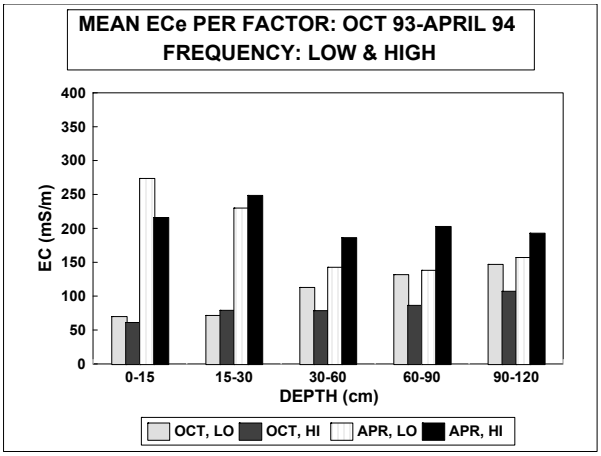
monitoring positions i.e. 0.25m and 0.5m away from the dripper lines.
.(F indicates the average of the Frequency values)

Figures 2.13 to 2.17 contain a selection of data with the aim of providing some insight into the fate of applied salts over the duration of the experiment. Although Figure 2.13 somewhat clouds the general EC_e trend with depth it highlights very clearly the differences between treatments as a function of depth. Frequency of irrigation did not have a large effect on the depth distribution of salts. A higher EC_e was found in the 0-15 cm depth of the low frequency treatment whereas the EC_e of the subsoil was increased by the high frequency treatment. As a result of problems with the frequency control system during the 1993-94 season, some caution should be exercised in interpreting these results. The results for the 1994-95 season did, however, confirm these findings. Subsurface irrigation led to a larger EC_e at the 0-30 cm depth (Figures 2.15 and 2.16). The differences between the effects of the two methods were nevertheless fairly small. The EC_i of the irrigation water (as factor) led to the largest differences between treatments (Figures 2.15 and 2.16). The largest increase in salinity occurred in the upper soil where Q2 water (350 mS m^{-1}) led to EC_e levels twice those emanating from Q1 water (150 mS m^{-1}). The increase in EC_e at a depth of 1.2 m reflects a restriction on the rate of deep drainage. To avoid over-irrigation the area factor was subsequently made smaller in calculating the water application rate.

For purposes of comparison Figure 2.14 shows the initial SAR_e values for both treatments and factors (baseline salinity levels were presented earlier in Table 2.02). Figure 2.15 shows the SAR_e and EC_e results in April 1994, after the first full-scale saline irrigation season. As a result of over-irrigation the SAR_e declined and EC_e was positioned around 200 mSm^{-1}. Figure 2.16, which presents the results of soil samples taken after the winter irrigation of 1994, shows a change in that the EC_e lines began showing a tighter pattern whereas the SAR_e curves became divergent such that even higher SAR_e values were measured after winter irrigation despite the fact that corresponding EC_e values had dropped back considerably. These higher SAR_e values after winter could possibly be interpreted in terms of a differential redistribution of salts during the period of winter rainfall and supplementary irrigation with canal water. The poorly wetted volume of soil between the rows of drippers has a higher salt content compared to that in the dripper rows (Figure 2.12b reflects this effect).

Quite possibly this enrichment of salt in the drier soil zone includes a preferential enrichment of Na as a result of its greater mobility compared with that of Ca and Mg. This would generate a stockpile of more sodic salt during summer which would then diffuse back into the dripper zone during whole-field wetting by winter rain, leaving a more sodic signature on exchange surfaces after leaching of salts and thus retaining a high SAR despite the drop in EC towards background levels. Further investigation of this phenomenon could be valuable because it suggests that drip irrigation coupled with certain soil types could give rise to higher sodicity levels in parts of the soil than would normally be expected on the basis of irrigation water quality.

Figure 2.17 shows the change, in relation to treatment, over the season in depth-averaged salinity of suction cup lysimeter samples taken from all the sites. Each site had five lysimeters at depths of 15, 30, 60, 90 and 120 cm below the dripper line. EC_{sw} increased sharply in response to irrigation with saline water, stabilising after about 100 days. The neutron probe data indicated that over-irrigation took place almost throughout the 1994-95 season, implying that conditions were conducive to the leaching of salts. Despite this, EC_{sw} still rose to levels almost twice that of the more saline irrigation treatment.



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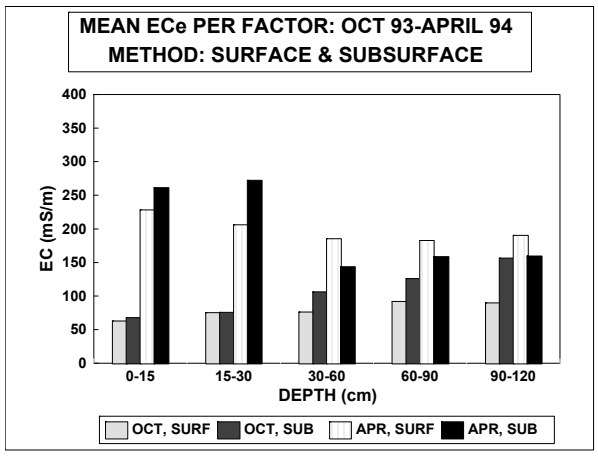

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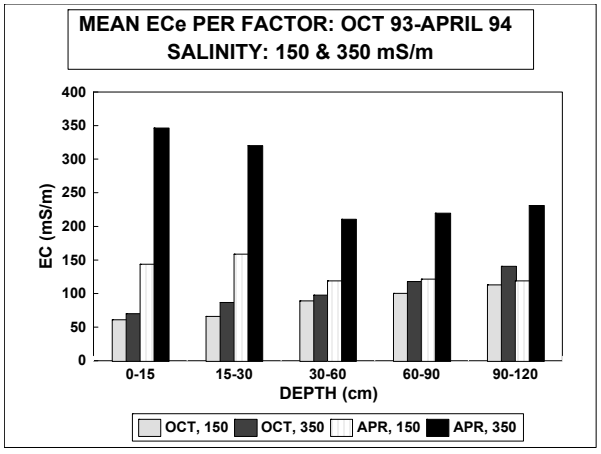
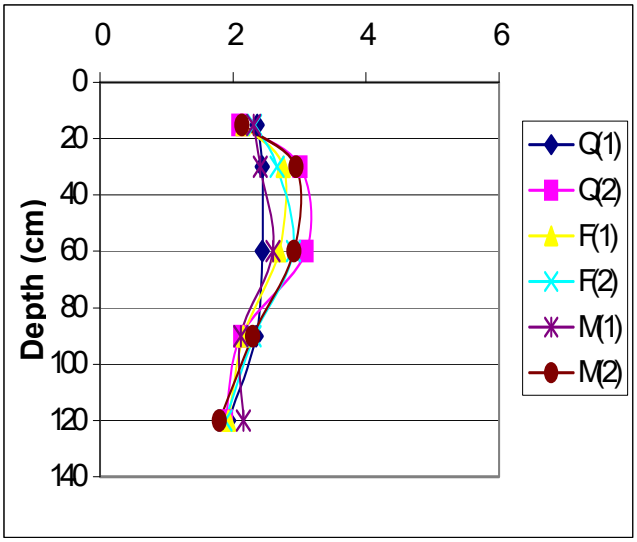
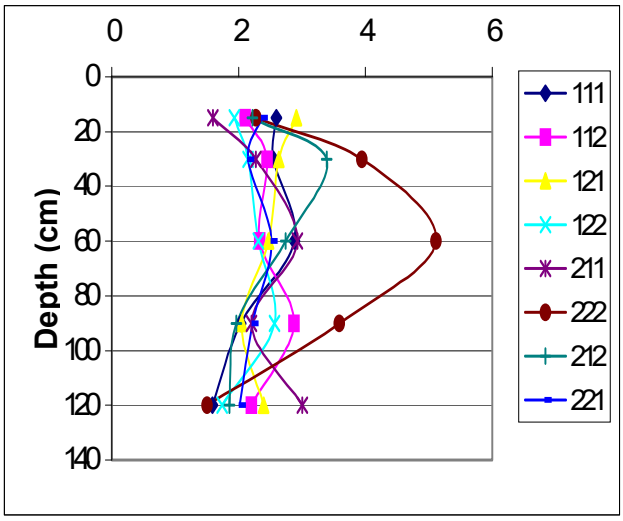


c)

Figure 2.13. Soil salinity (EC_e of saturated soil paste extracts) expressed as factor means measured in October 1993 and in April 1994: a) frequency (low and high), b) method (surface and subsurface) and c) salinity level (150 and 350 mSm^{-1}) of drip irrigation.



(a)



(b)

Figure 2.14. SAR_e values of the first pre-irrigation soil samples taken at all sites of the Robertson Pilot study in October 1993.

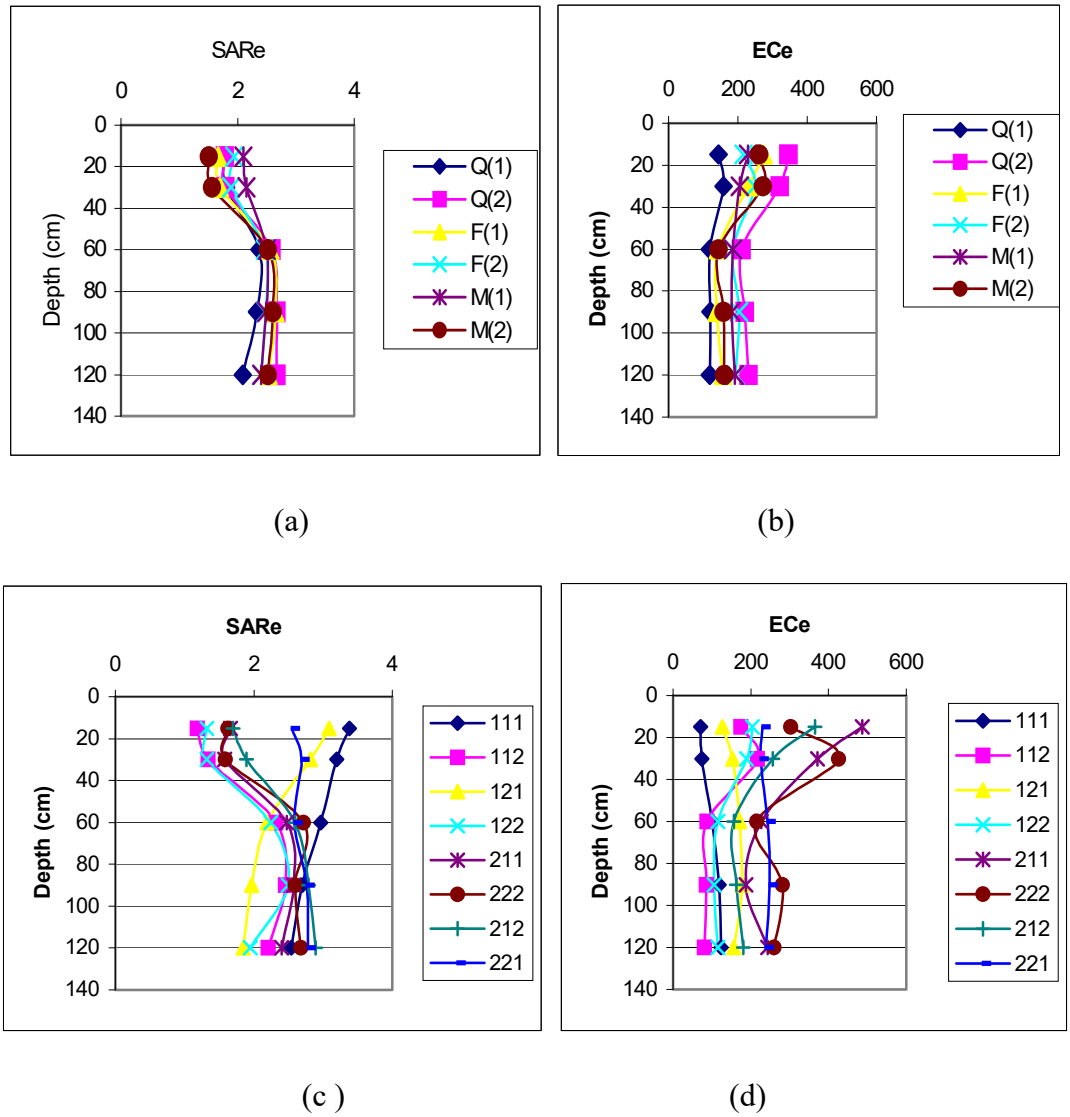


Figure 2.15. SAR_e and EC_e (mSm^{-1}) factor means (a and b) and treatment means (c and d) for soils sampled in April 1994 on the Robertson pilot trial.

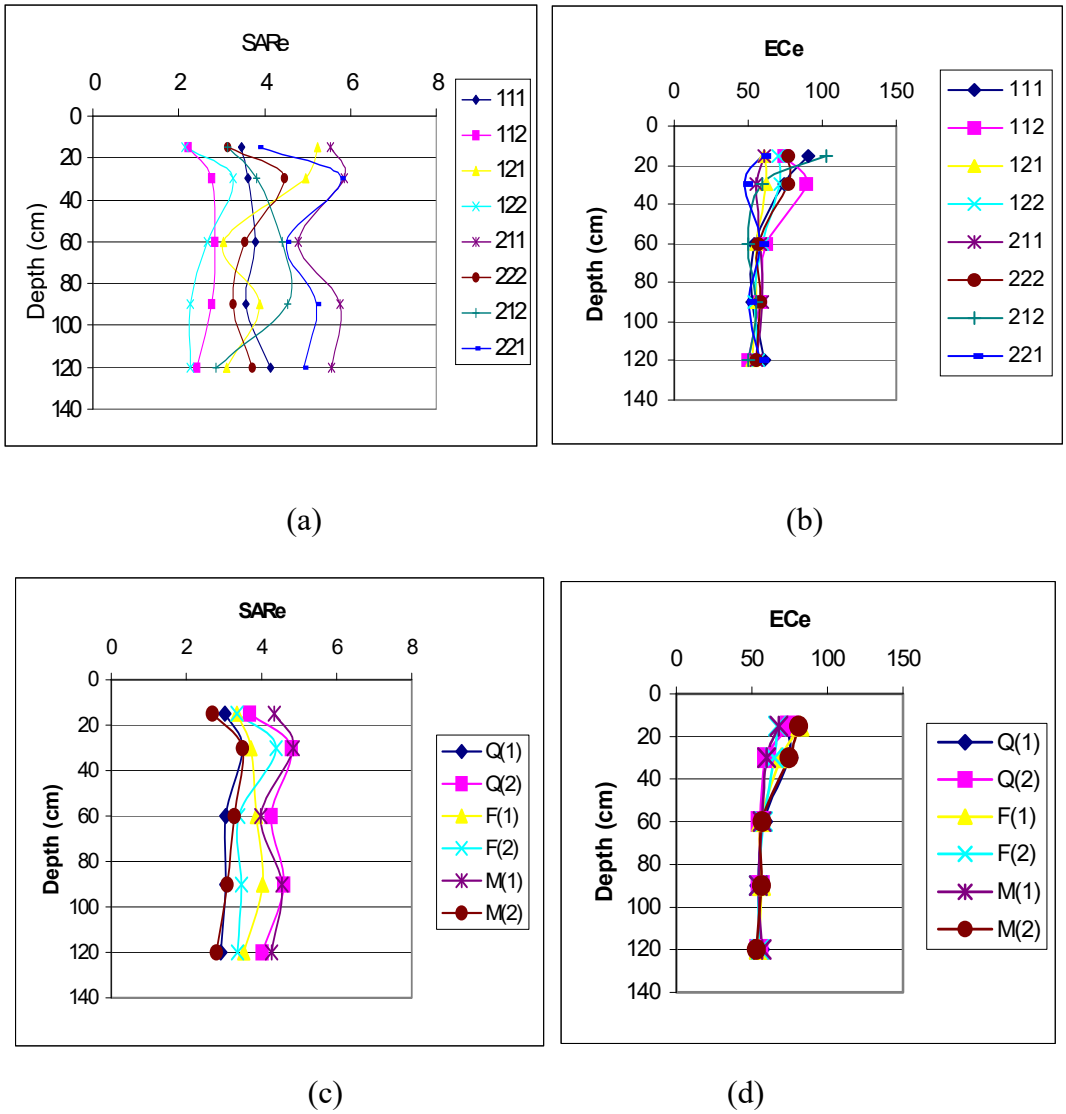


Figure 2.16. SAR_e and EC_e (mSm^{-1}) factor means (a and b) and treatment means (c and d) for soils sampled in September 1994 on the Robertson pilot trial.

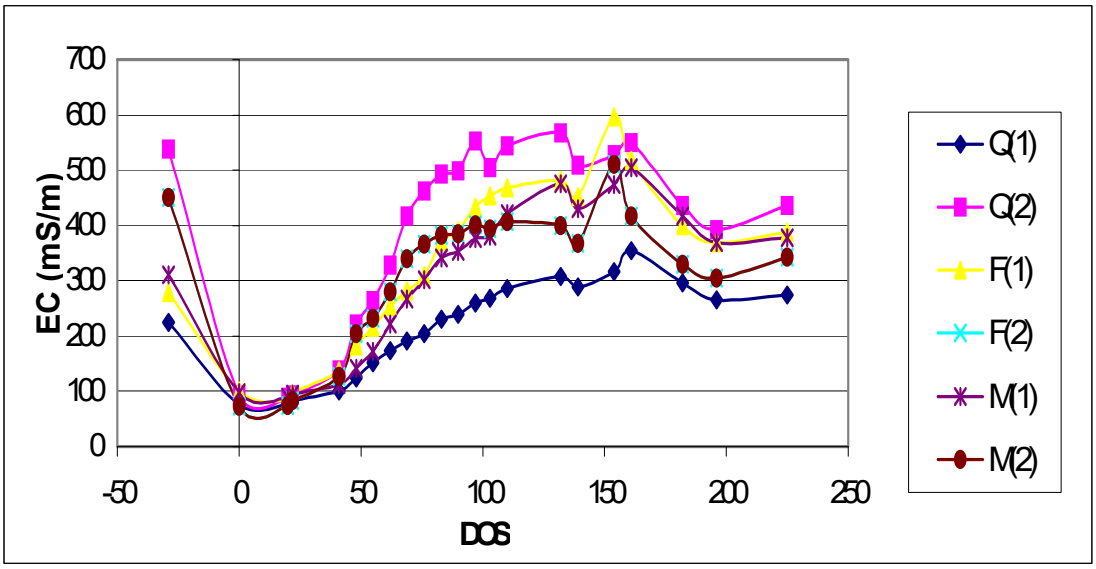


Figure 2.17. EC_{sw} (measured with suction cup lysimeters) in relation to treatments in the Robertson pilot study during the 1994/95 season (DOS = day of season commencing 1 September). Average values for the 5 sampling depths are presented.

2.4.3 Grape yield and salinity of the must

2.4.3.1 Yield

Chenin Blanc ripens earlier than Colombar and was harvested in both seasons during February whereas the Colombar section of the vineyard was harvested in March. In all cases the vines were harvested individually and the results were transformed to an average per site or per vine per site. The treatment means, factor means and the cultivar effect are shown in Tables 2.07 and 2.08. The same data are presented graphically in Figure 2.18 (a and b). There was a large difference in yield between Chenin Blanc (9.82 kg/vine) and Colombar (3.13 kg/vine; Table 2.07). This is a natural difference between cultivars and not a treatment effect. Treatment effects were not easily explained. The highest yield, 7.63 kg/vine, was obtained with treatment 121 (low frequency, subsurface drippers delivering 150 mS m^{-1} water; Table 2.08). A low frequency surface irrigation with saline water such as 211 might have been expected to produce the lowest yield but this was not the case. The lowest yield was in response to treatment 111.

c) The sequence of yield values in each factor is given here:

i) Frequency: low (6.8) > high (6.1);

ii) Method: subsurface (6.7) > surface (6.2);

iii) Salinity level: 150 (6.50) > 350 (6.45)

These differences are small and statistically non-significant.

At least three seasons with exactly the same treatment application would probably be needed to properly evaluate the differential effects caused by these factors.

Table 2.07 The effect of different saline irrigation treatment combinations on yield of Chenin Blanc and Colombar grapes for the harvest year 1994, expressed as treatment means.

Treatment	Yield (kg/vine)		
	Chenin Blanc	Colombar	Mean
111	7.6	1.9	4.8
112	11.2	3.4	7.3
121	10.8	4.5	7.6
122	8.9	3.8	6.3
211	10.1	1.4	5.8
212	10.8	2.7	6.8
221	9.8	3.7	6.8
222	9.5	3.6	6.5
Mean	9.8	3.1	6.5

Table 2.08 Effect of saline irrigation management on yield of Chenin Blanc and Colombar grapes for the yield year 1994, expressed as factor means.

		Yield (kg/vine)		
Factor	Description	Chenin Blanc	Colombar	Mean
Frequency	low	9.7	3.9	6.8
	high	9.9	2.4	6.1
Method	surface	9.6	2.9	6.2
	subsurface	10.1	3.4	6.7
Salinity level	150	9.6	3.4	6.5
	350	10.0	2.9	6.5

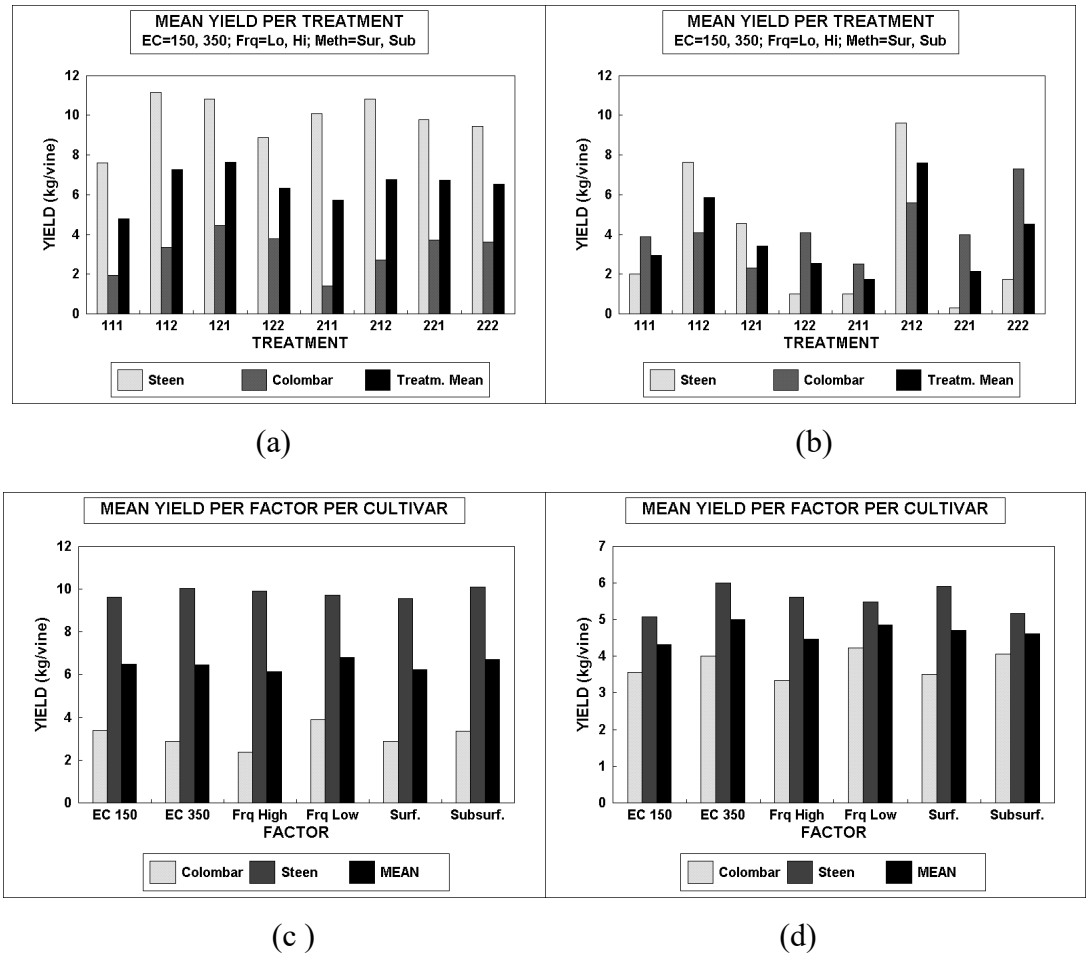
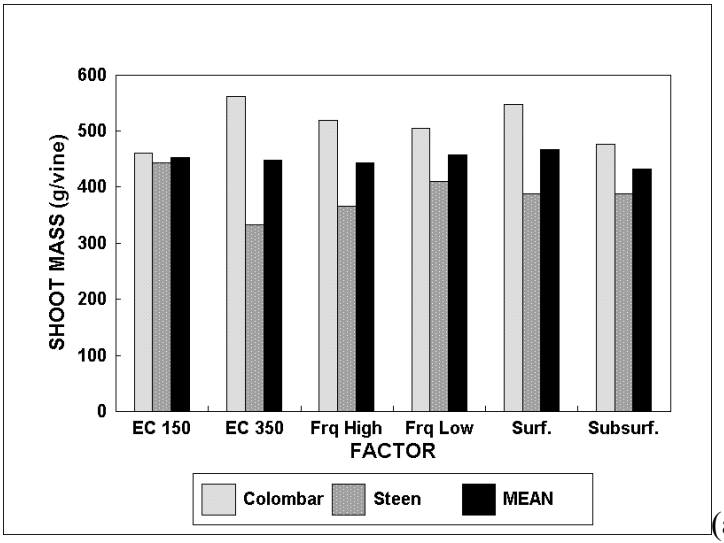
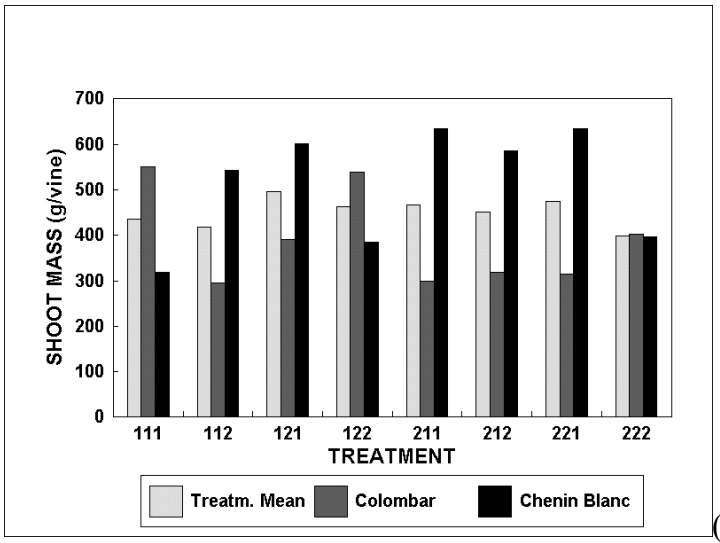


Figure 2.18. Graphical presentation of the data in Tables 2.07 (a and b) and 2.08 (c and d).

The pruned shoot mass (Figure 19) gives an indication of vigor and of the amount of woody material produced during the season. Shoot mass is invariably reduced by an increase in the salinity of irrigation water. Figure 2.19(b) shows the marked differences in shoot mass between treatments and cultivars. Treatment 212 had the highest shoot mass while treatment 211 had the lowest. The mean in Figure 2.19 (a) shows almost no difference between the effects of individual factors. Only salinity produced a noteworthy effect with EC 150 mS m^{-1} producing the highest mass and EC 350 mS m^{-1} the lowest.



(a)



(b)

Figure 2.19. Effect of saline irrigation management on pruned shoot mass of Chenin Blanc (Steen) and Colombar vines, expressed as factor means (a) and treatment means (b) in the Robertson pilot study (measured after harvest in 1995).

2.4.3.2 Leaf area index (LAI)

The leaf area index values are an indication of the size and density of the vine canopies. Table 2.09 shows that surface irrigation in the Chenin Blanc block produced the largest LAI value.

Table 2.09 Leaf area index (LAI) in relation to treatments in the Robertson pilot study measured in February 1995.

Cultivar	Water quality		Frequency		Method	
	Q1	Q2	Low	High	Surface	Sub-surface
Colombar	1.14	1.03	1.10	1.08	1.10	1.07
Chenin Blanc	1.12	1.29	1.16	1.24	1.33	1.07

2.4.3.3 Composition of the must with special reference to chloride content

The must of a representative number of bunches from each site was analysed for sugar, acid, pH and Cl content. The sugar content was determined with a refractometer (ºB), and acid and chloride with a Titrino automatic endpoint titrator. The results of the sugar and acid content showed no meaningful treatment effect but are presented in Tables 2.10 and 2.11. The data for the sunsequent season showed the same trend and therefore not shown. The chloride concentration of the must is shown in Figure 2.20.

Table 2.10 Effect of saline irrigation management on the sugar and acid content of Chenin Blanc and Colombar grapes for the yield year 1994, expressed as treatment means.

Treatment	Chenin Blanc	Colombar	Mean
	Acid content (g/L)		
111	8.5	8.4	8.5
112	7.5	10.0	8.8
121	8.2	8.8	8.5
122	8.7	8.1	8.4
211	9.0	7.6	8.3
212	8.6	8.0	8.3
221	7.0	7.3	7.2
222	8.4	8.6	8.5
	Sugar content (ºBalling)		
111	20.2	20.0	20.1
112	22.4	19.6	21.0
121	20.7	19.6	20.2
122	21.3	19.6	20.5
211	21.7	20.0	20.9
212	20.5	19.2	19.9
221	22.6	20.4	21.5
222	21.4	20.0	20.7

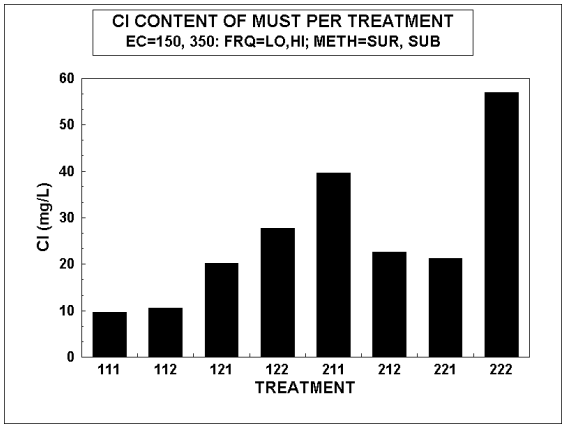
Table 2.11 Effect of saline irrigation management on the sugar and acid content of Chenin Blanc and Colombar grapes for the yield year 1994, expressed as factor means.

Factor	Description	Chenin Blanc	Colombar	Mean
		Acid content (g/L)		
Frequency	low	8.4	8.5	8.5
	High	8.1	8.2	8.1
Method	above	8.2	8.0	8.1
	subsurface	8.3	8.8	8.5
Salinity	150	8.3	8.8	8.5
	350	8.3	7.9	8.1
Mean		8.3	8.4	8.3
		Sugar (°Balling)		
Frequency	low	21.2	19.7	20.5
	High	21.5	19.9	20.7
Method	Above	21.3	20.0	20.7
	Subsurface	21.4	19.6	20.5
Salinity	150	21.2	19.7	20.4
	350	21.6	19.9	20.7
Mean		21.4	19.8	20.6

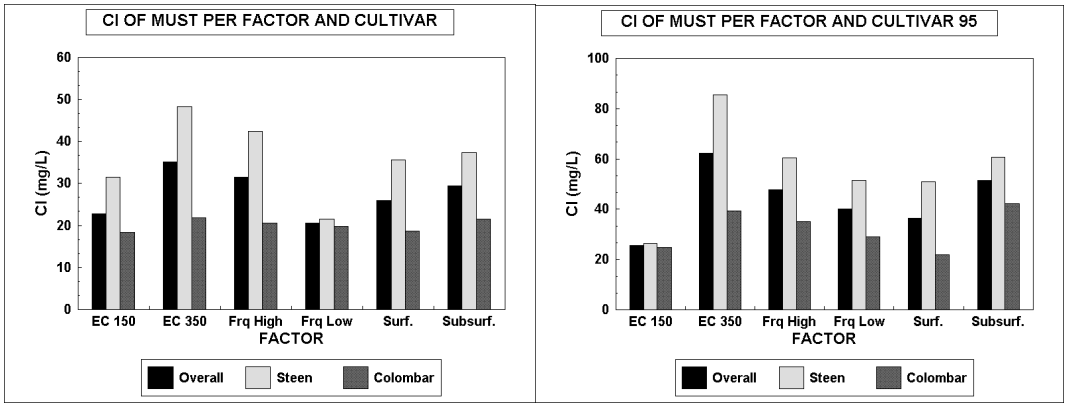
In all treatment combinations irrigated with 350 mS m^{-1} water, the chloride content of the must appeared to be higher (Figure 2.20a). The highest concentration of chloride was, in both years, found in treatment 222 and the lowest in treatment 111. The individual factor differences can be summarised as follows:

Frequency:	high (31.5 mg/L)	> low (20.7 mg/L)
Method:	sub-surface (29.5 mg/L)	> surface (26.0 mg/L)
Salinity:	350 (35.1 mg/L)	> 150 (22.7 mg/L)

These differences are probably not significant and the data were not subjected to statistical analysis. The pH of the must did not reveal much other than to underline the distinct difference between the two cultivars. This result is shown in Figure 2.21.



a)



(b) (c)

Figure 2.20. Effect of saline irrigation management on chloride content of the must of Chenin Blanc (Steen) and Colombar vines, expressed as (a) treatment means (a) and (b) factor means in the years 1994 and 1995, respectively, in the Robertson pilot study.

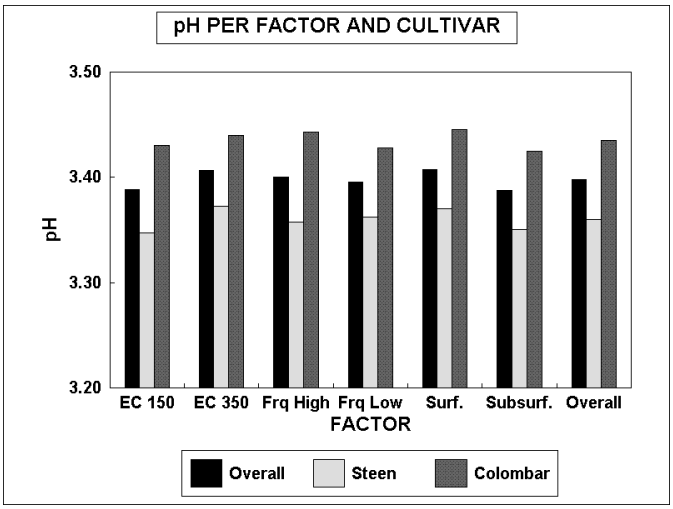


Figure 2.21. pH of the must from 1995 grapes in relation to treatment and cultivar in the Robertson pilot study.

2.4.4 Assessment of the first phase of the pilot study

Certain problems hampered the success of the experiment from the outset. The main obstacle was the remote location of the site with all diagnoses of the system and monitoring of irrigation operations having to be done by telephone.

Another serious problem was the corrosiveness of the stock solution. On numerous occasions the system failed as a result of control valves or electrical contacts corroding in spite of the fact that only stainless steel and brass equipment was installed. All electrical equipment made use of a common solid 1.5 cm diameter brass rod as earth. This had to be replaced every second year as a result of corrosion.

The automation presented difficulties in the calculation of the water deficit for high and low frequency irrigation. The effect on plant response was probably small relative to the effect of varying salinity but the effect on soil management aspects would have been more serious. The calculation of evapotranspiration was also faulty. The problem originated in the calculation of ET on a 15- or 60-minute basis for high and low frequencies of irrigation, respectively. This was corrected by adapting the equation for calculating the 15-minute based program.

A further pitfall was the use of a soil water monitoring system based on capacitance. Capacitance methods are of limited use in highly saline soils. For lack of another method we had to rely solely on the use of the neutron probe. Instead of measuring once per week, a program of twice per week was followed. To further aid the recording of soil water dynamics another set of neutron access tubes was installed. The first was installed 0.25 m away from the dripper line and the second, 0.5 m away. This provided some indication of the magnitude of the wetted soil volume and how it changed with time.

The depth at which the subsurface dripper lines were buried created some concern at the beginning of the experiment in that water rose to the soil surface. This effect gradually diminished suggesting that it may have resulted from compaction of the soil in the furrow accommodating the sub-surface dripper lines, and/or the fact that over-irrigation was applied initially. Bioturbation was thought to have occurred since after the second season standing water was no longer observed.

The treatments led to differences in soil salinity as well as differences in the depth distribution of salts and sodicity. The factor that had the largest effect was the salinity of the irrigation water. This also produced the largest differences in yield and quality of the must. The differences induced by application method (surface or subsurface) and by frequency of application were much smaller.

The soil response to treatments was best described by the EC of the saturated paste extract or the EC of suction cup samples together with SAR values from both. High irrigation volumes led to lower SAR values in spite of high EC values. During winter, when full surface wetting prevailed as a result of rain, the SAR values within the irrigation wetted zone rose. This gave the impression that fresh water, as was applied during winter, did not have the capacity to affect SAR significantly. Some kind of sodicity lay-by effect was hypothesised to explain this anomaly whereby differential movement of sodium into drier, more saline soil away from the drippers in summer is followed by its return into the monitored leached zone during whole field wetting in winter.

It was shown that the water content near the perimeter of the wetted zone (monitored 0.5 m away from the dripper line) declined steadily during the 1994-95 season. It was only at the harvest stage that the wetted zone 0.25 m away from the dripper line began to decline. This suggests that, for the bulk of the growing season, irrigation water was applied in excess of requirements and leaching of salts took place.

2.5 METHODS AND RESULTS FOR THE SECOND PHASE OF THE PILOT STUDY (1995-1998)

2.5.1 Introduction

As a reminder to the reader, this follow-up to the pilot study made use of the same trial site and irrigation system but with four important modifications:

1 The irrigation applications were controlled manually.

2 Frequency was dropped as a factor.

3 The division between systems was made on the basis of irrigation method (surface and sub-surface).

4 The 150 and 350 mS m^{-1} salinity levels were replaced either by a sequence of fresh (canal) water followed by 150 mS m^{-1} water or by the reverse sequence, with changeover being effected at the veraison stage in the vineyard.

2.5.2 Soil water status

2.5.2.1 Methods

Irrigation scheduling and water quantities of the drip irrigated pilot study, were based on the previous day's calculated evapotranspiration. Evapotranspiration was derived from climatic data registered by an automated weather station located next to the vineyard at Robertson. The Penman-Monteith equation was solved using an algorithm prepared by Prof. J. De Jager (Appendix D). The idea was to replenish the soil water deficit with an amount equal to the previous day's evapotranspiration (ET). This meant that small amounts of water were applied per irrigation, but at a high frequency. Unlike in previous years when the irrigation was supposed to have been activated and monitored automatically by an on-site computer, irrigation was controlled manually during the second phase. Each morning the weather station and on-site computer were interrogated by telephone line. The ET was calculated and the computer programmed to apply the necessary amount of irrigation water. The amount of irrigation applied at any given time was limited to 4 mm (per 3 m^2 soil surface). It was then possible to irrigate twice and even three times per day in extreme conditions. This aided infiltration and no ponding on the soil surface was subsequently found.

Irrigation water was sampled using the method described for the main study (Chapter 3). The Ca/Na ratio was the same as that employed throughout the study at both Stellenbosch and Robertson.

2.5.2.2 Irrigation quantities

Although the main study and the pilot study received comparable amounts of irrigation water during each season, the amount of water applied to the two sections of the pilot study differed over the 3 years of the study. In the pilot study 372 mm water use was recorded during the first season (Table 2.12). The reason for this significantly

smaller amount than that of the main experiment (see Chapter 3) was mainly due to faulty logging of data on the system and a problem with the water meters. A considerable amount of data loss (electronic failures, lightning, etc.) was experienced and for those days we had to interpolate evapotranspiration from previous records for the 1995/96 season. The data loggers also failed at times, with the result that data recorded (such as irrigation quantities applied during any particular period) could not be extracted. This system had one major problem in that anything that caused the computer to malfunction resulted in data loss, as open files on the computer were not backed up regularly enough. The irrigation and reference evaporation data shown in Table 2.12(a) should therefore be treated as underestimates rather than overestimates of the actual quantities.

From the 1996/97 season onwards, two weather stations were kept active resulting in a full climatic record. We did, however, lose bits of the drip irrigation record because of power failures, which are quite common on farms in this region. This was countered by programming the system to store data daily. The irrigation approach with respect to crop factors was altered. During 1995/96 a constant crop factor of 0.6 (for the surface and subsurface drip-systems) was maintained and an efficiency coefficient of 100% was used. This implied that the frequency of irrigation was changed to accommodate the water deficit.

For the 1996/97 and 1997/98 seasons the crop factors were switched to the published crop factors for the farm. Crop factors were changed during the season when so dictated by neutron probe readings and not strictly on a monthly basis. It was also decided to lessen the subsurface crop factor by one-third the amount of the surface irrigation. This was done in order to compensate for the small amount of evaporation from the soil surface where the sub-surface system was involved. This value was derived from the fact that the subsurface irrigation system did not use the 20 cm of soil above the irrigation pipe. This meant that instead of using mm/1.05 m, we used mm/0.85 m, which meant a reduction of 19 % in storage capacity. This implied in turn that the irrigation amount for the sub-surface system had to be 19 % less than the surface irrigation otherwise an equivalent amount would either have been lost through drainage or produced ponding on the soil surface. From the water use figures in this study (neutron probe readings), a difference of 14 % in the rate of water use was

calculated between the two systems. It was therefore decided to lessen the sub-surface irrigation amount by an amount equal to the sum of these two values. The rate of 14 % difference in water use was calculated from the end of summer data, when saline irrigation was terminated and the soil began to dry out.

The difference in wetted soil volume between surface and sub-surface drip cannot be inclusive of the rate of change in soil water content during a drying cycle. In fact, had the soil volumes been the same, the rate of change in soil water content between the two systems would have been larger. The rate of change in percent and the difference in soil volume in percent amounted to a combined figure of 33%, and the water supply to the sub-surface plots was consequently reduced by this amount. This was implemented in practice by applying a crop factor for the sub-surface drip treatments that was 67 % of the crop factor used for the surface drip system.

Table 2.12 Monthly irrigation statistics for the pilot study at Robertson, and Penman-Monteith reference evaporation on which the irrigation was based for the period November to April for seasons (a) 1995/96 and (b) 1996/97 and 1997/98.

(a)

Month	ETo (Recon-structed)	Mean ETo	I	I	I (application mean)	Rain
	(mm)	(mm/d)	(mm)	No/month	(mm)	(mm/ month)
Sept '95	ND	ND	ND	ND	ND	3
Oct '95	ND	ND	ND	ND	ND	32
Nov '95	233	8	159	17	9	33
Dec. '95	131	4	33	5	7	45
Jan. '96	113	4	54	16	3	9
Feb. '96	175	6	54	20	3	21
March '96	148	5	35	9	4	18
April '96	76	3	37	15	2	9
TOTAL	876		372	82		178
AVG/day	4.87		2.1			1

(b)

Month	ET0 (recorded)	ET0	I (recorded)		I (application mean)		Rain	
	(mm)	(mm/d)	H (mm)	L	H (mm)	L	(mm/ month)	
Sept '96	189	6	0	0	2	1	13	(4)
Oct '96	232	7	0	0	1	2	61	(4)
Nov '96	205	7	33	22	1	1	54	
Dec '96	294	9	143	163	4	3	13	
Jan '97	345	11	257	177	4	3	3	
Feb '97	292	10	59	139	6	5	2	(1)
Mar '97	273	9	57	5	4	3	21	(2)
Apr '97	190	6	31	82	2	2	25	(3)
TOTAL	2020		579	634			190	
AVG/ day	8.4		3	3.7			1	
Sept '97	183	6	139	140	10	10.0	18	
Oct '97	183	6	64	57	9	6	4	
Nov '97	225	8	174	176	10	10	34	
Dec '97	233	8	193	137	10	6	5	
Jan '98	238	8	111	73	10	7	39	
Feb '98	290	10	48	34	10	7	3	(1)
Mar '98	219	7	50	34	10	7	21	(2)
Apr '98	165	6	0	0				(3)
TOTAL	1744		777	651			125	
AVG/ day	7.2		3.7	3.1			0.5	

H = Surface and L = Sub surface irrigation. (1) = Stopped irrigation so that the Southern block could reach the correct sugar content to be harvested. (2) = Stopped irrigation for harvesting. (3) = Large post-harvest irrigation is included in these values. (4) = The fresh water canal was cut off for routine maintenance to the canal.

2.5.2.3 Electrical conductivity of irrigation water

The volume-weighted, seasonal mean salinity of the irrigation water for the different treatments used in 1995/96, 96/97 and 97/98 is shown in Table 2.13.

2.5.2.4 Soil water content

The differences in the seasonal mean soil water content between all treatments were small (Table 2.14; Figure 2.22). A special effort was again made to study the water distribution away from the emitters. Neutron access tubes 10 and 25 cm from the emitter were used for this purpose. The difference between wettest and driest measurements at these two distances was 19 and 24 mm/m, respectively.

These results suggested that the drip irrigated pilot study produced wetter soil conditions close to and below the emitter than prevailed anywhere in the main study. It was only the measurements made close to the emitter that were wetter than those of the main study. Measurements made at a distance 250 mm from a dripper are about 31 mm/m drier than those made at the emitter. Most neutron probe readings in the Robertson main experiment were made before an irrigation event and at least one week after the last irrigation. In the pilot study, by contrast, irrigation was applied daily and excessive wetness close to the drippers with a concomitant influence on root distribution could be expected to have prevailed.

The soil water content for the pilot study during seasons 1996/97 and 1997/98 is given in Figure 2.22. The irrigation season had a slow start at the beginning of the 1996/97 season as a result of maintenance work being done on the canal. However, for the bulk of the season the soil water content was kept between 260 and 350 mm/1.05m while in 1997/98 the soil water content was managed between 260 an 310 mm/1.05m. Of particular interest is how the water content differs between surface and sub-surface applications during the season (Figure 2.22), bearing in mind that the sub-surface irrigation plots received 33% less water. It must also be remembered that the neutron probe readings were done between two daily irrigation events when the soil water deficit would have been equivalent to somewhere between one and three days' deficit.

Table 2.13 Volume weighted seasonal mean electrical conductivities of the irrigation water for the pilot study at Robertson, summarized in terms of targets and actual means per treatment *(volume weighted data where enough data available*)

Treatment number*	Target EC_i (mSm^{-1})	Weighted mean EC_i (mSm^{-1}) 95/96	96/97	97/98
LS1	**25-35: Full bloom to veraison;**	56	53	NA
	150: veraison to harvest	228	NA	224
LS2	**25-35: Full bloom to veraison;**	57	90	NA
	150: veraison to harvest	220	NA	196
SL1	**150: Full bloom to veraison;**	172	146	NA
	25-35: veraison to harvest	38	NA	33
SL2	**150: Full bloom to veraison**	191	198	NA
	; 25-35: veraison to harvest	44	NA	25

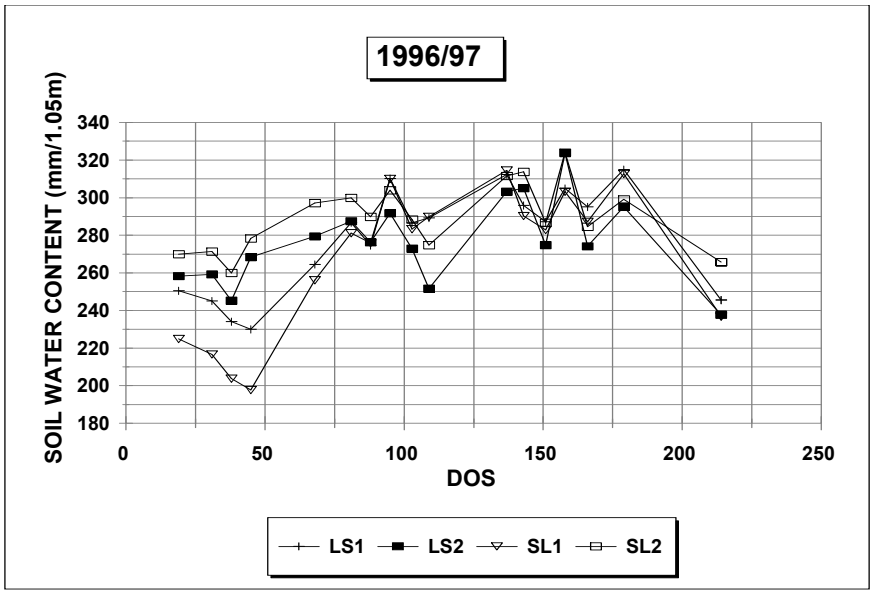
NA = Not available

* See section 2.3.2 for explanation of treatments

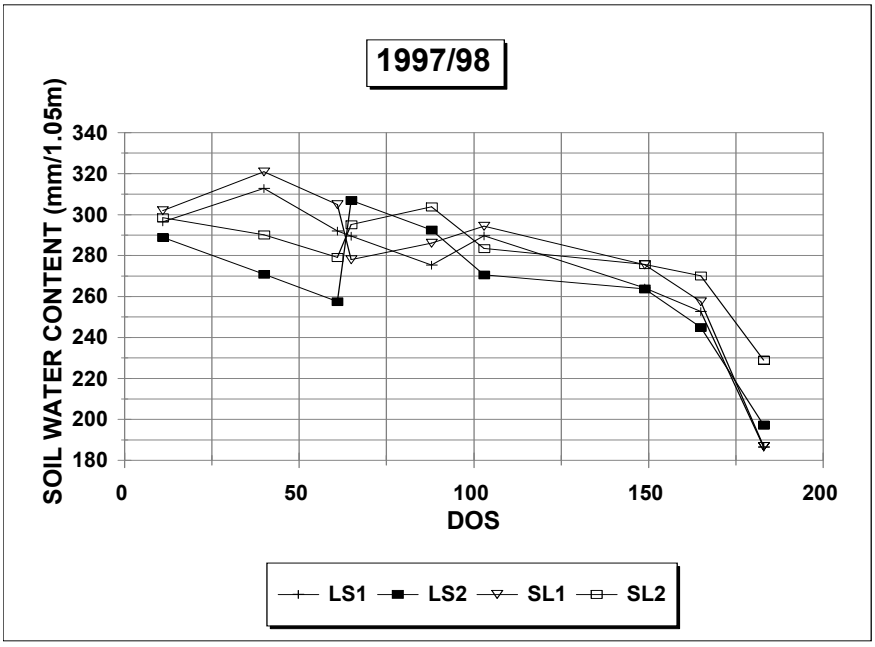
Table 2.14 Seasonal mean and standard deviation of soil water content (in mm/1.05m) from September 1995 to April 1996 in the pilot study at Robertson. Measurements were made 100 mm and 250 mm away from dripper lines.

Treatment number	D=100 mm (n=23)		D=250 mm (n=15)	
	Mean	Std. Dev.	Mean	Std. Dev.
LS1	287	20	244	12
LS2	268	17	235	9
SL1	281	21	253	16
SL2	279	14	259	5

D=distance of measuring point from emitter; n=number of days on which measurements were made.



(a)



(b)

Figure 2.22. Soil water content during (a) the 1996/97 season and (b) the 1997/98 season as a function of surface- or subsurface water application and sequence of saline and fresh water treatments.

2.5.3 Soil salinity and sodicity

2.5.3.1 Methods

EC_e was determined by taking soil samples on each plot at the end of winter (end of August) and again at the end of the irrigation season (end of April in the following year). Samples were always taken at the midpoint between two vines of the experimental row at depths of 15, 30, 60, 90 and 120 cm.

Soil samples were allowed to air-dry and were then ground and passed through a two-mm screen. Samples of 200 g were placed on a sand bed with constant water head and allowed to saturate for 15 hours. The solutions from these saturated pastes were extracted, and the following parameters determined: EC_e, pH, Ca, Na, Mg, K, Cl, NO_3, SO_4 and SAR.

During the irrigation season soil water samples (EC_{sw}) were taken with the aid of an elaborate suction system connected to 280 suction cup lysimeters placed in the field. Each plot had five, covering the 5 depths that were normally monitored for soil water content (15, 30, 60, 90 and 120 cm depth). Suction was always applied in 5 two-hour pulses irrespective of when irrigation had ceased. At least 5 sets per season were acquired and for practical reasons not all sets were fully analysed.

In almost all literature on plant response to salinity, response is best correlated with the weighted mean EC_{sw} over the season. Therefore, weighted means are also shown in this section where applicable. Weighted means of the EC_e were also calculated and correlated with yield. The latter provided a better basis for comparison between years and between experiments.

2.5.3.2 EC_e and SAR_e

Inspection of the treatment mean electrical conductivities (EC_e) showed the following trends (Table 2.15 and 2.16):

a) Subsurface applied water (S2) treatments resulted in more saline conditions at all depths < 300 mm, compared to surface applied water (S1) treatments.

b) The application of saline water early in the season, followed by non-saline water later (SL), resulted in less saline conditions in April of the following

year, compared to the LS sequence. The reason for this is the fact that leaching of the salt applied early in the season, can (and does) take place from January (veraison) to harvest (April).

c) Comparison of the EC_e data of the pilot study, specifically the LS1 and SL1 treatments with treatment 3 of the main study (also irrigated with EC_i = 150 mSm^{-1}), showed that in this study, drip irrigation resulted in more saline conditions than did micro-sprinkler irrigation (Chapter 3, Table 3.04). A possible explanation is that the leaching of salt during winter is less effective with drip than with micro irrigation systems. This was even more pronounced during the final season. The answer may lie in the effect winter rain has on the soil. Due to rainfall that wets the entire surface, salt is redistributed in the soil toward the root zone, in other words from the non-irrigated soil volume to the more leached drip zone.

d) The difference in length of growing season of the two grape cultivars may have some bearing on the different values shown in Tables 2.15 and 2.16. These values are correlated later with reproductive growth.

Table 2.15 Change in EC_e (mSm^{-1}) with depth and treatment of the drip irrigated Robertson pilot study Colombar section from March, 1995 to March, 1998. ***(Treatment numbers: LS = first fresh water then saline water and SL = first saline water and then fresh water. 1 and 2 = surface and sub-surface drip irrigation).***

TREATMENT	DEPTH	1995/3	1995/9	1996/3	1996/9	1997/3	1997/9	1998/3
LS1	**15**	231	96	161	62	58	78	190
LS1	**30**	288	95	93	95	51	72	186
LS1	**60**	183	102	105	76	48	51	98
LS1	**90**	183	86	101	89	53	50	72
LS1	**120**	217	103	127	154	53	57	69
	Mean	**221**	**96**	**118**	**95**	**52**	**61**	**123**
LS2	**15**	211	101	301	130	247	101	114
LS2	**30**	201	126	138	146	149	88	133
LS2	**60**	128	123	131	141	97	48	58
LS2	**90**	124	84	121	94	60	43	60
LS2	**120**	185	59	122	101	51	42	68
	Mean	**170**	**99**	**163**	**122**	**121**	**64**	**87**
SL1	**15**	332	130	140	87	82	66	124
SL1	**30**	292	166	76	109	96	69	143
SL1	**60**	235	146	81	62	113	60	130
SL1	**90**	231	130	88	50	91	58	119
SL1	**120**	234	86	112	51	97	58	93
	Mean	**265**	**132**	**99**	**72**	**96**	**62**	**122**
SL2	**15**	153	172	301	116	213	81	84
SL2	**30**	183	196	133	127	175	63	106
SL2	**60**	192	122	74	102	150	49	121
SL2	**90**	125	86	56	57	144	52	113
SL2	**120**	129	84	48	55	162	44	87
	Mean	**157**	**132**	**122**	**91**	**169**	**58**	**102**

Table 2.16 Changes in EC_e (mSm^{-1}) with depth and treatment of the drip irrigated Robertson pilot study Chenin Blanc section from March, 1995 to March, 1998. ***(Treatment numbers: LS = first fresh water then saline water and SL = first saline water and then fresh water. 1 and 2 = surface and sub-surface drip irrigation).***

TREATMENT	DEPTH	1995/3	1995/9	1996/3	1996/9	1997/3	1997/9	1998/3
LS1	**15**	281	53	424	60	58	59	91
LS1	**30**	175	47	226	70	56	66	111
LS1	**60**	148	58	179	63	59	57	64
LS1	**90**	181	58	137	63	52	62	79
LS1	**120**	195	57	188	68	50	60	114
	Mean	**196**	**54**	**231**	**65**	**55**	**61**	**92**
LS2	**15**	184	109	389	73	308	91	58
LS2	**30**	201	113	249	81	212	97	73
LS2	**60**	179	63	168	85	130	80	53
LS2	**90**	153	52	149	77	81	60	62
LS2	**120**	160	67	273	67	83	54	128
	Mean	**175**	**81**	**246**	**76**	**163**	**76**	**75**
SL1	**15**	184	49	74	85	64	61	223
SL1	**30**	167	46	64	80	72	63	295
SL1	**60**	162	47	57	52	84	55	127
SL1	**90**	194	54	48	54	87	54	141
SL1	**120**	246	58	54	53	90	52	210
	Mean	**190**	**51**	**59**	**65**	**79**	**57**	**199**
SL2	**15**	263	117	228	65	210	88	108
SL2	**30**	351	104	92	69	170	100	167
SL2	**60**	228	72	42	51	166	62	114
SL2	**90**	148	70	43	52	131	48	115
SL2	**120**	134	87	81	44	125	42	99
	Mean	**225**	**90**	**97**	**56**	**160**	**68**	**120**

2.5.3.3 EC_{sw}

In the pilot study EC_{sw} was determined using suction cup lysimeters. As a result of the change in water quality at the veraison period, samples were taken at the start of the season, at veraison and after harvest. These results are presented in Figure 2.24. It is clear that with both surface and sub-surface irrigation the EC_{sw} changed rapidly within the season from a low salinity level to a high salinity level and back again. This is a very important finding in that the soil responded more rapidly here than was expected on the basis of results obtained in the micro irrigated vineyard (Chapter 3). This is conceivably due to the smaller soil volume relative to the amount of water applied in the drip-irrigated system.

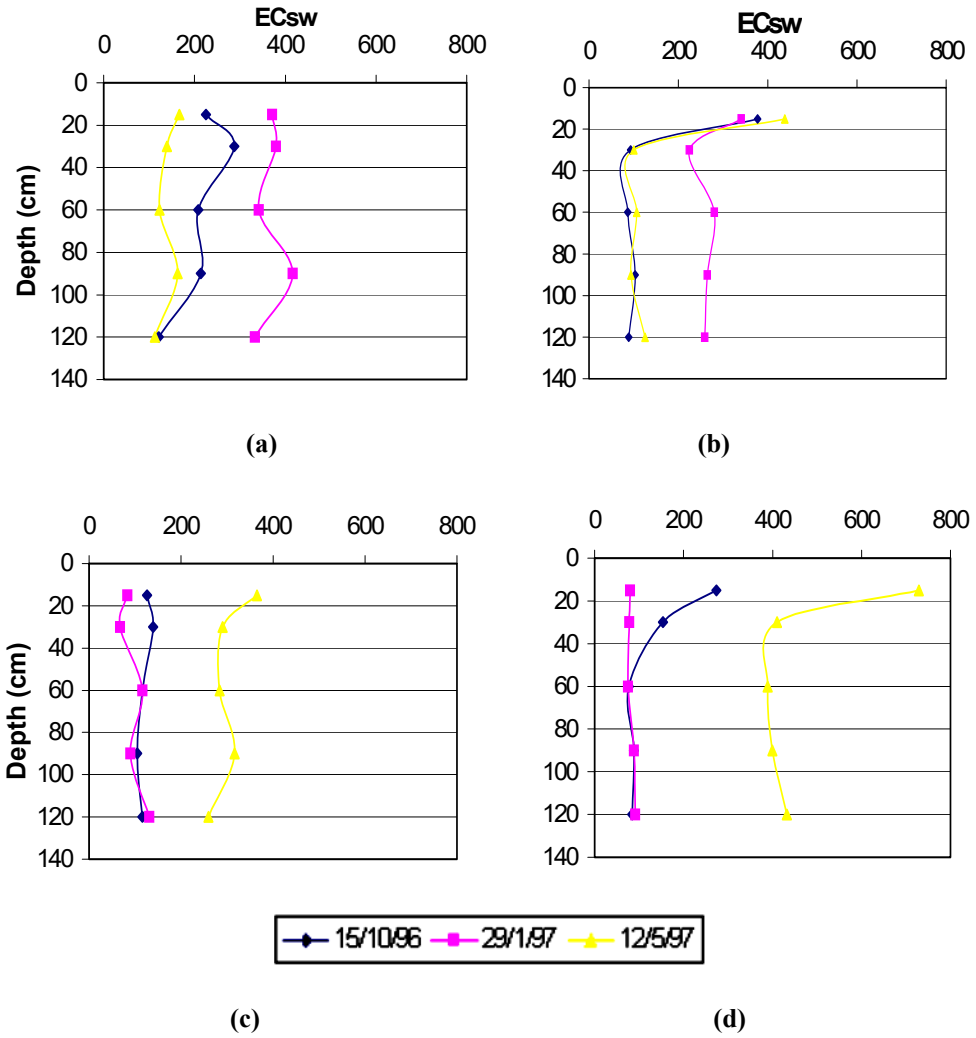


Figure 2.23. EC_{sw} (acquired through suction cup lysimeters) of (a) SL1, (b) SL2, (c) LS1 and (d) LS2 in the Robertson pilot study (treatment means) for three dates 15/10/96 (start of the season), 29/1/97 (at veraison corresponding with the changeover of irrigation salinity) and 12/5/97 (end of the season).

Also noteworthy is the fact that the EC_{sw} was higher when the season ended with saline water than the EC_{sw} before veraison. This is due to the fact that a higher soil water status was maintained before veraison than after veraison. Before veraison a part of the salt load would have been leached whereas after veraison more salts would have accumulated as a result of reduced water application, greater evapotranspiration and therefore little or no leaching. SAR_{sw} in this case was not determined (the water samples were not fully analysed).

2.5.4 Plant growth and yield

2.5.4.1 Method

Shoots were sampled for all three experiments at the five main development stages during the season. Shoot lengths were firstly measured and the shoots were then separated so that the dry and wet mass of the shoot, petioles and leaves could be determined. It was found that the data collected at harvest were sufficient to express the effect of all irrigation treatments that were applied during the season.

2.5.4.2 Effect of saline water at different growth stages on yield components

2.5.4.2.1 Leaves and petioles

Tables 2.18 and 2.19 present the leaf and petiole fresh and dry mass ratios taken during the last season of the project. The variation over time (rows) is a result of the movement of reserves to and from the leaves. The variation across treatments (columns) is due to differences in plant response toward saline irrigation.

Saline irrigation in the pilot study commenced later than usual in this season and therefore did not have an effect on the vines up until full bloom. The values at full bloom are indicative of a minimal carry-over effect from the previous season. The pilot study ended the season with a clear difference between saline and fresh water treatments, although not statistically significant. In the middle of the season, however, the pilot study did not show this distinction. This possibly resulted from the relatively higher soil water status that was maintained during the initial period.

2.5.4.2.2 Trunk circumference

Trunk circumference data were found to be of no real value. As a result of the overall degenerated state of the vineyard, trunk circumferences did not vary much over the last 3 seasons and the standard deviation of measurements between plants within a treatment was found to be larger than between treatments. The 1995/96 results were also used as a covariate in the statistical analyses of the yield components, but this did not produce a usable result. The standard deviation increased to such an extent that no treatment effect was apparent in the data.

2.5.4.2.3 Pruned shoot mass

Individual vine shoot mass was measured at the end of the season. This was done to establish the effect of saline irrigation on the woody part of the vines. The drip experiment show higher shoot masses under both surface and subsurface drip when the season is commenced with saline irrigation. In both subsurface treatments the masses are higher than those of surface treatments, with the highest value being that of SL2. This suggests that when saline water was replaced with fresh water after veraison, it allowed the plant to adjust and rectify the damage. The SL treatments had the advantage over the LS treatments in that the second half of the season plus winter irrigation aided leaching of the soil. This gave the SL treatments a more favourable start in the new season. This actually represents the reverse of the natural pattern of salinisation of the Breede River system during the summer. There is usually an abundance of fresher water at the start of the season and the salinity builds up toward the end of the season.

Table 2.17 Pruned shoot mass (g/vine) for the Robertson pilot study (treatment means) for the seasons 1995/96, 1996/97 and 1997/98.

Treatment	1995-96	1996-97	1996-98
LS1	423	454	361
LS2	461	459	364
SL1	487	565	417
SL2	485	595	405

Because of over-irrigation in the first half of the season when ET is low and the canopy is still small, the saline treatments would not affect the plants to any serious extent. It is in the second half of the season when ET is high, water consumption by the plant is high and irrigation is reduced to aid ripening of the fruit that saline water is likely to pose a problem. During the later part of the season a salt build-up is therefore inevitable. This implies that it would be better to irrigate with low quality water in the earlier part of the season.

Table 2.18 Leaf fresh and dry mass ratios (dry/fresh) in the Robertson pilot study, for the season 1997/98 (treatment means).

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
LS1	0.31	0.31	0.43	0.57	0.93
LS2	0.31	0.30	0.44	0.58	0.91
SL1	0.31	0.32	0.43	0.56	0.87
SL2	0.31	0.32	0.43	0.58	0.81

Table 2.19 Petiole fresh and dry mass ratios (dry/fresh) in the Robertson pilot study, for the season 1997/98 (treatment means).

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
LS1	0.15	0.17	0.31	0.39	0.74
LS2	0.14	0.17	0.30	0.35	0.69
SL1	0.16	0.21	0.30	0.34	0.81
SL2	0.13	0.16	0.27	0.36	0.79

2.5.4.3 Trends in reproductive growth and yield

The surveyed data at harvest time for all sites and treatments of the drip irrigated pilot study will be shown and discussed in this section. The results were divided into the Colombar and Chenin Blanc sections because of the different seasonal lengths of the two cultivars which gave rise to large differences in reproductive growth and yield measured at harvest. Tables 2.20 and 2.21 contain the shoot mass data. There was a decline in shoot mass in the Colombar whereas an increase was found in 1997 in the Chenin Blanc block and a decrease in 1998. Tables 2.22 and 2.23 give the mean number of bunches per vine. Tables 2.24 to 2.27 contain the yield data for the experiment. The yield of the Chenin Blanc section was almost twice that of the Colombar section. Both sections showed a yield increase from 1997 to 1998. The treatment means for the Colombar section showed the highest yields in response to both of the sub-surface irrigation treatments. The Chenin Blanc treatment means were greatest in the LS2 treatment and the lowest in the SL2 treatment. This is opposite to the trend shown by the Colombar results. A possible explanation lies in the different season lengths of the two cultivars.

Table 2.20 Mean shoot mass per vine of the Colombar section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	0.31	0.33	0.3	0.46	0.35
1997	0.28	0.32	0.29	0.45	0.34
1998	0.17	0.19	0.15	0.28	0.20
MEAN	0.25	0.28	0.25	0.40	

Table 2.21 Mean shoot mass per vine of the Chenin Blanc section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	0.54	0.64	0.62	0.49	0.57
1997	0.61	0.76	0.62	0.61	0.65
1998	0.50	0.59	0.50	0.52	0.53
AVG	0.55	0.66	0.58	0.54	

The large reduction in the number of bunches from 1996 to 1997 in both blocks can possibly be ascribed to management and not specifically treatment. This, however, had an effect on the yield data presented in Tables 2.24 to 2.27.

Table 2.22 Mean number of bunches per vine in the Colombar section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	49	51	46	52	50
1997	23	25	21	27	24
1998	25	26	23	28	26
MEAN	33	34	30	36	

Table 2.23 Mean number of bunches per vine in the Chenin Blanc section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	61	60	58	52	58
1997	31	30	32	27	30
1998	39	46	39	45	42
MEAN	44	46	43	41	

Table 2.24 Mean yield per vine (kg) in the Colombar section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	4.36	4.27	3.69	4.72	4.26
1997	1.26	2.00	1.80	1.62	1.67
1998	2.67	2.55	1.85	2.87	2.49
MEAN	2.76	2.94	2.45	3.07	

Table 2.25 Mean yield per vine (kg) in the Chenin Blanc section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				YEARLY AVERAGE
	LS1	LS2	SL1	SL2	
1996	9.37	10.26	9.93	8.15	9.43
1997	5.45	5.74	5.77	4.76	5.43
1998	7.39	8.11	7.42	7.62	7.64
AVG	7.40	8.04	7.71	6.84	

Table 2.26 Mean ratio (yield per bunch) in kg of the Colombar section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	0.088	0.085	0.080	0.092	0.086
1997	0.055	0.082	0.086	0.096	0.080
1998	0.087	0.097	0.080	0.099	0.091
MEAN	0.077	0.088	0.082	0.096	

Table 2.27 Mean ratio (yield per bunch) in kg of the Chenin Blanc section in the pilot study at Robertson for the 1996 to 1998 yield years in relation to treatment.

YEAR	TREATMENT				ANNUAL MEAN
	LS1	LS2	SL1	SL2	
1996	0.154	0.17	0.171	0.157	0.163
1997	0.173	0.19	0.182	0.174	0.180
1998	0.188	0.176	0.190	0.171	0.181
MEAN	0.172	0.179	0.181	0.167	

The results of the pilot study were separated because of the large differences between the two cultivars, Colombar and Chenin Blanc. It was not foreseen that the difference would be so substantial. Instead of 4 replicates of 4 treatments the experiment efeectively had two replicates of four treatments applied to two different cultivars on separate blocks. Not only were the degrees of freedom much fewer than anticipated but there was also the problem of having to apply treatments at a certain growth stage and these did not coincide. (Thus changeover of salinity, for example, was done at Colombar veraison).

2.5.4.4 Statistical analysis of reproductive growth and yield

The means that were calculated in the previous section do not account for possible interaction between treatment, yield, number of bunches, shoot mass and trunk circumference. As a first approximation, a covariate was needed. In studies related to the performance of grapevines, a covariate such as trunk circumference is used to account for differences in growth. This did not work because the saline irrigation was introduced to adult plants that responded not according to size but in terms of genetic capacity to cope with salinity. The plants of the Robertson site were also in a state of decline rendering variations in trunk circumference over the duration of the experiment smaller than the standard variation between plants of the same treatment.

The pilot study was designed to test four treatments, LS1, LS2, SL1 and SL2, on two sites to the north and south of the main trial in Robertson, with two replications on each of the two sites. It was decided to analyse the two sub-trials separately but in

addition to conduct a single analysis of variance. The disadvantage of conducting the analysis as two separate trials is the fewer degrees of freedom available for error (3 degrees of freedom for treatments, 1 for replicates and 3 for error). Consequently, $F=MS_{treatments}/MS_{error}$ has an F-distribution with 3 degrees of freedom. The analysis of variance was calculated for two data sets. One set combined the data for the three years of observation, and the second separated the data for the three consecutive years.

In order to reduce the mean square for error in the analysis of variance, it made sense to introduce those covariates which are closely related to the response variables shoot mass, number of bunches, yield and average yield per bunch. Plotting the three response variables measured in 1996, 1997 and 1998 over collar circumference of the plant, as well as over the three response variables for 1995, in most cases indicated close relationships, although the closeness varied over different years and for different covariates. PROC GLM in SAS (a sub-module in SAS) was thereafter used to test various models, not only making the basic assumption of an additive effect of the covariates in the analysis of covariance, but in addition assuming that the slope of the regression lines might differ for different treatments. It seemed reasonable to first test for additivity (or rather parallelism) and to continue the ANCOVA as if there was no evidence of different slopes. This was done for each of the three years separately. None of the analyses of covariance produced evidence of different slopes. The second part of the analysis of covariance did not significantly reduce the error mean square (and thereby generate higher F-values for treatments). Consequently it served no useful purpose to introduce covariates but rather to continue with a straightforward analysis of variance for the four target variables: shoot mass, number of bunches, yield, and yield per bunch for the 3 years combined and for the years 1996, 1997, 1998 separately. As mentioned above this was done for each of the two sub-trials (described as “group”) separately as well as for the pooled data. The ANOVA for the pooled data is based on the model

- Shoot mass = group, year, treatment, treatment*group
- No of bunches = group, year, treatment, treatment*group
- Yield = group, year, treatment, treatment*group

- Ratio (=yield/No of bunches) = group, year, treatment, treatment*group

The results are summarised in Table 2.28.

Table 2.28 Analysis of variance for the pilot study with interaction between group and treatment.

Shoot mass			
	F	Ass.P	R^2
Model	8.5	**0.0001**	0.668
Group	59.7	**0.0001**	
Treatment	<1	NS	
Year	4.2	**0.022**	
Group*treatment	1.9	NS	
No of bunches			
	F	Ass.P	R^2
Model	26.4	**0.0001**	0.862
Group	40.1	**0.0001**	
Treatment	<1	NS	
Year	96.2	**0.0001**	
Group*treatment	<1	NS	
Yield			
	F	Ass.P	R^2
Model	40.9	**0.0001**	0.906
Group	274.0	**0.0001**	
Treatment	<1	NS	
Year	42.9	**0.0001**	
Group*treatment	2.2	NS	
Yield/bunch			
	F	Ass.P	R^2
Model	54.2	**0.0001**	0.927
Group	473.6	**0.0001**	
Treatment	1.0	NS	
Year	2.6	NS	
Group*treatment	2.2	NS	

Table 2.28 is self-explanatory. There is convincing evidence that the differences between the means of the target variables in the two sub-trials are highly significant. There is no evidence of treatment effects. Table 2.28 should be read and interpreted in conjunction with the tabulated means (Tables 2.20 to 2.27). The relevant descriptive statistics (N, mean, coefficient of variation (CV) and standard error of the mean (std err), for the three years combined are given in the table.

Some attention was given to the question of how to deal with "year" as a variable. The value of a straightforward ANOVA, based on the model

y_1, y_2, y_3 y_4 = rep year treatment year*treatment

is debatable. The variable "year" constitutes a time series. In consequence, the assumption of independently (and normally) distributed residuals is violated. Some reservation is therefore called for in the interpretation of the analysis of variance. However, there is convincing evidence of differences between the group (sub-trial) means and between years. The differences between treatment means were non-significant.

In order to examine the effect of the variable "years" a linear regression equation y_3 = years was fitted for each experimental plot. It did not make sense to test for a real change of y_1, y_2, y_3 and y_4 over time, firstly because only 1 degree of freedom would be available for error, and secondly because of the violation of the assumption of independence. However, the rate of change, expressed by the regression coefficients b_1, c_1 and d_1 (they apply to shoot mass, No of bunches and yield) is an independently distributed target variable. The results are given in Table 2.29.

Table 2.29 Regression coefficients to indicate the response of shoot mass, number of bunches and yield when subjected to saline irrigation.

	b_1 (shoot mass)	c_1 (No of bunches)	d_1 (yield)
Mean	-0.053	-0.998	-0.997
Standard error	0.00868	0.905	0.088
t (H_o : mean = 0)	6.1***	11.0***	11.3***

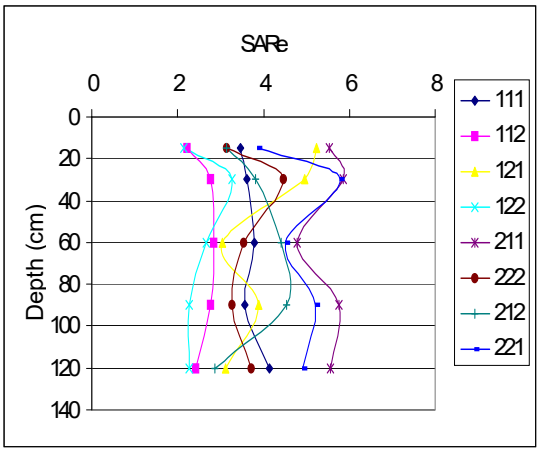
It can be seen that the decreasing trend is statistically highly significant. It is of interest to note that the decrease in yield is much greater than the decrease in shoot mass and amounts to 1 kg yield per year. The number of bunches also decreased by one per year.

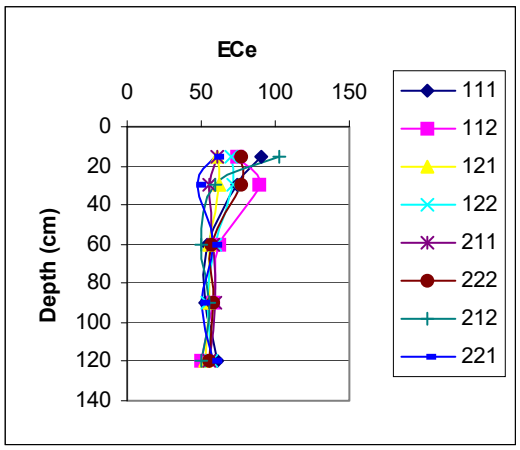
Analyses of variance were also calculated for each of the sub-trials separately. They did not disclose new information and for this reason, the ANOVA tables have not been included in the report.

2.5.4.5 Quality differences of wine from vineyards subjected to saline irrigation

Moolman *et al*. (1999) found that a highly significant correlation existed between elements in the must and their occurrence in their resulting wines. It was therefore decided to test the must of the 16 sites rather than to make 16 wines.

Wines were made at the experimental cellar of the Department of Viticulture and Oenology at the University of Stellenbosch to study the effect of salinity treatments on wine composition and quality. Because of the weakness in the statistical design of the experiment, it was decided to simply make and test a combined wine sample of the Colombar section of the trial, to be compared with treatments 1 and 3 of the main study at Robertson. The procedures and results are given in the next chapter which deals with the main study at Robertson.





3. RESULTS FROM THE MAIN EXPERIMENT AT ROBERTSON: RESPONSES OF SOIL WATER SALINITY STATUS AND OF PLANT GROWTH AND PRODUCE QUALITY TO IRRIGATION WITH SALINE WATER

3.1 EXPERIMENTAL DESIGN

3.1.1 Previous salinity treatments (1990-95, Colombar grapevines)

For the sake of completeness and clarity, the salinity treatments used previously in the Robertson main study are described again below (Moolman *et al*., 1999). During the previous study it was established that exposure of grapevines to saline conditions during earlier years, had a marked effect on vegetative and reproductive growth in subsequent years. The results reported here are those that were induced by treatments applied during the previous years.

These treatments were as follows:

Main study (Evaluating the effects of saline irrigation water on Colombar grapevines at Robertson).

Treatment 1	25-40 mSm^{-1} (Robertson canal water)
Treatment 2	75 mSm^{-1}
Treatment 3	150 mSm^{-1}
Treatment 4	250 mSm^{-1}
Treatment 5	350 mSm^{-1}
Treatment 6	500 mSm^{-1} (replaced with canal water since Sept. 1994 at Robertson).

Each treatment had four replications as shown in Figure 3.01. The treatments were applied by micro-sprinkler irrigation.

The salinity levels in the irrigation water were obtained by mixing a 30% stock solution of $CaCl_2$ and NaCl in a 1:1 molar ratio with the Robertson canal water.

3.1.2 Treatments applied at the Robertson main study during 1995-98

Irrigation with saline water was continued throughout each growing season from September to April, with treatments 1-5 remaining unchanged. Treatment 6 was split as follows:

Treatment 6a: Saline water was replaced with canal water on two of the original plots (plots 6 & 17).

Treatment 6b: Saline water was replaced by a sequence of canal water followed by moderately saline water on the remaining two plots (plots 7 and 19). The canal water was applied until after full bloom; thereafter, water was applied with the same salinity as that of treatment 3 (150 mSm-1)

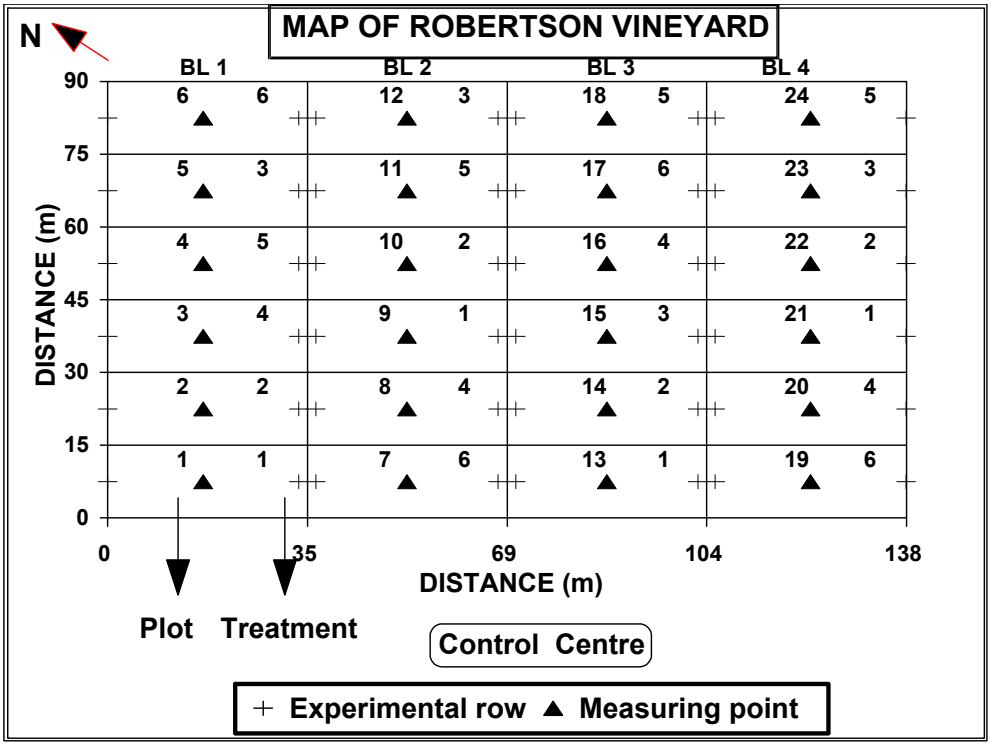


Figure 3.01. Diagram of the Robertson experimental vineyard showing the distribution of six salinity treatments replicated four times over 24 plots of equal size.

3.2 SOIL WATER STATUS

3.2.1 Introduction

Irrigation scheduling in the main study at Robertson was based on the mean soil water deficit of the four control plots, using a neutron probe to measure the water content. Measurements were made weekly and, in most cases, irrigation was applied directly after measurement.

Irrigation water was sampled by attaching a 2 Lh^{-1} dripper to the irrigation system on each plot and collecting the effluent in a 25 L container. All containers were usually emptied after each irrigation event. This provided feedback on the dosing system to see whether the irrigation's salt injection control was on target. These data also formed the basis for a salt balance study.

3.2.2 Irrigation

The amount of water applied to the vineyard was based on neutron probe readings carried out on treatment one only. The soil water deficit was calculated from the neutron probe readings and then applied in programming the irrigation and salinity control system. All irrigation events were thus preceded by neutron probe readings.

During the 8 years of the main study at Robertson, yield of the control treatment decreased continuously. The highest yield was achieved in the first season when most water was applied and significant leaching was recorded. There is also a popular belief among the farmers of the Breede River Valley that over-irrigation during the period August to October is beneficial to yield. In an attempt to increase the yield of the control treatment at Robertson, more water per irrigation was applied during the early part of the seasons between 1995-96 and 1997-98 than in previous years. This was achieved by adding a 20% leaching fraction to each irrigation event. An irrigation frequency of once per week was used (as opposed to every two weeks in the four previous seasons), irrespective of the actual soil water deficit at that stage.

The water balance is summarised in Table 3.01. In the 1995-96 season, 661 mm water was applied which is 57 mm more than that applied during the previous season. In 1997-78, 402 mm was irrigated which is 259 mm less than in the 1995-96 season. This can possibly be explained by the similar shift in PET over the same seasons. There is a good correlation between PET and applied irrigation.

3.2.3 Electrical conductivity of irrigation water (EC_i)

The salinity of the irrigation water treatments used in 1995-96, 96-97 and 97-98 are listed in Table 3.02. Controlling the salinity level depends very much on a control of hydraulic pressure differences in the salt injection and main supply lines. For this reason, the water pressure and the salinity control of the whole system was checked before each irrigation event.

Table 3.01. Irrigation, rainfall and water balance data for the growing season (September to April), summarised per season for the main Robertson experiment (evaporation based on class A-pan or Penman-Monteith calculation where indicated).

September to April	1991/2	1992/3	1993/4	1994/5	1995/6	1996/7	1997/8
Irrigation (mm)							
per vineyard, 12150 m^2	926	613	566	604	661	583	402
per wetted area, 8100 m^2	1389	920	849	907	992	875	604
Rainfall (mm)	126	252	113	201	169	191	125
PET = A-pan data (mm)	1794	1967	1678	1607*	1647*	2020*	1553*
AET=PET x crop factor (mm)	782	823	702	672*	689*	841	649

* = *Reconstructed A-pan record based on Penman-Monteith equation.*

Table 3.02. Salinity of irrigation water during three seasons of application (volume weighted means) in relation to the target level for each treatment.

Treatment number*	Target EC_i (mS/m)	Weighted mean EC_i (mS/m)		
		95/96	96/97	97/98
1	25-35	38	30	41
2	75	75	73	76
3	150	129	139	126
4	250	226	300	249
5	350	347	388	399
6a (plots 6 & 17)	25-35	38	29	40
6b (plots 7 & 19)	150	129	137	125

* *See Chapter 2 for explanation of treatments*

3.2.4 Soil water content

The soil water content for the 1995-96 season is shown in Table 3.03. As was the case during the previous project, treatments 2 and 3 were the wettest and driest, respectively. However, the difference between these two extremes was only 16 mm/m, which is not significant in terms of the standard deviation.

Table 3.03. Soil water content from September 1995 to April 1996 for the corresponding different treatments at Robertson.

Treatment number	Water content mm/m (n=19)	
	Mean*	Std. Dev
1	253	14
2	266	18
3	250	16
4	265	13
5	259	11
6	264	17

n=number of days on which measurements were made.
**=mean of all 4 replicates*

The change in soil water content during the season as a function of treatment is plotted in Figure 3.02 for the three seasons of the current study. The neutron probe readings were always made just before an irrigation event and at least one week after the previous irrigation. The aim was to keep the soil water status as constant as possible. The values therefore generally represent the lowest soil water content between irrigations. The practice was to irrigate every Wednesday. This was, however, not always the case either as a result of an irrigation control failure or at the end of the season before harvest. Harvest is at about day of season (DOS) 200 and the decline in soil water content immediately prior to this is due to the practice of terminating irrigation at least two or three weeks before harvest. During this period the grapes ripen quickly and the sugar and titratable acid content of the grapes were checked regularly.

It is also important to note that since it was decided to irrigate at a fixed time every week, water use differed each week. This is possibly the most important effect shown in Figure 3.02.

Treatment 3 of the main study was generally driest in water content over all three growing seasons and treatment 2 the wettest. For the majority of treatments and days of season the mean soil water content was managed between 230 and 280 mm/1.05m soil depth. However, in the 1997-98 season the soil water content ended up being much drier than that of the two previous seasons.

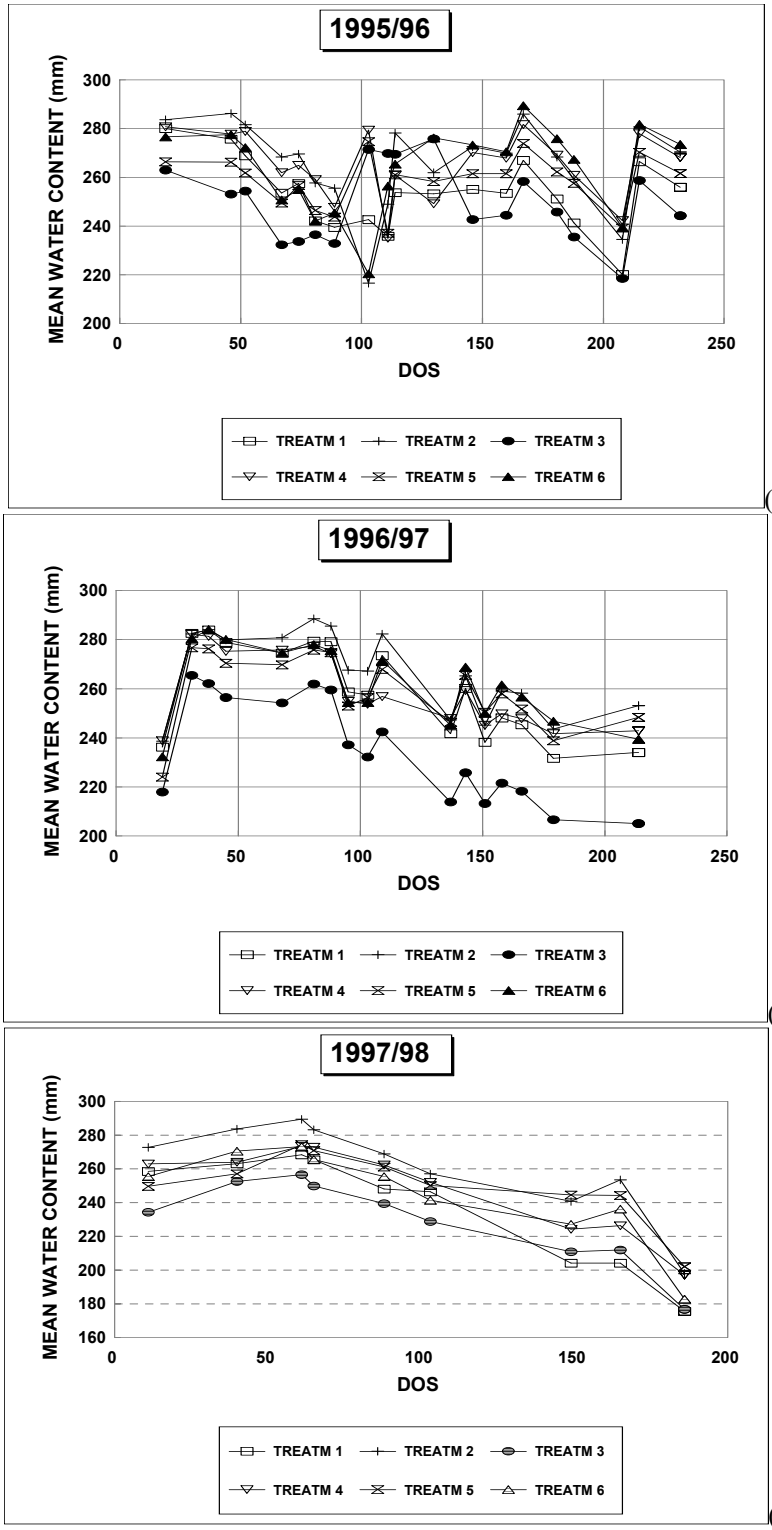


Figure 3.02. Soil water content (treatment means) for seasons (a) 95-96,(b) 96-97 and (c) 97-98 at Robertson. Water content is expressed in mm/1.05m (DOS = day of season)

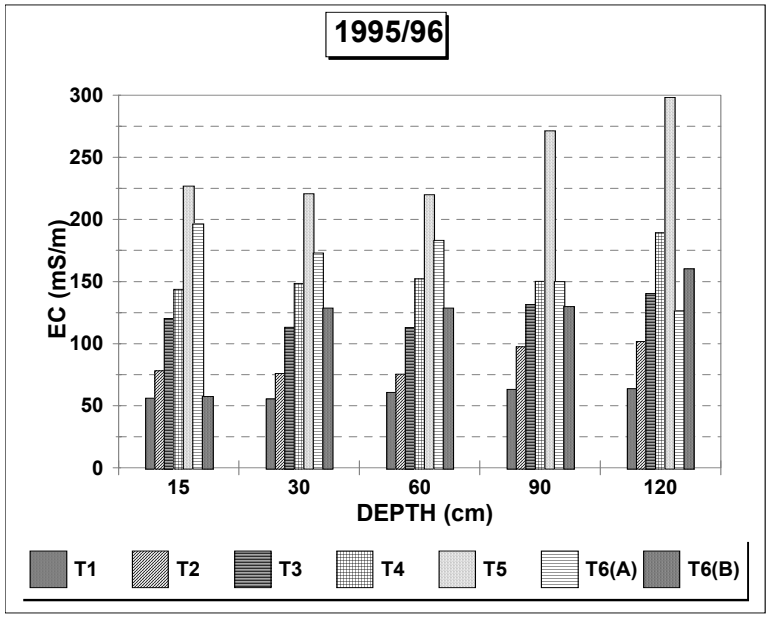
3.3 SOIL SALINITY AND SODICITY

3.3.1 Introduction

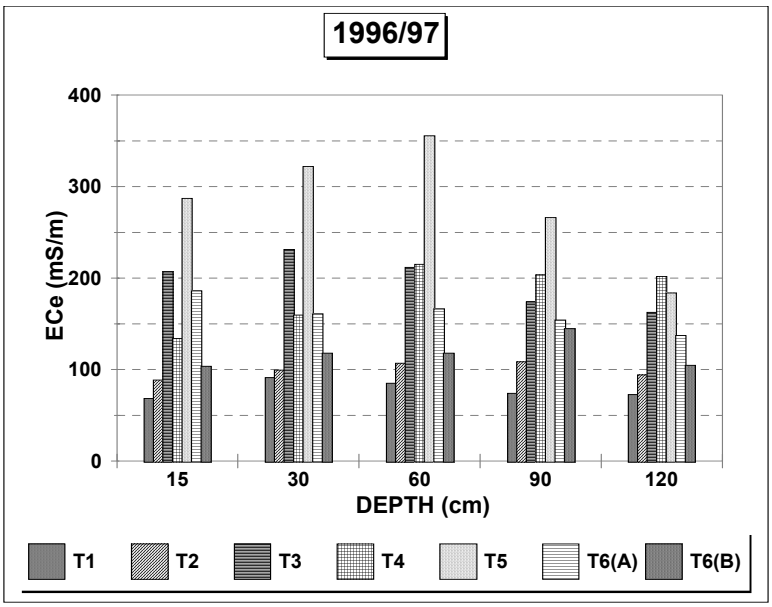
The soluble salt content of the soil was determined by taking soil samples from each plot at the end of winter (late August) and again at the end of the irrigation season (late April of the following year). Samples were always taken centrally between two vines of the experimental row at depth increments of 0-15, 15-30, 30-60, 60-90 and 90-120 cm. The sampling procedure is described in section 2.5.3.1 and will therefore no be repeated here.

3.3.2 EC_e and SAR_e

At all depths the soluble salt content of all the salinity treatments increased from September 1995 (end of winter) to April 1996 (end of summer). By April 1996 treatment 5 (EC_i = 350 mSm^{-1}) represented the most saline, and treatment 1 (EC_i = 25-35 mSm^{-1}) the least saline soil condition. This repeated itself during the 1996-97 and 1997-98 seasons. These trends, except for treatments 6(a) and 6(b), are in line with the trends reported for the 1991-95 phase of the experiment (Moolman *et al*., 1999). Treatment 6(a) received fresh water, while 6(b) received 150 mSm^{-1} water. It is clear from Figure 3.03 (a) that treatment 6(a) suffered from reduced permeability when compared with treatment 6(b). This resulted from fresh water being applied to a saline soil. The infiltration was visibly poor. Treatment 6(b) suffered no infiltration problems and much of the salt in the soil was therefore better leached than by treatment 6(a). One must also keep in mind that the irrigation scheduling was based on soil water content measurements for treatment 1.



(a)



(b)

Figure 3.03. End of season EC_e of the Robertson main study for (a) 1995-96 and (b) 1996-97 in relation to salinity treatment.

The vines on treatments 6(a) and 6(b) had much lower water consumption, presumably because of salinity damage from the 500 mSm^{-1} irrigation from the previous years. These plots were therefore over-irrigated and treatment 6(b) thus had a better chance of undergoing a reduction in soil salinity during the 1995-96 season.

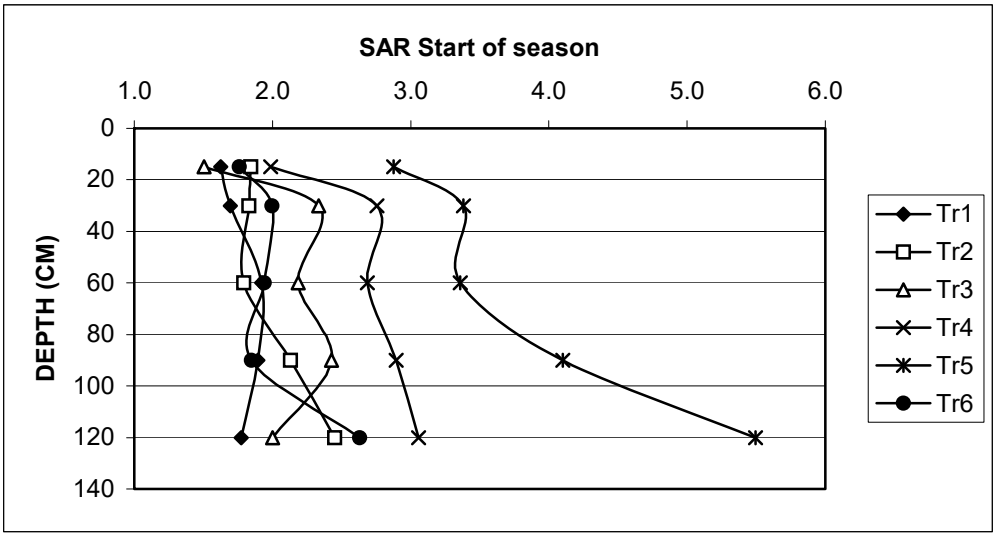
Because of the winter irrigation, treatment 6(a) did eventually catch up with that of 6(b) at the end of the 1996-97 season.

SAR_e was determined by calculating the treatment mean averages over the 1995-96, 1996-97 and 1997-98 seasons of the study (Figure 3.04). From this result, it is clear that only the SAR_e of treatments 1 and 2 remained below 2.5 for the whole season. Treatments 3 and 6 reacted similarly in spite of treatment 6 being previously a 500 mSm^{-1} treatment. Only treatments one and two showed near-uniformity with depth throughout the season. Treatments 3, 4 and 6 showed a considerably higher SAR_e with depth at the end of the season. Treatment 5 showed that winter irrigation did not rectify the salinity problem to a satisfactory depth.

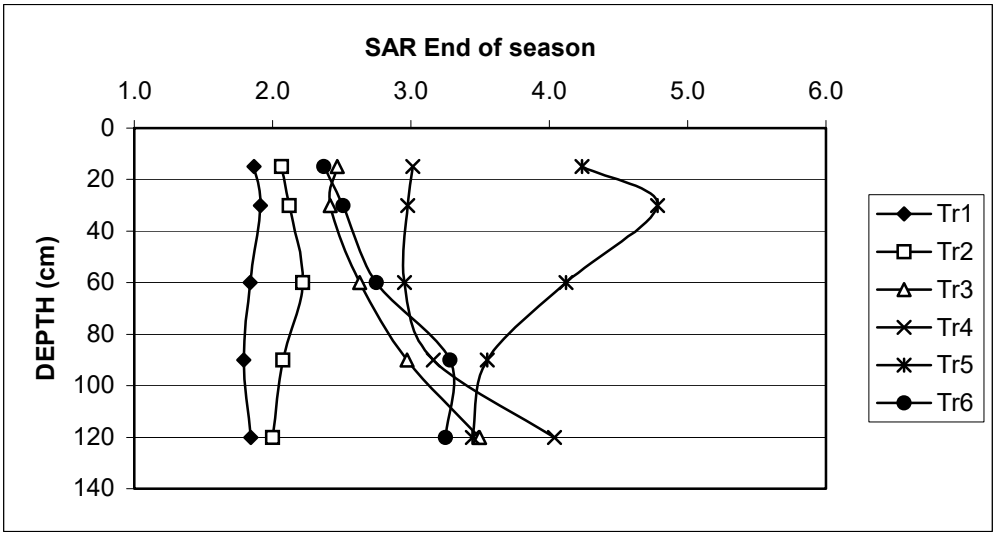
Treatment 5 again showed poor infiltration at the end of summer when the change-over was made between saline water and the fresh canal water. The time available to overcome this problem was too short. In practice, the solution would be to either lower the EC_i gradually or to apply gypsum to aid infiltration.

With respect to Figure 3.04, the salt that accumulated below 80 cm depth during winter, was leached with saline irrigation during summer and a new critical zone developed between the surface and 80 cm depth.

Changes in the soluble salt content at Robertson are given in Table 3.04. If the SAR_e treatment means over the three seasons are compared with the EC_e treatment means, the EC_e trends do not appear to provide the same picture as SAR_e suggesting that SAR_e is a more sensitive index of chemical response to the different salinity treatments. In order to describe treatment response, the response time for a change in EC_e is quite important and will be discussed in a Chapter 5 of this report. The response times is linked to soil volume and amount of water passing through a specific soil volume. This can therefore give an indication of how much water is needed to achieve a certain effect and therefore also the possibility of managing EC_e through the manipulation of irrigation water volumes.



(a)



(b)

Figure 3.04. Unadjusted SAR_e of the Robertson main study at the start (a) and end (b) of season. Treatment mean averages over the 1995/96, 1996/97 and 1997/98 seasons of the study were used. Treatment 6(a) and 6(b) was combined as treatment 6.

Table 3.04. Changes in the soluble salt content with depth and treatment of the Robertson plots from September 1995 to April 1998, expressed in terms of EC_e (mSm^{-1}).

TREAT MENT	DEPTH (cm)	Month					
		1995/9	1996/3	1996/9	1997/3	1997/9	1998/3
1	**15**	48	56	52	68	62	52
1	**30**	46	56	50	91	56	73
1	**60**	49	61	46	85	55	80
1	**90**	57	63	51	74	58	64
1	**120**	63	64	58	73	62	56
Mean		**52**	**60**	**52**	**78**	**58**	**65**
2	**15**	65	78	39	89	62	61
2	**30**	49	76	34	100	64	73
2	**60**	53	76	36	107	59	88
2	**90**	76	97	38	109	60	80
2	**120**	76	102	45	94	63	110
Mean		**64**	**86**	**38**	**100**	**61**	**83**
3	**15**	50	120	30	207	54	63
3	**30**	43	113	37	231	51	104
3	**60**	52	113	42	212	68	159
3	**90**	63	131	66	174	69	138
3	**120**	66	140	43	163	68	124
Mean		**55**	**124**	**44**	**197**	**62**	**117**
4	**15**	62	144	41	134	56	94
4	**30**	54	149	49	160	58	159
4	**60**	63	152	47	215	56	166
4	**90**	98	150	52	204	68	159
4	**120**	125	189	48	202	94	164
Mean		**80**	**157**	**47**	**183**	**66**	**148**
5	**15**	52	227	48	287	58	135
5	**30**	58	221	93	322	58	224
5	**60**	55	220	140	355	58	297
5	**90**	87	271	171	266	72	199
5	**120**	138	298	179	184	66	192
Mean		**78**	**247**	**126**	**283**	**62**	**209**
6(a)	**15**	63	54	36	76	58	49
6(a)	**30**	38	53	45	88	62	56
6(a)	**60**	65	58	47	130	58	57
6(a)	**90**	118	68	34	91	70	50
6(a)	**120**	119	76	63	75	86	44
Mean		**81**	**62**	**45**	**92**	**67**	**51**
6(b)	**15**	58	99	36	104	57	58
6(b)	**30**	52	96	39	118	55	121
6(b)	**60**	50	101	37	150	45	155
6(b)	**90**	70	120	40	145	46	101
6(b)	**120**	76	155	44	105	49	79
Mean		**61**	**114**	**39**	**124**	**50**	**103**

3.4 PLANT GROWTH AND GRAPE YIELDS

3.4.1 Introduction

The effect of full-season saline irrigation and saline irrigation applied at different growth stages is under investigation. These treatments had a differentiating effect on plant growth and yield. The main components tested were trunk circumference, leaf and petiole fresh and dry weight, sugar and acid content of the must, yield per vine and pruned shoot mass per vine. The aim was therefore not so much to describe plant reaction during the season but rather to quantify yield components as indicators to show best management options. It is also worthwhile to mention that (as was reported in Moolman *et al*., 1999), treatment effects on vines approach a maximum effect after three years of application. It is therefore better to exclude the results of years one and two from the analysis because their inclusion may conceal the true effect.

Trunk circumferences were measured to act as a covariate in eliminating previous treatment effects. Shoots were sampled at the 5 main development stages during the season. Shoot lengths were first recorded. The shoots, leaves and petioles were then separated in order to obtain dry and wet masses of the specified organs.

It was found that the samples taken at harvest in each season were sufficient to express the effect of all irrigation techniques that were used during the season. The cumulative effect of saline irrigation on the soil and the plant manifested itself most clearly at harvest time due to the time it took for the soil to react and thereafter for the plant to react. It is therefore better to test management options against harvest components.

3.4.2 Petioles and leaves

Tables 3.05 and 3.06 represent the leaf and petiole fresh and dry mass ratios, i.e. dry mass divided by fresh mass, taken during the final season of the project. The time variation across (rows) is a result of the movement of reserves to and from the leaves. The variation across treatments (columns) is due to differences in the plant response to saline irrigation.

Table 3.05. Leaf dry and fresh mass ratios (dry/fresh) for the season 1997-98 at Robertson.

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
1	0.32	0.31	0.45	0.33	0.86
2	0.32	0.33	0.46	0.33	0.88
3	0.31	0.31	0.46	0.36	0.88
4	0.27	0.31	0.48	0.36	0.92
5	0.41	0.34	0.44	0.35	0.89
6(A)	0.33	0.33	0.49	0.32	0.86
6(B)	0.33	0.34	0.53	0.40	0.84

For the Robertson main experiment, the season started off with differences among treatments, mainly as a result of the difference in time of budbreak induced by the saline treatments of the previous season. Differences in growth at the start of the season can be seen in Moolman *et al*. (1999). Budbreak occurred first in the most saline treatment and last in the least saline treatments. This resulted in leaves that had an age difference at the time of sampling At pea size stage, differences were smaller and this is about the time when the less saline treatments caught up with the more saline treatments in terms of shoot development. The same argument also accounts for differences in the petiole data.

Table 3.06. Petiole fresh and dry mass ratios (dry/fresh) for the season 1997-98 at Robertson.

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
1	0.18	0.18	0.29	0.27	0.79
2	0.24	0.19	0.32	0.25	0.75
3	0.18	0.15	0.28	0.28	0.71
4	0.20	0.15	0.28	0.30	0.78
5	0.19	0.16	0.23	0.24	0.83
6(A)	0.18	0.17	0.23	0.26	0.80
6(B)	0.16	0.20	0.32	0.28	0.75

3.4.3 Trunk circumference

As a result of the overall degenerated state of the vineyard, trunk circumferences did not vary much over the last 3 seasons and the standard deviation of measurements was found to be larger than the possible change in circumference of the vines. The results from the previous study (1990-95) showed that trunk circumference did not work as a

covariate for eliminating the carry-over effect of the preceding study. The 1995/96 results were meant to be used as covariates for the 1995-98 study in the statistical analyses of the yield components, but no results worth reporting were found.

3.4.4 Pruned shoot mass

Individual vine shoot mass was taken at the end of the season for all the experimental vines at all of the plots at Robertson and Stellenbosch. This was done to establish the effect of saline irrigation on the woody part of the vines. Figure 3.05 clearly shows a decline in shoot mass over the 4 years and over treatments 1 to 5. For the last 3 years, treatment 6 of the 1990-1995 experiment was split in treatment 6(a) and 6(b). The first received only canal water and the last received canal water up to full bloom each year, then saline water of 150 mSm^{-1} until the end of the season. In spite of the overall decline in shoot mass, 6(a) started to recover while 6(b) seemed to take the same position as treatment 3 of the main experiment. Table 3.06 also shows that pruned shoot mass is lower in 6(a) than in 6(b).

Figure 3.05 shows the constant decline in vigour over the years 94-95 to 97-98, as well as the remarkably constant pattern with treatment 4, maintaining its position almost in line with treatment 2. No definite answer could be given to the treatment 4 effect. It is possible, however, that treatment 3 is the one showing an out-of -line response as a result of receiving the lowest amount of irrigation water over all seasons. The progressive decline is ascribed to ageing of the vineyard. At the end of the study period the vineyard was 24 years old. The overall decline in the vineyard is largest in treatment 1 and smallest in treatment 5.

Table 3.07. Pruned shoot mass averages (g/vine) for the Robertson main experimental site for the seasons 1995-96, 1996-97 and 1997-98.

Treatment	1995-96	1996-97	1997-98
1	691	557	382
2	461	401	267
3	295	342	137
4	409	122	230
5	161	231	116
6(a)	209	228	186
6(b)	301	256	180

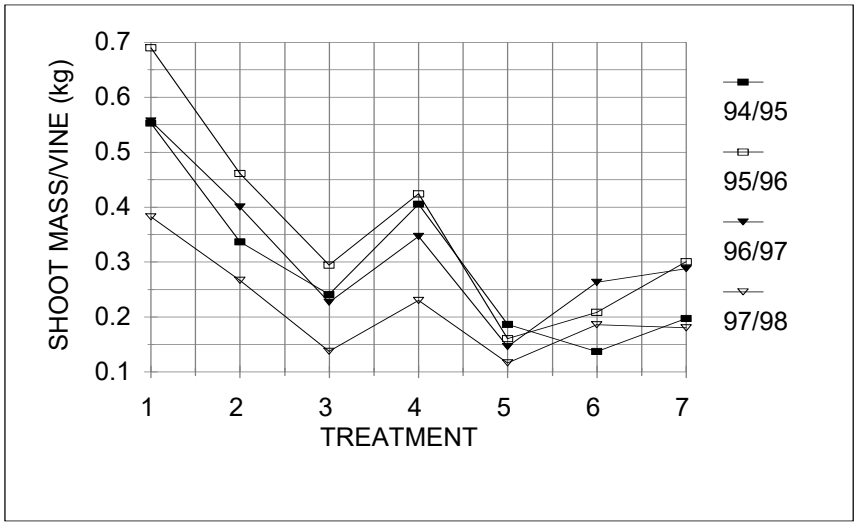


Figure 3.05. Pruned shoot mass per vine of the Robertson main experiment over the seasons 94-95, 95-96, 96-97 and 97-98. ***[Treatment 6 = 6(a) and 7 = 6(b)]***

3.4.5 Yield components

The data obtained at harvest time over all sites and treatments will be shown and discussed in this section. This includes the number of shoots, number of bunches, shoot mass and yield. The main aim is to shed light on management options for saline irrigation. Every management option that was applied had an effect on yield and yield primarily determines the best irrigation management option.

The historical yield results of the Robertson main experiment are given in Table 3.08 and it is against this background that the results of this experiment will be discussed. The yields of the 1995-96 to 1997-98 are also listed in Table 3.08. The results can be summarised as follows:

a) There was an increase in the yield of the control treatment from 1994/95 (4.99 kg per vine) to 1995/96 (6.80 kg per vine). The reason for this increase as well as the previous continuous decline in yield of the control remains obscure. It might be related to the greater amount of water that was applied in 1995/96 compared to the previous year, or to more favourable weather conditions.

b) The yield of treatment 4 (EC_i = 250 mSm^{-1}), which in previous years was greater than or equal to that of the control, decreased from 6.53 to 5.96 kg per

vine whereas the yield of treatments 1, 2 and 3 showed an increase. In absolute terms, treatment 2 for the first time since the start of this research gave a higher yield than treatment 4 and continued this trend to 1998. These trends suggests that the previous explanations as to why treatment 4 gave such high yields, might have been correct, i.e. that the response is related to tree size and that irrigation water with an EC_i of 250 mSm^{-1} will eventually harm the vines.

Table 3.08. Mean yield per plot of the saline irrigated main study at Robertson (Colombar grapes) for the 1992 to 1998 yield years.

YEAR	TREATMENT							YEARLY AVERAGE
Treatment	**1**	**2**	**3**	**4**	**5**	**6**		
mSm^{-1}	**~25**	**75**	**150**	**250**	**350**	**500**		
1992	13.28	10.95	11.65	12.90	10.19	9.72		11.45
1993	10.05	7.86	7.56	8.78	5.26	4.81		7.39
1994	7.83	5.49	5.73	7.50	3.54	2.68		5.46
1995	4.99	4.61	4.20	6.53	2.69	1.91		4.16
AVG	9.04	7.23	7.29	8.93	5.42	4.78		
Treatment	**1**	**2**	**3**	**4**	**5**	**6(a)**	**6(b)**	
mSm^{-1}	**~25**	**75**	**150**	**250**	**350**	**~25**	**150**	
1996*	6.80	6.06	4.98	5.95	1.16	1.50	2.05	4.41
1997*	4.74	3.13	3.02	3.20	1.11	0.83	2.14	2.67
1998*	4.56	3.25	2.30	3.07	0.79	1.03	1.71	2.50
AVG	5.37	4.15	3.43	4.07	1.02	1.12	1.97	
GLOBAL AVG	**7.46**	**5.91**	**5.63**	**6.85**	**3.53**	**3.21**		

c) The yearly average yield per vine shows a progressive decline over time. This decline occurs over all treatments including the fresh water treatment. The decline in the fresh water treatment and also to some extent the saline treatments was previously ascribed to winter irrigation and the possible leaching of nutrients. It is also possible that the overall decline in the vineyard was a consequence of the ageing of the vineyard. A lateral redistribution of salt in the water below a possible water table was also investigated. Firstly, no water table existed above the hard pan, which is at a depth of 1.2 m. No chloride and sodium accumulation was picked up either in the vines or in the soil of the control treatment.

d) The new treatments 6(a) and 6(b) were introduced to investigate the possibility that the vines of these treatments, which previously had received EC_i of 500 mSm^{-1}, might either recover or decline further. Table 3.08 shows that treatments 6(a) started to recover in 1998 while 6(b) declined further.

Table 3.09 shows the mean number of bunches per vine of the Robertson main study. All treatments show a sharp decline in bunch number. The annual mean shows a six bunch decline for the second season and an almost two bunch decline in the last year.

Table 3.10 shows a similar decline in shoot mass. Table 3.11 shows the average bunch mass per treatment. There was a similar decline over all treatments except in treatments 6(a) and 6(b). Treatment 6(a) showed a larger bunch mass in the last season and treatment 6(b) showed a larger bunch mass in 1997 compared to the previous season. This implies that, as argued previously, the poor infiltration rate of fresh water on a saline soil resulted in a slower leaching response in 6 (a) than the 6(b) treatment.

Table 3.09. Mean number of bunches per vine of the saline irrigated main study at Robertson (Colombar grapes) for the 1996 to 1998 yield years.

YEAR	TREATMENT							YEARLY AVERAGE
Treatment	**1**	**2**	**3**	**4**	**5**	**6(a)**	**6(b)**	
MSm^{-1}	**~25**	**75**	**150**	**250**	**350**	**~25**	**150**	
1996	49.23	42.93	34.25	43.58	17.17	16.05	27.8	33.0
1997	42.25	33.5	29.53	34.45	16.35	13.1	26.6	27.97
1998	40.43	33.4	25.08	32.65	12.85	15.3	23.6	26.19
AVG	43.97	36.61	29.62	36.89	15.46	14.82	26.0	

Table 3.10. Mean shoot mass per vine of the saline irrigated main study at Robertson (Colombar grapes) for the 1996 to 1998 yield years.

YEAR	TREATMENT							YEARLY AVERAGE
Treatment	**1**	**2**	**3**	**4**	**5**	**6(a)**	**6(b)**	
MSm^{-1}	**~25**	**75**	**150**	**250**	**350**	**~25**	**150**	
1996	0.69	0.46	0.29	0.42	0.15	0.3	0.56	0.41
1997	0.56	0.4	0.23	0.34	0.12	0.2	0.29	0.31
1998	0.38	0.27	0.13	0.23	0.09	0.14	0.17	0.20
AVG	0.54	0.38	0.22	0.33	0.12	0.21	0.34	

Table 3.11. Average bunch mass per treatment of the saline irrigated main study at Robertson (Colombar grapes) for the 1996 to 1998 yield years.

YEAR	TREATMENT							YEARLY AVERAGE
Treatment	**1**	**2**	**3**	**4**	**5**	**6(a)**	**6(b)**	
MSm^{-1}	**~25**	**75**	**150**	**250**	**350**	**~25**	**150**	
1996	0.141	0.135	0.13	0.132	0.06	0.091	0.074	0.109
1997	0.115	0.09	0.094	0.091	0.07	0.063	0.086	0.087
1998	0.113	0.096	0.08	0.09	0.063	0.067	0.071	0.083
AVG	0.123	0.107	0.101	0.104	0.064	0.074	0.077	

3.4.6 Statistical analysis of reproductive growth and yield

3.4.6.1 Introduction

The means that were calculated in the previous section do not account for the possible interaction between treatment, yield, number of bunches, shoot mass and trunk circumference. Also the modelling aspect of these parameters was not touched on in the previous sections. As a first approximation, a covariate was needed. In studies related to the performance of grapevines, a covariate such as trunk circumference is used to account for differences in growth. This did not work with old plants that were subjected to saline irrigation. The main reason for this is that saline irrigation was introduced to adult plants that reacted not so much according to size as to genetic capacity to cope with salinity. The plants of the Robertson site were also in a constant

state of decline, which made variation in trunk circumference per plant over the duration of the experiment smaller than the standard variation among plants of the same treatment.

Due to the wealth of information that was created by subjecting the data to SAS routines, only selected parameters showing most relevance to the aims of the study will be reported.

3.4.6.2 ANOVA Results

The results of the ANOVA for the Robertson experiment are given in Table 3.12. Treatment effects are considered to be significant when $P_{ass} < 0.05$.

Table 3.12. ANOVA for Robertson main trial for shoot mass, bunch number, yield and yield per bunch on all years combined and per year individually.

Shoot mass – all years			
	F	Ass.P	R^2
Model	8.9	**0.001**	0.563
Replicates	3.7	**0.017**	
Treatment	12.1	**0.0001**	
No of bunches – all years			
	F	Ass.P	R^2
Model	13.6	**0.0001**	0.664
Replicates	4.5	**0.006**	
Treatment	19.2	**0.0001**	
Yield – all years			
	F	Ass.P	R^2
Model	7.91	**0.0001**	0.534
Replicates	6.1	**0.0001**	
Treatment	9.14	**0.0001**	
Yield/bunch – all years			
	F	Ass.P	R^2
Model	6.78	**0.0001**	0.496
Replicates	8.99	**0.0001**	
Treatment	5.78	**0.0001**	
Shoot mass (1996)			
	F	Ass.P	R^2
Model	2.676	**0.043**	0.640
Replicates	<1	NS	
Treatment	3.89	**0.018**	
No of bunches (1996)			
	F	Ass.P	R^2
Model	5.6	**0.002**	0.783
Replicates	1.66	NS	
Treatment	7.9	**0.0007**	

Yield (1996)			
	F	Ass.P	R^2
Model	3.57	**0.016**	0.697
Replicates	3.43	**0.050**	
Treatment	3.71	**0.013**	
Yield/bunch (1996)			
	F	Ass.P	R^2
Model	3.95	**0.011**	0.718
Replicates	5.88	**0.008**	
Treatment	2.96	**0.044**	
Shoot mass (1997)			
	F	Ass.P	R^2
Model	4.61	**0.006**	0.748
Replicates	2.76	0.081	
Treatment	5.95	**0.003**	
No of bunches (1997)			
	F	Ass.P	R^2
Model	2.63	**0.05**	0.629
Replicates	<1	NS	
Treatment	3.75	**0.02**	
Yield (1997)			
	F	Ass.P	R^2
Model	3.41	**0.02**	0.687
Replicates	2.42	NS	
Treatment	4.18	**0.013**	
Yield/bunch (1997)			
	F	Ass.P	R^2
Model	3.32	**0.022**	0.681
Replicates	4.28	**0.024**	
Treatment	3.01	**0.042**	
Shoot mass (1998)			
	F	Ass.P	R^2
Model	4.06	**0.010**	0.723
Replicates	1.68	NS	
Treatment	5.45	**0.004**	
No of bunches (1998)			
	F	Ass.P	R^2
Model	5.1	**0.004**	0.765
Replicates	1.81	NS	
Treatment	7.02	**0.001**	
Yield (1998)			
	F	Ass.P	R^2
Model	4.31	**0.008**	0.734
Replicates	2.11	NS	
Treatment	5.61	**0.004**	
Yield/bunch (1998)			
	F	Ass.P	R^2
Model	3.09	**0.029**	0.665
Replicates	2.53	NS	
Treatment	3.47	**0.026**	

The above ANOVA is a general analysis of variance. It is clear from Table 3.12 that only the replicates of number of bunches produced results that were non-significant.

The SNK multiple range test (at P=0.05) was carried out to identify the existence of homogeneous groups. The results in which treatment 1 is given as 0 and 6(a) and 6(b) as 6 and 7, respectively, can be summarised as follows:

Shoot mass (all years together)

0	2 4 7 3	4 7 3 6	7 3 6 5

No of bunches (all years together)

0	4 2	4 2 3	3 7	5 6

Yield (all years together)

0 2 4 3	3 7	7 6 5

3.5 PRODUCE QUALITY

3.5.1 Must

The chemical analysis of the must showed nothing new over that reported on previously. The titratable acid content of the must showed a maximum for treatment 3 and a minimum for treatment 6(a) (Figure 3.06). Treatment 6(b) is also significantly different from treatment 3 that received the same EC_i. The reason for this differentiation resulted from treatments 6(a and b) having been previously irrigated with an EC_i of 500 mSm^{-1}. This left the plants in a stunted state and with a much smaller water consumption. Treatments 6(a and b) received much more water than was needed and therefore the lower state of the soil EC_e had a smaller impact on the sugar and acid contents of the must. This resulted from irrigation scheduling having been based on the monitoring of treatment one alone.

Figure 3.06 also illustrates the fact that in a salinity experiment of this magnitude, it was impossible to harvest each treatment separately and at exactly the correct time of ripening for the grapes to be used for wine making. The general rule of thumb is that the sugar content must be 2.5 times that of the acid level (Figure 3.07). The grapes were therefore harvested when the average over all plots tested in the field had the correct ratio.

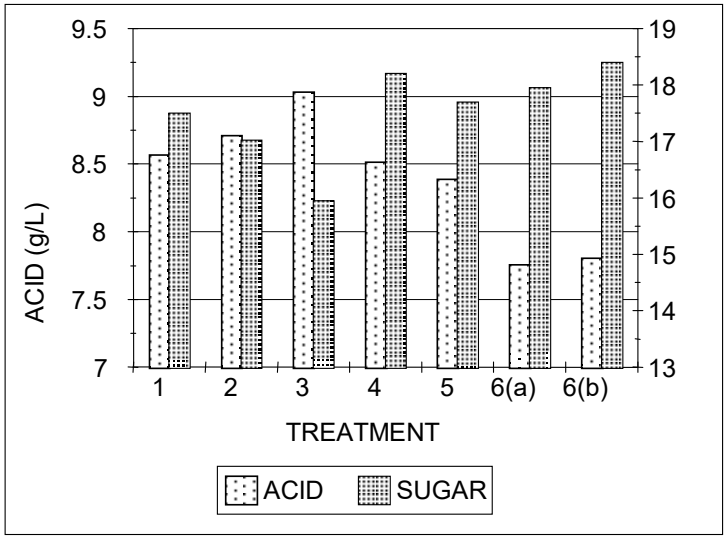


Figure 3.06. The titratable acid (gL^{-1}) and sugar (ºBalling) content of the must at Robertson main experiment at harvest of the season 1997/98.

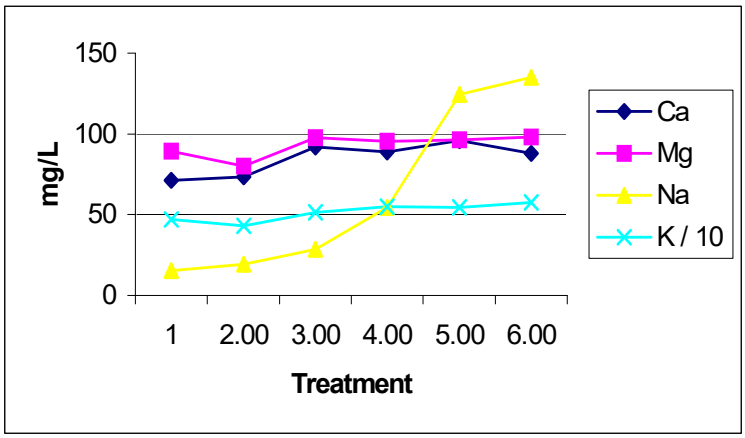


Figure 3.07. The cation content of the must in mgL^{-1} as measured in 1997 from samples taken at harvest on the Robertson main trial.

3.5.2 Quality differences in wine

3.5.2.1 Introduction

Four wines were produced, one from treatment 1, one from treatment 3 and one from a combined sub sample of the Colombar section from the Robertson pilot study. All wines were subjected to an organoleptic evaluation on 16/10/97. Wines were made at the experimental cellar of the Department of Oenology and Viticulture at the University of Stellenbosch to study the effect of the salinity treatments on wine composition and quality. The procedures and results are given in this section.

3.5.3 Materials and methods

3.5.3.1 Grape treatment and wines

The grapes from replicates of the specific treatments were combined for the purpose of this experiment. Three Weisser Riesling and four Colombar wines were made. Standard procedures were used for experimental winemaking at the University of Stellenbosch. The following methods were applied:

Starting with 20 kg of grapes.
Crushing and destemming.
SO_2 added before fermentation: 30 mg/l.
Skin contact of 10 hours.
Clarification of juice.
Acid adjustments with tartaric acid (to 6 g/l) prior to fermentation when necessary.
Wines fermented with yeast strain VIN 13 at 15°C.
The fermentation was stopped at the specific sugar level in the wines.
Stabilisation and bottling.

3.5.3.2 Analysis of juice

Balling (sugar) by refractometer.
Titratable acidity by titration to pH 7, expressed as g/l tartaric acid.
pH with pH meter.

3.5.3.3 Wine analysis

Routine analysis methods were used for alcohol, specific gravity, reducing sugar, volatile acidity, titratable acidity, pH and SO_2.

3.5.3.4 Wine quality evaluation

The wines were evaluated by a panel of 23 experienced wine judges in the wine tasting room of the University of Stellenbosch. The wines were served in a random

order with coded numbers. The judges were asked to rank the wines according to the intensity of the salty character as well as overall quality. The judges were also asked to indicate the wine quality on a 20-point scale frequently used for wine evaluations.

3.5.4 Results of wine quality

The results are given in Tables 3.13 to 3.15 followed by a short discussion.

Table 3.13. Sugar, titratable acidity and pH in Colombar juice

Wine	Treatment	Sugar (Balling)	Titr. Acidity G/l	pH
98/535	Treatment 1	17.2	6.63	3.34
98/536	Treatment 3	17.1	6.65	3.30
98/537	Treatment 5	18.1	6.32	3.33
98/538	Treatment L	18.1	5.86	3.36

All the juice samples had low sugar concentrations with treatments 5 and L being slightly higher than the other two treatments. Differences in the acid and pH levels in the juice were of no significant value in winemaking terms.

Table 3.14. Routine analysis: Colombar wines

Wine nr	Treatment	Alcohol Vol %	SG	Extract g/l	Sugar g/l	SO_2 Free mg/l	SO_2 Total mg/l	Volatile Acidity g/l	Titr. Acidity g/l	pH
98/535	Treatm. 1	9.80	0.9961	24.2	4.7	27	100	0.31	6.6	3.19
98/536	Treatm. 3	9.75	0.9963	24.5	4.9	28	83	0.44	6.8	3.05
98/537	Treatm. 5	10.39	0.9960	25.5	4.6	26	77	0.52	6.9	3.11
98/538	Treatm. L	10.45	0.9956	24.8	4.8	26	89	0.44	6.7	3.17

Remarks

a) Low levels of alcohol in all wines.

b) No significant differences in the main chemical compounds analysed were found here.

Table 3.15. Sensory evaluation data for Colombar wines.

Wine nr	Treatment	Ranking* Salty taste	Ranking* Overall wine quality	Median** point/20	Comments
98/535	Treatment 1	56 a	70 b	11	Neutral
98/536	Treatment 3	55 a	57ab	12	Neutral
98/537	Treatment 5	55 a	42 a	12	Light fruity
98/538	Treatment L	77 b	65ab	11	Salty

* Rank sum of 23 tasters

* Lower values for ranking indicate less salty taste or higher wine quality

** Median indicates wine quality on a 20-point scale

Remarks

a) The wines made from grapes of Treatment L were rated significant higher in salty taste than the other treatments (P =0.05).

b) The overall wine quality of Treatment 5 was significantly better and the wines made from Treatment 1 significantly inferior to the other treatments (P = 0.05) (ranking).

c) All the wines lack typical character. The tasting panel rated the wines low in quality with points from 11 to 12 on a 20-point scale.

From these results it is evident that although the treatments had no marked effect on the sugar, acidity, pH levels of the juice after crushing and the chemical composition of the wines, the effect of saline irrigation becomes more pronounced in the quality of the resulting wines. Wines made from higher salinity treatments showed a significant detectable saltiness on taste and were judged lower in sensory quality than the corresponding wines made from the grapes of the control treatment. Unfortunately, all the wines lacked the typical cultivar character, an aspect that cannot be related to irrigation alone, but to the overall quality of the grapes.

4 RESULTS OF THE EXPERIMENT AT STELLENBOSCH: RESPONSES OF SOIL WATER AND SALINITY STATUS OF PLANT GROWTH AND PRODUCE QUALITY TO IRRIGATION WITH SALINE WATER

4.1 EXPERIMENTAL LAYOUT

4.1.1 Previous salinity treatments during the 1990/95 seasons (Weisser Riesling grapes)

The same six treatments were applied at the Nietvoorbij (Stellenbosch) site as those applied at Robertson with the experimental layout shown in Figure 4.01. in this case Treatment 1 consisted of Stellenbosch dam water with an EC_i of 25-40 mSm^{-1}. The study at Stellenbosch was delayed until the 1993-94 season owing to the fact that the vineyard was established much later than that at Robertson.

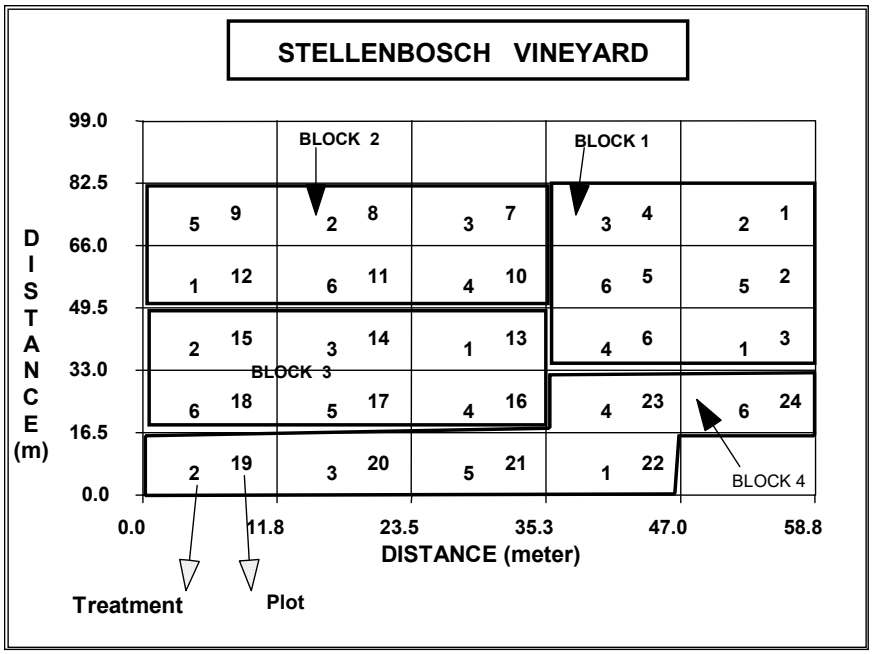


Figure 4.01. Diagram of the Stellenbosch experimental vineyard showing the distribution of six salinity treatments replicated four times over 24 plots of equal size.

4.1.2 Treatments applied during 1995-98

Supplementary irrigation with saline water was applied as required throughout the season from September to April. All six treatments remained the same and represented a continuation of the experiment from its onset in the 1993-94 season.

4.2 SOIL WATER STATUS

4.2.1 Introduction

At Stellenbosch, supplementary irrigation was used and water was applied at predetermined growth stages only. However, soil water content was always measured before and after an irrigation event. In November 1997, 135 mm rain was recorded and therefore no irrigation was applied before 1/98.

Irrigation water samples were taken in the same manner as that described in Chapter 3. Saline irrigation water was produced from a stock solution of NaCl and $CaCl_2$, with Na and Ca in a 1:1 molar ratio.

4.2.2 Irrigation quantities

Although the different treatments received similar amounts of irrigation water per plot, the volume of water applied to the vineyards varied among the three different studies.

At Stellenbosch a total amount of 120 mm irrigation water was applied to the Weisser Riesling vineyard on three occasions: 14/12/95 (48 mm), 25/1/96 (50 mm) and 6/2/96 (22 mm). Each treatment received equal quantities of water during the 1995-96 season. In the 1996-97 season, the vineyard was again irrigated on three occasions: 13/11/96 (49 mm), 20/01/97 (42 mm) and 20/02/97 (40 mm). In the 1997-98 season the vineyard was irrigated with saline water on two occasions, namely 16/01/98 (79 mm) and 3/03/98 (69 mm).

4.2.3 Electrical conductivity of irrigation water

The volume-weighted, seasonal mean salinity of irrigation water for the different treatments in 1995-96, 96-97 and 97-98 are listed in Table 4.01. At the lower and intermediate levels, the actual salinities at Stellenbosch differed considerably from the target values during the first season. This can possibly be attributed to the automated salinity control system. Controlling the salinity level depends very much on controlling hydraulic pressure differences in the salt injection and main supply lines, which at Stellenbosch turned out to be more difficult than at Robertson. The irrigation at Stellenbosch was also complicated by the steep inclination of the site and special care had to be taken to ensure equal distribution of water over all sites. For this

reason, the water pressure and the salinity control of the whole system had to be carefully controlled during each irrigation event. During the 1996/97 and 1997/98 seasons, the control of EC_i was more successful as is reflected by Table 4.01.

Table 4.01. Volume-weighted, seasonal mean electrical conductivities of the irrigation water for each of the three study areas, summarised in terms of targets and actual means per treatment *(volume weighted data where enough data available)*

Treatment number	Target EC_i (mSm^{-1})	Weighted mean EC_i (mSm^{-1})		
		95-96	96-97	97-98
1	25-35	45	44	45
2	75	198	72.5	92
3	150	181	132	122
4	250	298	245	240
5	350	269	335	330
6	500	468	460	514

4.2.4 Soil water content

The differences in the seasonal mean soil water content between treatments were small (Table 4.02). The standard deviation between replicates is fairly constant while the difference in treatment means cannot be related to a treatment effect. This is probably rather due to differences in soil texture, soil depth and the inclination of the site. Most readings at the Stellenbosch site were made before an irrigation event and at least one week after the last irrigation.

The soil water content for all treatments fell between 140 and 220 mm/1.05m soil depth (Figure 4.2). Treatments 1, 5 and 6 were the wettest throughout the study and treatment 2 the driest. In the 1995-96 season, 3 irrigation events and one rainfall event are evident between day of season (DOS) 100 and 200 (Figure 4.02a). For the same period in 1996-97, 3 irrigation events are evident, of which the last is a large post harvest irrigation. The same period in 1997-98 was foregone by a 135 mm rainfall event. Two irrigation events can be seen after that.

Table 4.02. Seasonal mean and standard deviation of soil water content in mm m^{-1} from September 1995 to April 1996, Stellenbosch.

Treatment number	Stellenbosch (n=28)	
	Mean	Std. Dev.
1	208	21
2	161	21
3	181	20
4	184	19
5	207	20
6	208	21

D=distance of measuring point from emitter; n=number of days on which measurements were made.

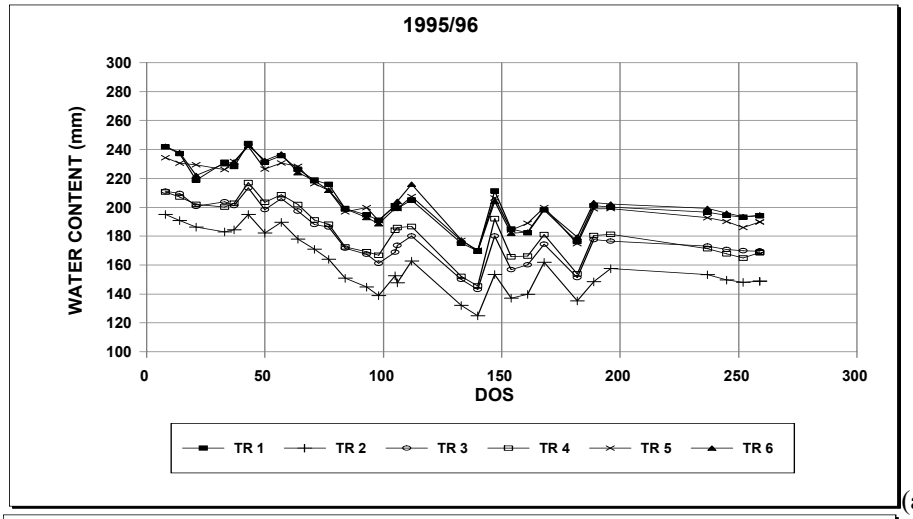
All sites were drained separately by an elaborate subsurface drainage system. This provided an opportunity to measure drainage water after irrigation or during winter rains. Not much data could be gathered, as the drains from different sites did not all react with the same magnitude. It is also possible that preferential flow paths played a larger role on some sites, causing their drains to respond more rapidly.

4.3 SOIL SALINITY AND SODICITY

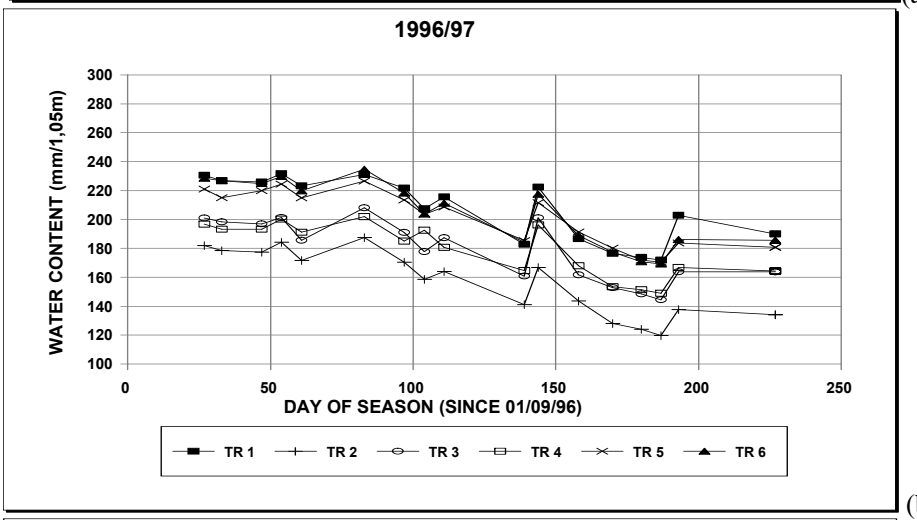
4.3.1 Methods

The soluble salt content of the soil was determined by taking soil samples on each plot at the end of winter (end of August) and again at the end of the irrigation season (end of April of the following year). Samples were always taken centrally between two vines of the experimental row at depths of 0-15, 15-30, 30-60, 60-90 and 90-120 cm. Soil samples were processed and analysed as described in Chapter 3.

During the irrigation season soil solution samples (EC_{sw}) were taken with the aid of an elaborate suction system connected to 280 suction cup lysimeters placed in the field. Each plot had 5, covering the 5 depths that were normally monitored for soil water content (15, 30, 60, 90 and 120 cm depths). This system did not work that well in this soil as a result of swelling clay in the soil.



(a)



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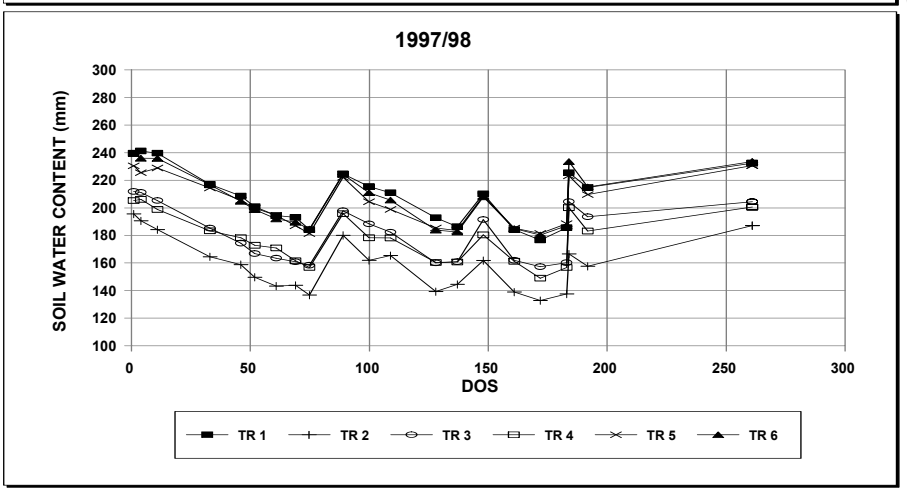


(c)

Figure 4.02. Stellenbosch experiment treatment mean soil water contents for seasons (a) 95-96,(b) 96-97 and (c) 97-98. Water content is expressed in mm/1,05m.

In almost all literature on plant response to salinity, response was best correlated with the weighted mean EC_{sw} over the season. Therefore, weighted means will also be

shown in this section where applicable. Weighted means of the EC_e were also calculated and were found in this study to give the best results when correlated with yield data.

4.3.2 EC_e and SAR_e

Since this site was chosen to investigate the effect of saline supplementary irrigation on yield of vines, the possibility of no irrigation existed depending on the climatic conditions of a particular season. This was however not the case. Timing of the first irrigation of the season was affected by rainfall. At least two irrigations per season were applied. This had an effect on the salt balance late in the season and therefore also the vine performance later in the season. However, this is a true reflection of the practical situation in this particular wine-producing region.

Table 4.03 provides a summary of the changes in EC_e with depth over the duration of the project. The downward trend in profile means for all treatments can simply be ascribed to the fact that for the first two seasons, supplementary irrigation had to begin in December and was therefore applied 3 times. For the last two seasons, irrigation commenced in January and was applied twice before harvest.

It is also worth noting how well the soil reacted to winter rain over all treatments. Even treatment one shows a salt accumulation over every irrigation season and a return to normal after winter.

Table 4.03. Changes in the soluble salt content (EC_e) with depth and treatment of the micro irrigated Stellenbosch Weisser Riesling vineyard from September 1995 to April 1996, expressed in terms of EC_e (mSm^{-1})

TREATMENT	DEPTH	1995/3	1995/9	1996/3	1996/9	1997/3	1997/9	1998/3
1	**15**	78	24	44	26	45	48	49
1	**30**	52	24	44	25	47	23	43
1	**60**	37	22	34	26	33	26	37
1	**90**	36	26	35	27	31	24	28
1	**120**	32	27	32	26	26	26	29
	Mean	**47**	**25**	**38**	**26**	**36**	**29**	**37**
2	**15**	87	25	54	25	65	34	67
2	**30**	71	25	62	27	59	26	60
2	**60**	58	27	85	28	56	25	43
2	**90**	52	25	85	50	41	35	32
2	**120**	48	24	71	32	40	40	28
	Mean	**63**	**25**	**72**	**32**	**52**	**32**	**46**
3	**15**	132	27	68	32	77	42	59
3	**30**	91	23	92	29	82	26	57
3	**60**	80	31	84	29	70	33	52
3	**90**	65	39	61	37	71	47	51
3	**120**	55	39	46	33	51	40	47
	mean	**85**	**32**	**70**	**32**	**70**	**38**	**53**
4	**15**	245	27	130	35	81	46	95
4	**30**	174	21	172	34	74	35	82
4	**60**	142	25	182	24	63	29	73
4	**90**	84	35	147	35	74	35	58
4	**120**	74	56	118	34	68	49	54
	mean	**144**	**33**	**150**	**32**	**72**	**39**	**72**
5	**15**	288	25	128	26	102	37	135
5	**30**	197	26	156	23	101	28	128
5	**60**	157	35	151	29	98	30	108
5	**90**	134	84	158	52	120	43	79
5	**120**	113	94	127	43	136	72	66
	mean	**178**	**53**	**144**	**34**	**111**	**42**	**103**
6	**15**	560	32	90	34	255	39	239
6	**30**	365	32	197	39	188	31	193
6	**60**	282	35	232	63	148	31	165
6	**90**	249	47	213	103	112	55	177
6	**120**	189	79	175	95	97	59	154
	mean	**329**	**45**	**181**	**67**	**160**	**43**	**186**

4.4 PLANT GROWTH AND YIELD

4.4.1 Vegetative growth

Shoots were sampled at the 5 main development stages during the season. Shoot lengths were firstly measured. The shoot organs were then separated so that the dry and wet mass of the shoot, petioles and leaves could be determined. Thereafter, chemical analysis was performed on all three. They were tested for their Na, K, and Cl contents. Standard methods, as reported in Moolman *et al.* (1999), were used. Shoot elongation was determined at the start of the season, as this gave an indication of the carry-over effect that saline irrigation had on the vines.

It was known from the previous study that the cumulative effect of saline irrigation on the soil and the plant manifested itself most strongly at harvest time due to the time it took for the soil to react and thereafter for the plant to react. It was, however, found that the data taken at harvest showed almost no treatment effects as did measurements made at other stages of the season.

4.4.2 Effect of saline supplementary irrigation on vegetative growth

During the 1996-97 season at Nietvoorbij the effect of the three supplementary irrigations was clearly evident. The harvest data showed a similar decline to that observed at the Robertson site when irrigation with saline water was initiated. It is possible that the effect of salinity on the vines of this site was somewhat disguised by another external effect that could not be pinpointed at the time of writing this report. It is suspected that the inclination of the site and the fact that the site occurs on a gradual transition from a predominantly granitic soil to a predominantly shaly soil, may both have played a role. Plant response, where possible and necessary, will be discussed against the backdrop of results obtained during the earlier years.

4.4.2.1 [illegible]

Tables 4.04 and 4.05 represent the leaf and petiole fresh and dry mass ratios for the final season of the project. The variation with time (rows) is a result of the movement of reserves to and from the leaves. The variation across treatments (columns) is due to differences in the plants reaction toward saline irrigation.

These values at full bloom are also indicative of a minimal carry over effect from the previous season. This trend was evident at the Stellenbosch site. The leaf and petiole mass ratio exhibited a trend that does not appear to reflect treatment effects (Tables 4.04 and 4.05).

Figures 4.03 and 4.04 show for instance that between 1995 (day 80) and 1996 (day 80) the average shoot length was 950 and 500mm respectively. Development of shoots was generally slower in 1996/97 and the differences between treatments were more pronounced.

Table 4.04. Leaf fresh and dry mass ratios for the Stellenbosch study during 1997-98 season.

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
1	0.29	0.31	0.36	0.48	0.57
2	0.30	0.29	0.39	0.49	0.53
3	0.30	0.29	0.39	0.46	0.51
4	0.29	0.30	0.35	0.44	0.58
5	0.30	0.30	0.38	0.47	0.51
6	0.31	0.29	0.37	0.44	0.56

Table 4.05. Petiole fresh and dry mass ratios at the Stellenbosch study for the 1997-98 season.

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST	POST HARVEST
1	0.12	0.15	0.21	0.20	0.07
2	0.13	0.15	0.24	0.32	0.13
3	0.13	0.16	0.25	0.33	0.07
4	0.12	0.15	0.21	0.32	0.07
5	0.14	0.15	0.23	0.27	0.05
6	0.13	0.15	0.24	0.23	0.06

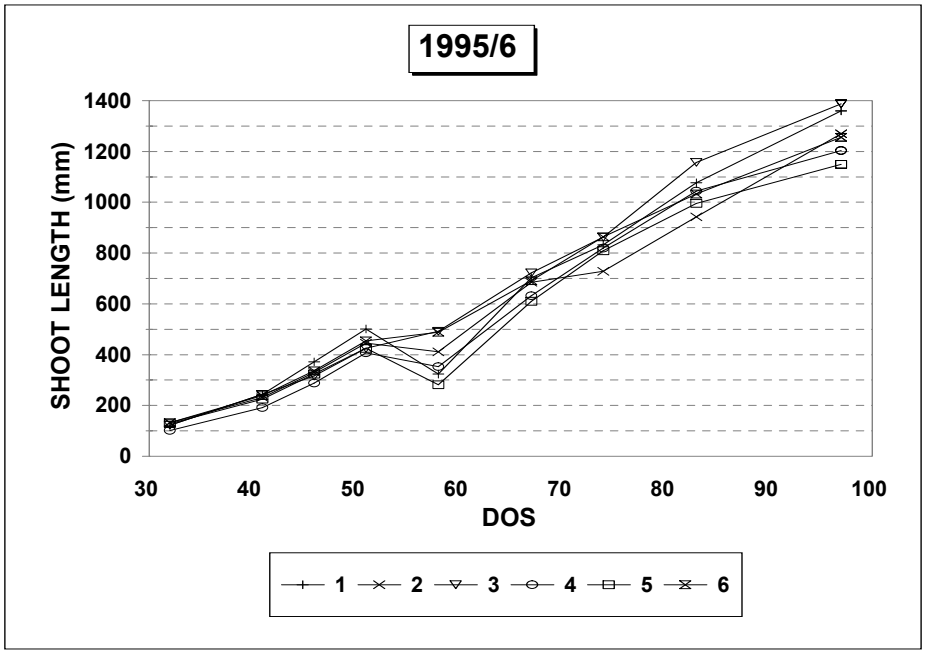


Figure 4.03. Average shoot growth (mm) in relation to treatment during 1995-96 at the Stellenbosch site.

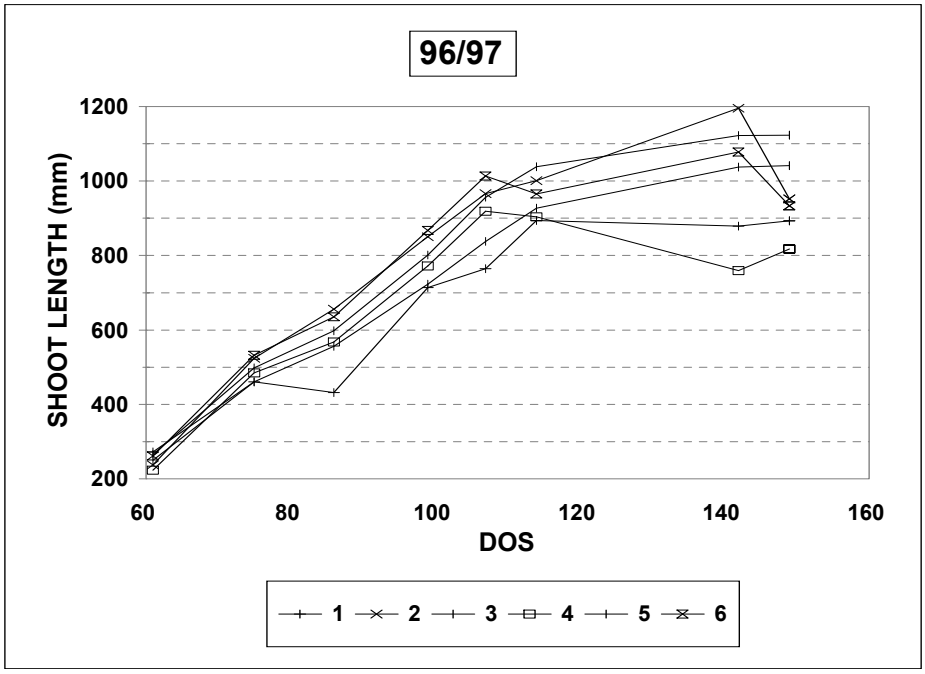


Figure 4.04. Average shoot growth (mm) in relation to treatment during 1996-97 at the Stellenbosch site.

As a first approximation, we were interested in the possible effect that saline water could have on the fresh and dry mass of the shoots themselves. The data for the Stellenbosch site are presented in Table 4.06. It is remarkable that the first differentiation in fresh/dry mass ratio between treatments started after the veraison

period, which is the time at which the first saline irrigation was applied. The petioles and leaves of the Stellenbosch site acted similarly (Tables 4.04 and 4.05).

At the Stellenbosch site, leaf scoring was done by allocating points between one and five according to leaf degradation by a person not familiar with the treatment layout. A score of one meant no damage and a score of five meant that 100% of the leaves had damage and/or discoloration. The advantage of this procedure was that plant size was ignored. The trend that was found in Figure 4.05, clearly shows a larger occurrence of damaged leaves in the more saline treatments.

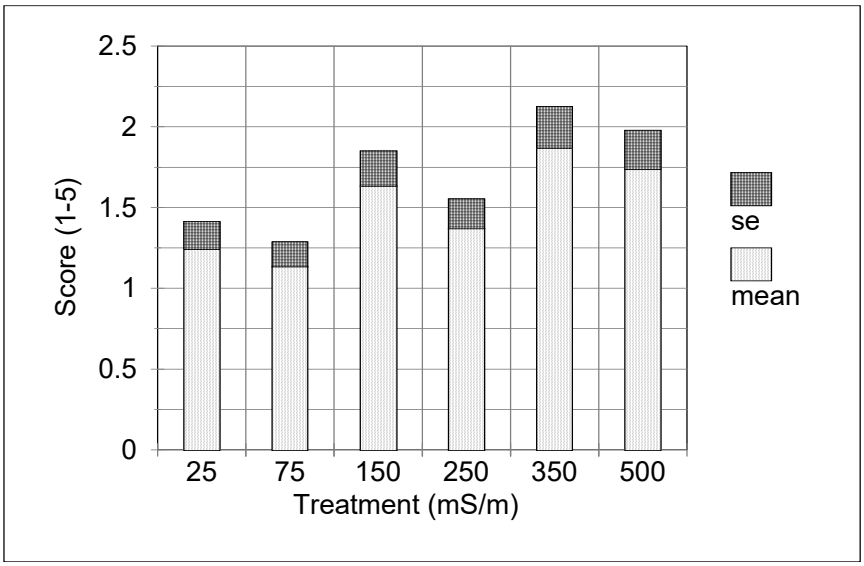


Figure 4.05. Leaf score conducted at Stellenbosch 11/1997 against treatment in mSm^{-1}. A value of one represents no leaf damage and a value of five, total leaf damage and or change in colour.

Table 4.06. Shoot fresh and dry mass ratios (dry/fresh) in the Stellenbosch study for the five growth stages during the season 1997-98. The ratio is expressed as oven dried mass over fresh mass.

TREATMENT	FULL BLOOM	PEA SIZE	VERAISON	HARVEST
1	0.30	0.36	0.48	0.62
2	0.31	0.33	0.49	0.6
3	0.30	0.33	0.49	0.57
4	0.29	0.36	0.48	0.61
5	0.32	0.35	0.49	0.61
6	0.30	0.33	0.49	0.59

Leaf mass was measured at Stellenbosch on the 5 main development stages during the explanation. The leaf and petiole wet and dry mass ratio, which is presented in Tables 4.04 and 4.05 respectively, indicates that variation between treatments started after or at the veraison period when the first saline irrigation was applied for the season. The reason for the large decline in numbers at the post harvest sampling, lies in the fact that the samples were taken late in the season, after colouring of the leaves had started. Again there was no clear trend in these data which resemble the leaf score data presented in Figure 4.05.

The chemical analyses of shoots, petioles and leaves for the 1997-98 season are given in Table 4.08. The only elements that showed a treatment effect were Na in the petioles at full bloom and post harvest, and Cl in the leaves, shoots and possibly petioles at post harvest. The Na content of the petioles at full bloom was the only hint of a carry-over effect. The fact that Na and Cl had a treatment effect only at the post harvest stage was due to the fact that saline irrigation was applied only after veraison. With almost no Na and Cl in the full bloom stage, it is safe to say there was no carry-over effect from Na and Cl residing in the perennial parts of the vines.

4.4.2.2 ☒⑨❶⑤② ⋈⓪⑨⋈❶④⋘⋙⑨⋙⑤⋈⋙⑩

Trunk circumferences were measured since 1995 at Nietvoorbij. Table 4.07 gives a summary of the averages over the last two seasons in reaction to treatment and the standard deviation within a treatment. The trunks were not affected by the treatment. Table 4.07 shows the difference in two sets of average circumference measurements calculated by subtracting the one from the other. The result indicates that treatment with saline water did not have an effect on growth of the trunk circumference.

4.4.2.3 ❵⋙⋘⋘ ⋘⑨⋙⋘ ⓪⑤⋘⋙❹

Resulting from larger canopies each year, the shoots were tied between two wires of the trellising system and long shoots were trimmed to keep the canopy firm. This affected the outcome of the leaf area index (LAI) since most plants were moulded into the same volume that was created by the trellising system. The only parameter that could have had an effect on the outcome of LI 2000 plant canopy analyser derived LAI measurements, was the leaf density of the plant. Figure 4.06 shows the results for three years, each subtracted from the results of 1995. One can see the downward shift

in the line between years implying an increased difference from the start of the experiment that does not clearly reflect treatment effects. The inclination of the 1998 line on the graph does begin to show a downward trend among treatments but this is too small to ascribe to the EC_i treatment. The downward shift is not likely to be due to management practices as described above. These practices cause the leaf density and the outer perimeter of the canopy to change. This makes the interpretation and modelling of remotely sensed LAI very difficult.

Table 4.07. Mean and standard deviation of trunk circumferences at Stellenbosch over 3 years as affected by different salinity levels in irrigation water.

TREATMENT	2/10/95	13/3/96	9/12/97	Difference*
25	58.38	65.88	71.19	5.24
75	54.81	62.56	67.25	4.69
150	56.56	65.59	70.84	5.25
250	57.31	64.72	69.44	4.72
350	57.50	64.97	69.78	4.81
500	58.38	66.84	71.66	4.82
STD DEV.				
25	6.26	6.38	7.26	
75	5.39	5.07	6.12	
150	8.06	9.44	8.76	
250	7.29	8.08	6.95	
350	6.72	7.42	8.00	
500	6.78	7.31	8.15	

* Difference is data from 9/12/97 subtracted from 13/3/96

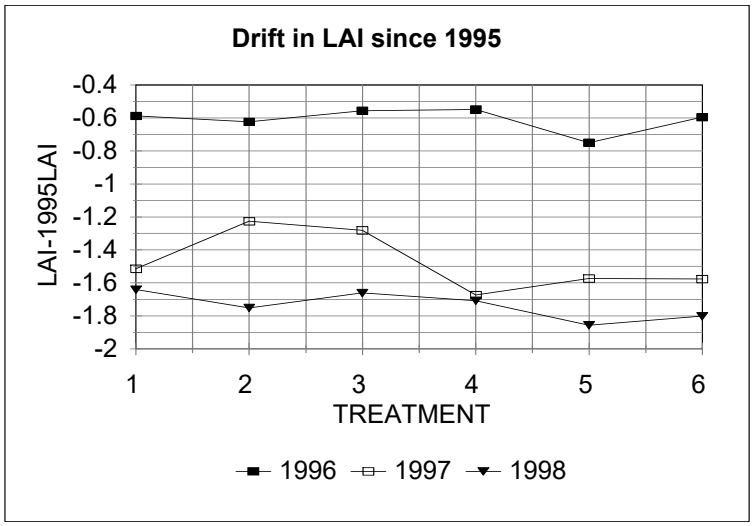


Figure 4.06. The LICOR estimated LAI for years 1996, 1997 and 1998, subtracted from the LAI of 1995.

Table 4.08. Mean Na, K and Cl concentrations in the leaves, petioles and shoots for the seasons 1995-96 and 1996-97 seasons.

- Na CONTENT OF LEAVES %

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	0.30	0.30	0.29	0.46	0.46
Treatment 2	0.30	0.31	0.29	0.41	0.49
Treatment 3	0.27	0.35	0.22	0.36	0.56
Treatment 4	0.32	0.35	0.27	0.40	0.44
Treatment 5	0.26	0.36	0.29	0.49	0.52
Treatment 6	0.28	0.32	0.28	0.46	0.49

- Na CONTENT OF SHOOTS %

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	0.44	0.52	0.33	0.32	0.27
Treatment 2	0.49	0.60	0.36	0.30	0.33
Treatment 3	0.45	0.53	0.33	0.31	0.34
Treatment 4	0.38	0.56	0.33	0.28	0.31
Treatment 5	0.48	0.58	0.36	0.28	0.32
Treatment 6	0.53	0.61	0.35	0.36	0.31

- Na CONTENT OF PETIOLES %

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	0.85	1.05	0.99	1.37	1.77
Treatment 2	0.96	1.04	0.74	1.40	1.98
Treatment 3	0.80	1.05	0.76	1.36	1.82
Treatment 4	0.97	0.99	0.84	1.43	1.90
Treatment 5	0.88	1.03	0.78	1.50	2.02
Treatment 6	1.02	0.95	0.78	1.51	2.02

- K CONTENT OF LEAVES (%)

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	1.26	1.25	0.97	0.76	0.42
Treatment 2	1.24	1.21	1.04	0.87	0.47
Treatment 3	1.24	1.32	0.97	0.98	0.49
Treatment 4	1.18	1.18	0.96	0.77	0.43
Treatment 5	1.36	1.19	1.01	0.85	0.48
Treatment 6	1.22	1.32	1.01	0.87	0.45

- K CONTENT OF SHOOTS (%)

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	1.85	1.33	0.82	0.61	0.56
Treatment 2	1.87	1.30	0.86	0.62	0.58
Treatment 3	1.88	1.50	0.79	0.67	0.55
Treatment 4	1.76	1.37	0.76	0.65	0.57
Treatment 5	2.04	1.38	0.82	0.61	0.52
Treatment 6	1.94	1.47	0.82	0.65	0.54

- K CONTENT OF PETIOLES (%)

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	2.92	3.05	1.09	1.75	0.94
Treatment 2	2.36	3.06	1.23	1.96	0.91
Treatment 3	2.88	3.29	1.16	2.31	1.09
Treatment 4	2.55	2.88	1.10	1.94	1.10
Treatment 5	2.57	3.18	1.22	2.16	1.02
Treatment 6	2.70	3.27	1.16	2.12	0.95

- Cl CONTENT OF LEAVES %

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	1.57	1.92	1.57	2.32	1.04
Treatment 2	2.24	1.65	1.62	2.62	1.10
Treatment 3	1.47	1.83	1.48	2.14	1.14
Treatment 4	1.33	1.63	1.46	2.36	0.98
Treatment 5	1.44	1.82	1.78	3.16	1.25
Treatment 6	1.75	1.64	1.69	2.50	1.13

- Cl CONTENT OF SHOOTS %

	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	1.63	2.24	1.28	0.87	0.31
Treatment 2	1.32	2.12	1.46	0.99	0.33
Treatment 3	1.39	2.13	1.20	0.88	0.33
Treatment 4	1.79	1.98	1.04	0.89	0.34
Treatment 5	1.47	2.11	1.20	1.25	0.37
Treatment 6	1.49	1.72	1.33	0.89	0.36

- Cl CONTENT OF PETIOLES %

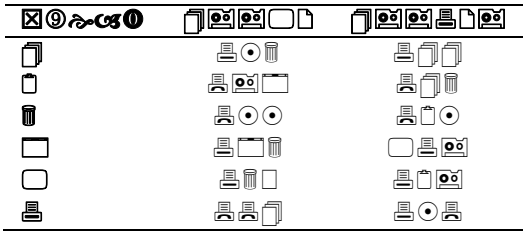
	Full Bloom	Pea Stage	Veriason	Harvest	Post Harvest
Treatment 1	3.92	6.28	5.05	6.74	NA
Treatment 2	4.32	5.65	4.88	9.30	NA
Treatment 3	4.12	5.90	4.69	6.25	NA
Treatment 4	3.57	4.18	4.63	8.72	NA
Treatment 5	3.78	3.73	4.08	10.63	NA
Treatment 6	3.83	3.92	4.98	7.87	NA

4.4.2.4 ✓⑨❶⑤➭☙ ⑩➢⑥⑥❶ ④☙⑩⑩

Individual vine shoot mass was measured at the end of the season for all the experimental vines at Stellenbosch. This was done to establish the effect of saline irrigation on the woody part of the vines.

Table 4.09 shows that pruned shoot mass shows a similar pattern to that encountered initially at the Robertson site in 1992 (Chapter 3), namely that there is no clear trend among treatments.

Table 4.09. Mean pruned shoot mass (g/vine) at Stellenbosch over the 1995-96 and 1996-97 seasons.



4.4.3 Summary of the means in regard to reproductive growth and yield

The shoot mass, yield and mean bunch mass for each treatment at Stellenbosch is shown in Tables 4.10 to 4.12. No clear treatment effects could be found in the data, indicating that in a situation where only supplementary irrigation is needed late in the season, it is probably safe to use water of inferior quality.

Table 4.10. Mean number of bunches at the Stellenbosch site for the years 1996 to 1998.

YEAR	TREATMENT						YEARLY AVERAGE
	0	75	150	250	350	500	
1996	30.6	35.8	30.8	35.9	34.5	32.4	33.3
1997	37.3	35.3	35.2	36.2	34.0	34.6	35.4
1998	34.6	35.6	36.7	34.9	34.1	33.5	34.9
AVG	34.2	35.6	34.2	35.7	34.9	33.5	

Table 4.11. Mean yield per bunch (kg) at the Stellenbosch site for the years 1996 to 1998.

YEAR	TREATMENT						YEARLY AVERAGE
	0	75	150	250	350	500	
1996	0.067	0.073	0.069	0.069	0.071	0.070	0.070
1997	0.083	0.078	0.076	0.090	0.081	0.079	0.081
1998	0.054	0.065	0.061	0.052	0.059	0.058	0.058
AVG	0.068	0.072	0.068	0.070	0.070	0.069	

Table 4.12. Mean yield (kg) at the Stellenbosch treatments for the years 1996 to 1998.

YEAR	TREATMENT						YEARLY
	0	75	150	250	350	500	AVERAGE
1996	2.06	2.64	2.11	2.49	2.57	2.28	2.36
1997	3.09	2.73	2.65	3.23	2.76	2.72	2.86
1998	1.87	2.29	2.27	1.82	2.02	1.95	2.04
AVG	2.34	2.55	2.34	2.51	2.44	2.32	

The tables above show a variation between seasons that is higher than the variation between treatments. Much less response was observed than in the Robertson study. Supplementary irrigation later in the season therefore does not have the same impact on vines as the intensive irrigation that is demanded in a drier region.

4.4.4 ANOVA of reproductive growth and yield

The need for further analysis of reproductive growth and yield existed. The means that were calculated in the previous section do not account for the possible interaction between treatment, yield, number of bunches, shoot mass and trunk circumference.

The results of the general analysis of variance and that of the test that the mean of the control does not differ from the mean of the other treatments are given in Table 4.13. The pooled results for all years did not reveal any new information. The only data with slight significance were those of 1996. This was at the start of the experiment when extensive target values were set for the salinity controller in the irrigation system. It was also one of the years in which we irrigated 3 times during the season, with the first irrigation event in December 1995. The implication is that salinity only had an effect on the vines when saline irrigation commenced early in the season.

Table 4.13. General analysis of variance of the Stellenbosch trial, for number of bunches, yield and yield per bunch over the years 1996, 1997 and 1998.

No of bunches (all years)			
	F	Ass.P	R^2
Model	<1	NS	0.049
Replicates	<1	NS	
Treatment	<1	NS	
Yield (all years)			
	F	Ass.P	R^2
Model	<1	NS	0.060
Replicates	<1	NS	
Treatment	<1	NS	
Yield/bunch (all years)			
	F	Ass.P	R^2
Model	<1	NS	0.070
Replicates	1.3	NS	
Treatment	<1	NS	
No of bunches (1996)			
	F	Ass.P	R^2
Model	4.2	0.008	0.693
Replicates	3.4	**0.050**	
Treatment	4.7	0.009	
Yield (1996)			
	F	Ass.P	R^2
Model	3.9	0.011	0.675
Replicates	4.2	**0.024**	
Treatment	3.7	**0.022**	
Yield/bunch (1996)			
	F	Ass.P	R^2
	1.9	NS	0.500
Replicates	4.0	**0.029**	
Treatment	<1	NS	
No of bunches (1997)			
	F	Ass.P	R^2
Model	<1	NS	0.317
Replicates	1.5	NS	
Treatment	<1	NS	
Yield (1997)			
	F	Ass.P	R^2
Model	1.4	NS	0.420
Replicates	<1	NS	
Treatment	1.9	NS	

Yield/bunch (1997)			
	F	Ass.P	R^2
Model	1.3	NS	0.409
Replicates	<1	NS	
Treatment	1.6	NS	
No of bunches (1998)			
	F	Ass.P	R^2
Model	<1	NS	0.076
Replicates	<1	NS	
Treatment	<1	NS	
Yield (1998)			
	F	Ass.P	R^2
Model	<1	NS	0.247
Replicates	<1	NS	
Treatment	<1	NS	
Yield/bunch (1998)			
	F	Ass.P	R^2
Model	1.2	NS	0.412
Replicates	1.4	NS	
Treatment	1.2	NS	

Thus only the results from 1996 disclosed any significant information and this was related to the higher salinity target values and the time during the season that the experiment was irrigated with saline water. In other words, treatment effects for the other years when saline irrigation was started later in the season (January), were not evident.

4.5 PRODUCE QUALITY

4.5.1 Analysis of the must

The sugar and titratable acid content of the must in Figure 4.07 do not reveal a strong treatment effect. Only the 1998 must data are shown here. Virtually no treatment effect is evident (Figure 4.07). From this, it can be expected that there will be no treatment effect in the quality of resulting wines.

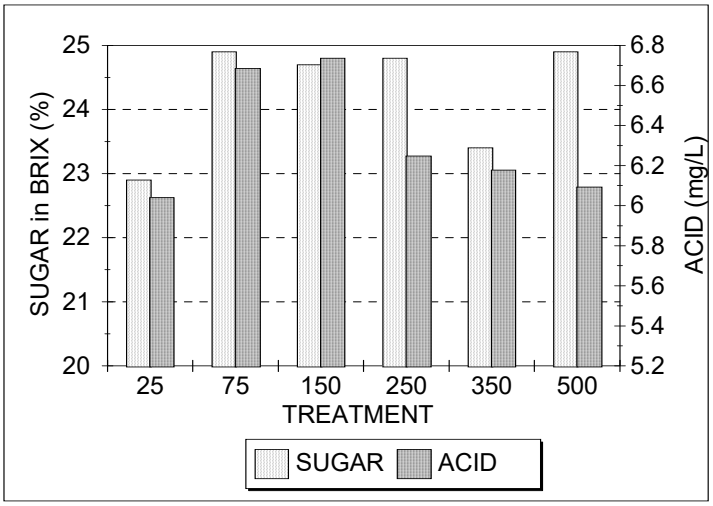


Figure 4.07. The sugar content and the titratable acid content of the must from the Stellenbosch site at harvest 1998

4.5.2 Quality differences in wine from vineyards subjected to saline irrigation

4.5.2.1 [illegible]

The effect of saline irrigation on wine produced from Weisser Riesling grapes was tested in the 1996-97 season. Three wines were produced, one from treatment 1, one from treatment 3 and one from treatment 6. The three wines were subjected to an organoleptic evaluation on 16/10/97. The wines were prepared by the Department of Viticulture and Oenology, University of Stellenbosch.

4.5.2.2 [illegible]

The grapes from replications of the specific treatments were combined for the purpose of this experiment. Three Weisser Riesling wines were made. The methods employed for making and testing the wines are described in detail in Chapter 3.

4.5.2.3 [illegible]

The results are given in Tables 4.14 to 4.16 followed by a short discussion.

Table 4.14. Sugar, titratable acidity and pH in Weisser Riesling juice

Wine	Treatment	Sugar (°B)	Titr. Acidity g/l	PH
98/494	Control	25.3	4.72	3.27
98/495	Treatment 3	26.0	5.39	3.25
98/496	Treatment 6	26.0	5.22	3.26

From Table 4.14 it can be seen that the grapes were harvested at excessive sugar levels. This is normally corrected in the wine making process. The differences in the sugar levels of the control and the treatments were too small to have any significant effect on wine quality. Juice from the treatments showed slightly higher titratable acid concentrations than the control.

Table 4.15. Routine analysis: Weisser Riesling wines

Treatm	Alcohol Vol %	SG	Extract G/l	Sugar g/l	SO_2 Free mg/l	SO_2 Total mg/l	Volatile Acidity g/l	Titr. Acidity g/l	pH
1	14.34	1.0037	57.7	28.2	30	102	0.46	6.4	3.24
3	15.96	0.9971	45.2	24.8	29	112	0.57	6.0	3.46
6	15.06	1.0021	55.3	27.6	29	96	0.52	6.1	3.32

In Table 4.15 it is evident that the alcohol concentration of the wines was high (from high grape sugar). The pH of treatment 3 was highest. No marked differences in the composition of the other chemical constituents were evident.

Table 4.16. Sensory evaluation data for Weisser Riesling wines

Wine nr	Treatment	Ranking* Salty taste	Ranking* Overall wine quality	Median** point/20	Comments
98/494	Control	42 a	41 a	14	Light fruity, medium bodied
98/495	Treatment 3	48 a	56 b	11	Lack of character
98/496	Treatment 6	58 b	51 a	12	Salty, neutral character

* Rank sum of 23 tasters

* Lower values for ranking indicate less salty taste or higher wine quality

** Median value for wine quality on a 20-point scale

The wines from treatment 6 were judged to be significantly more salty to taste than those from the control and treatment 3 (P = 0.05). When the wines were compared by way of ranking, the quality of the wines made from treatment 3 was significantly lower than the other two treatments. The wines made from the untreated grapes (control) showed more fruitiness in flavour and were given a median of 14 on a 20-point scale. All the wine lacked a typical Weisser Riesling character.

From these results it is evident that although the treatments had no remarkable effect on the sugar, acidity, pH level of the juice after crushing and the chemical composition of the wines, the effect of saline irrigation becomes more pronounced in the quality of the resulting wines. Wines made from higher salinity treatments showed a significant detectable saltiness on taste and were judged lower in sensory quality than the corresponding wines made from the grapes of the control treatment. Unfortunately, none of the wines possessed the typical cultivar character, an aspect that cannot be related to irrigation only, but to the overall quality of the grapes.

4.6 TRANSPIRATION OF VINES SUBJECTED TO SALINE IRRIGATION

4.6.1 Introduction

A stem heat energy balance technique was used as described by Savage *et al*. (1993). A steady state condition was created around the stem with heater and sensors in contact with the stem and totally insulated around this portion of the stem. The leaf surface area of the plant was determined by various methods, as destructive measurements of the plant would have jeopardised future measurements on these plants.

4.6.2 Materials and methods

The 0.6 ha site at Nietvoorbij consisted of 24 plots which were divided into 6 treatments. Each plot consisted of 6 rows with 10 vines. The 8 vines in the middle of the plot were used as the experimental plants. No destructive measurements were

conducted on experimental plants. For this study, however, only two sites were used and only 4 vines from each. One plot was of treatment 1, i.e. ~40 mSm^{-1} and the other of treatment 6, i.e. 500 mSm^{-1}. All plots received the same amount of water during the season. Irrigation events were for supplementary irrigation only, which amounted to 3 events per season.

The main properties measured were soil water, soil EC_e , transpiration, weather and canopy parameters. Transpiration was measured using the Dynamax heat energy balance system and the software supplied was used to calculate transpiration. Soil water was measured using a CPN neutron probe. Soil samples were taken to determine the level of salinity in the soil and its possible effect on the plant. An MCS weather station was used to monitor wet and dry bulb temperature, radiation, rainfall, wind speed and direction. The canopy characteristics were measured by determining leaf size per shoot, number of leaves per shoot, number of shoots per plant and the LAI with a LI2000 plant canopy analyser (LI2000 PCA).

The weather data from an MCS-system was used to determine the hourly and daily evapotranspiration according to the Penman-Monteith equation. The data were collected every minute and then averaged and logged every hour. The weather station was situated at the edge of the vineyard, which was 50m away from the site where transpiration measurements were made.

Soil samples were taken using a Thompson auger at depths of 0-15, 15-30, 30-60, 60-90 and 90-120cm. They were tested for EC_e and the concentration of Na, Ca, Mg, K and Cl in the saturated paste extract.

Transpiration measurements were made on woody stems under field conditions. The method as first described by Sakuratani (1981) and later by Savage et.al. (1993) was applied. The Dynamax heat energy balance system was used. The data were logged onto a CR10X data logger. With the sensors used for measurements, diameter may be within the range of 24 to 32mm. The sensor was applied to the middle of the stem, as this is the only section that has minimal deformities. The sensor itself consists of a heater embedded in a thin sheet of cork with a pair of copper-constantan thermocouples placed above and below the heater. The heater and the thermocouples were placed in contact with the stem. To ensure the best possible contact, the stem

was stripped of all loose bark and sanded to get a smooth surface close to the cambium. A heat conductive paste was first applied to the stem and then covered with thin plastic film. The heater and thermocouples were insulated with white closed cell rubber foam as supplied by the manufacturer. This in turn was covered with a reflective thick aluminium sheet. A second aluminium foil layer was applied over the whole sensor to further minimise the effect of radiation and wind. The aluminium shield was large enough to shade the lower part of the stem from direct sun as well. All connections in the wiring were insulated with double-sided mirror tape. A 12V rechargeable battery was used on site and was charged from a 12V-transformer charger, which was situated at the closest power point 50m away. The battery was connected to the charger via a 50m lead.

The logger was programmed to sample every 15 seconds and then to log the average value every 30 minutes. The memory capacity of the logger was sufficient to log for a week. The data were downloaded to a portable computer via an optically isolated serial interface (Campbell Scientific SC32A).

Every possible precaution was taken to prevent an environmental impact on the transpiration measurements. Shackal *et al.* (1992) recorded that environmental temperature changes may be large enough to cause temperature differentials in the stem. In this study only days with similar weather conditions were taken into account and every possible measure was taken to isolate the measuring area from environmental temperature changes.

The programs supplied by the manufacturer of the system were used to calculate sap flow and no reason to question the outcome of the results was found. The software allowed enough room to recalculate the data if any of the variables was found to be incorrect.

The canopy characteristics of the plant were assessed in two ways. More than one approach was followed for the reason that destructive measurements of the canopy could not be made. Firstly, the LI2000 PCA was used to determine the LAI. Secondly, leaf length measurements were transformed to leaf area. Because of the good correlation that existed between shoot length and leaf area as well as shoot length and the LI2000 PCA-derived LAI, shoot length data gave the best approximation of the

LAI. It was also possible to model the leaf area very accurately by making use of the 2nd order equation derived from the variation of leaf length (or size) from the base of the shoot to the apex. This resulted in a statistical method whereby the leaf surface of a shoot could be very accurately determined. To be able to predict the leaf surface area, all that is required is the leaf length (or area) of the base leaf, the leaf length (or area) of the largest leaf with its number as an (x,y) pair (this is also the turning point) and lastly the number of leaves on the shoot. Side shoots are treated in exactly the same manner. The advantage of this method is that minimal disturbance of the canopy is involved.

4.6.3 Results and discussion

4.6.3.1 [illegible]

The LI2000 PCA was used at first to determine the LAI of the plants that were used to determine transpiration. This instrument constantly underestimated the LAI and the data had to be corrected. It was then decided to find a way of measuring LAI of the plants that were going to be monitored directly. We then decided to model leaf area from physical measurements.

4.6.3.2 [illegible]

Though every effort was made to calibrate the LCA for use in circumstances where accurate leaf area measurements are needed, it failed to produce a result within the 95% range. For these purposes the leaf lengths were measured and converted into leaf area. Leaves were sampled over the whole experiment and both leaf length and leaf surface area were determined. The following regression equation was determined

$$\text{Leaf area } (cm^2) = 1.36 \times \text{leaf length}^{1.962}\ (cm) \qquad R^2 = 0.76 \qquad 4.1$$

$$LAI = LA_{shoot} \times N_{sp} / S_{ap} \qquad 4.2$$

where LA_{shoot} is the total leaf area per shoot, N_{sp} is the number of shoots per plant and S_{ap} is the total soil area per plant.

Equations for the prediction of leaf length per shoot were also determined from the above. Leaf length and leaf position (P) from the base of the shoot were entered into a

model by which the length of any leaf on the shoot could be predicted. It thus became possible to predict total leaf area per shoot by simply measuring the length of the shoot, counting the number of leaf positions on the shoot and the length of the largest leaf on the shoot. For side shoots the same procedure was followed. This produced the following equations for treatments 1 and 6:

Tr 1: Leaf length = $62.0 + 6.9196P - 0.3407P^2$ $R^2=0.9622$ 4.3

Tr 6: Leaf length = $26.3 - 0.21P + P^2$ $R^2=0.56$ 4.4

The data were compared with the direct measurement of total leaf length data converted to leaf area, and they compared quite well (Figure 4.08).

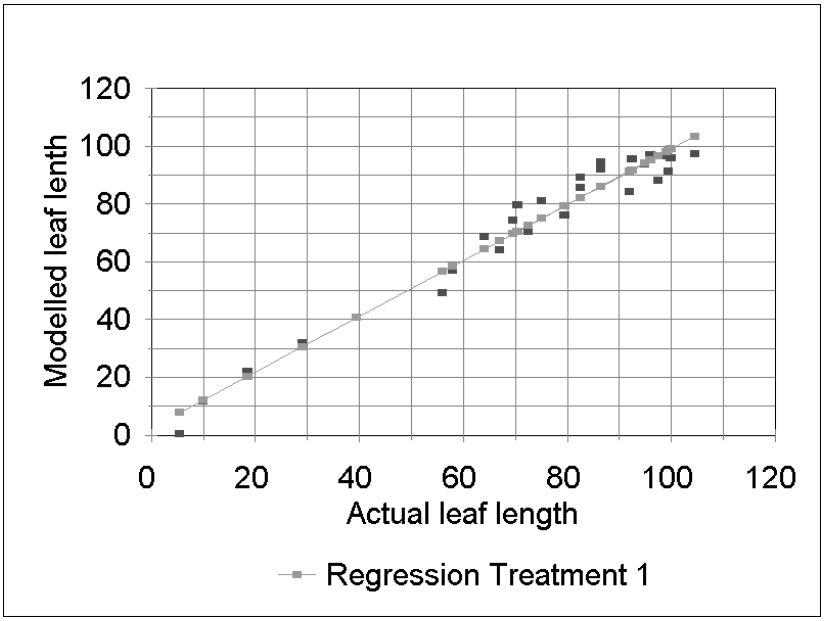


Figure 4.08. The relationship between actual leaf area and modelled leaf length.

4.6.3.3 ☒⑨☙⑤⑩⑦⓪⑨☙❿⓪⑥⑤ ④↝☙⑩❶⑨↝④↝⑤❿⑩

Transpiration measurements were done on 15 consecutive days with very little change in weather. Transpiration measurements were firstly calculated using only leaf area and not LAI. The soil water conditions were very dry and irrigation was inevitable. An irrigation event took place within this 15 day monitoring period. As a result of the dry topsoil, the soil's contribution to ET was very small. Though the soil was wetter after irrigation, the transpiration rate declined (Figure 4.10) but so also did ET. The

data presented in Figure 4.10 are the averaged data for five days before irrigation and five days after irrigation.

4.6.3.4 ☒⑨ↀ⑤⑩⑦⓪⑨ↀ❶⓪⓪⑤ ↀ⑤ↀ ➢❷ↀ⑦⑥❶⑨ↀ⑤⑩⑦⓪⑨ↀ❶⓪⓪⑤🗐

Evapotranspiration (ET) was calculated using the Penman-Monteith equation. The data from the logger of the on-site weather station were used to calculate hourly ET values (mm h^{-1}). For the purpose of this report the ET was calculated and averaged for the same 5 days before irrigation and after irrigation as the transpiration measurements. The results are presented in Figure 4.10.

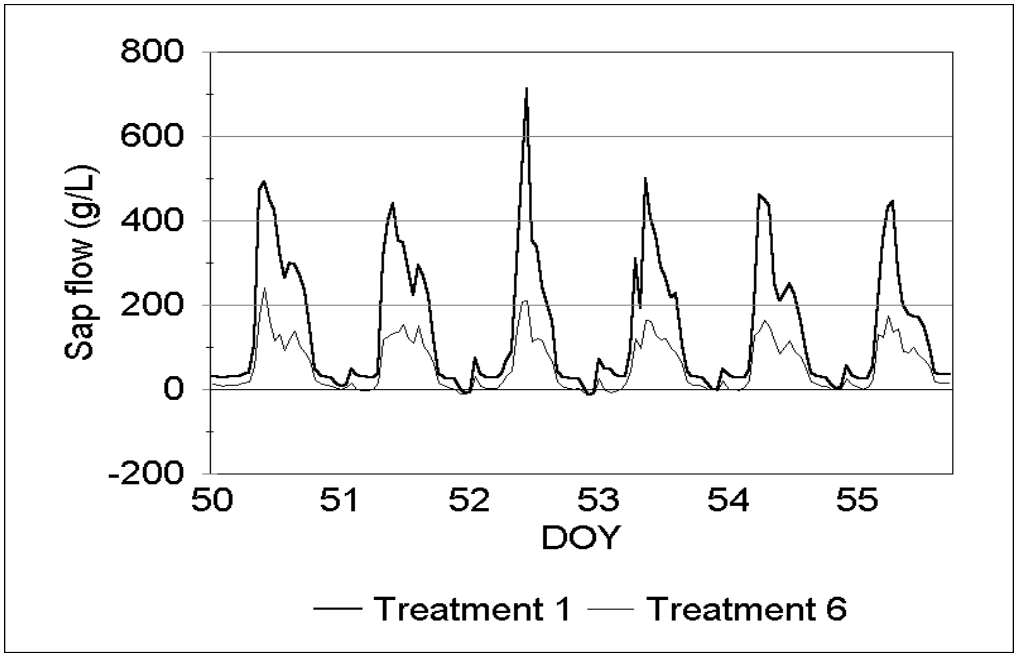


Figure 4.09. Simultaneous sap flow over 6 days of one vine in the fresh water and one in the 500 mSm^{-1} irrigation water treatment *(DOY = Day of Year)*.

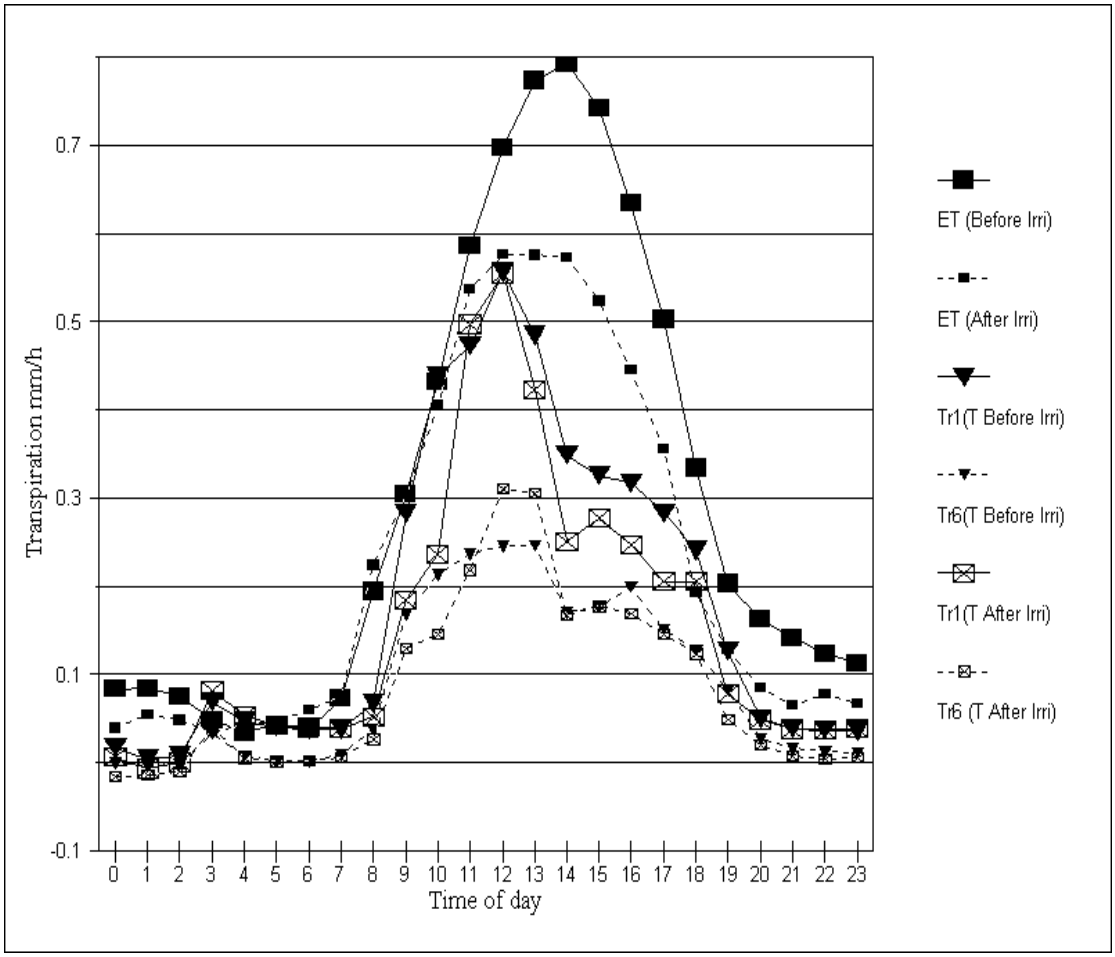


Figure 4.10. Simultaneous ET and T of two vines, one vine in the fresh water and one in the 500 mSm^{-1} irrigation water treatment.

It is quite clear from Figure 4.10 that though ET and T declined after irrigation, T became relatively more pronounced after irrigation. The relative and absolute values are given in Table 4.17.

Table 4.17. The relative change in T of treatments 1 and 6, ET and soil water values after irrigation.

		Before irrigation	After irrigation
T (mm per day)	Treatment 1	4.36	3.62
	Treatment 6	2.16	2.01
ET (mm per day)		7.2	5.5
T as % of ET	Treatment 1	60.4	65.5
	Treatment 6	29.9	36.4
Soil water content	Treatment 1	186.8	238.1
mm m^{-1}	Treatment 6	170.1	235.8

4.6.3.5 [illegible]

We found that the change in soil water content over the five days before irrigation was too small for the neutron probe to measure correctly. The soil water increases after irrigation were, however, significant and merely confirmed that both plants received the same amount of water. Soil samples from the two sites also confirmed the difference in EC_e and chemical composition of the extract (Table 4.18).

Table 4.18. The EC_e and SAR_e of the two sites in the Stellenbosch experiment.

	Treatment 1		Treatment 6	
Depth (cm)	**SAR_e**	**EC_e**	**SAR_e**	**EC_e**
15	2.18	62.2	2.79	162.1
30	2.16	49.9	2.83	61.1
60	2.08	31.5	2.97	89.9
90	2.39	43.1	2.48	81.9
120			2.16	48.2

4.6.4 Conclusion

In an effort to obtain a better LAI for the vines that were used for measuring transpiration, it was necessary to model the leaf area of the vines since other methods failed to be exact and any change in the canopy dimensions would possibly alter the outcome of transpiration measurements. The method worked well and although it is more time-consuming than remote methods it is easier than stripping the plant of all its leaves. It also has the benefit that any of the measurements can be repeated.

With transpiration measurements, no other field data were available with which to calibrate or compare transpiration, other than the weather station and soil water depletion data. The transpiration method, if applied correctly, does not need calibration. The method as applied by Savage *et al*. (1993) is based on the accountability of the total heat flux within the area of measurement. Since maximum precautions were taken to account only for energy lost through sap flow, the sap flow rates were considered to be accurate. The published crop factor for vines during this time of season is 0.4. The estimate in this study from T and ET was 0.42.

The fact that the same method was applied between the fresh water treatment and the 500 mSm^{-1} treatment makes these findings very relevant. The response of grapevines

to salinity and the different water consumption figures over the duration of one day is very clear from this study. The plant reaction after an irrigation event is also very clear. Transpiration rates fell while evaporation rates went up. This means that evaporation from the wet soil surface caused a higher relative humidity and resulted in less transpiration.

Since vines similar in size, leaf colour, overall leaf condition, LAI and soil water status were chosen for these measurements, it is quite clear that transpiration measurements are more sensitive to salt stress than can be deduced from visible differences in the vine canopy. Leaf area measurements alone can thus not be used as an indicator of stress in plants in a management sense. Leaf damage, because of saline irrigation water, is in most cases a cumulative effect over the whole season and cannot be rectified once it is visible, even though it can be recorded.

5. RESPONSE INDICES, EVALUATION OF IRRIGATION WATER AND MANAGERIAL OPTIONS

5.1 INDICES THAT DESCRIBE THE RESPONSE OF PERENNIAL CROPS TO SALINE IRRIGATION

5.1.1 Yield and salinity

The response curve used by Maas & Hoffman (1977) and Ayers and Westcot (1989) postulated a reduction in yield of 1 percent for every 10 mSm^{-1} rise in EC_e for grapes whereas Moolman *et al*. (1999) found a 3 percent reduction in yield for every 10 mSm^{-1} rise in EC_e (Figure 5.01). On first inspection the latter result appeared to be confirmed by the additional three years' data presented in this report, suggesting that the Colombar grape cultivar is indeed highly sensitive to salinity and considerably more so than the general literature would suggest. A more detailed look at the yield information on a seasonal basis is presented later in this section.

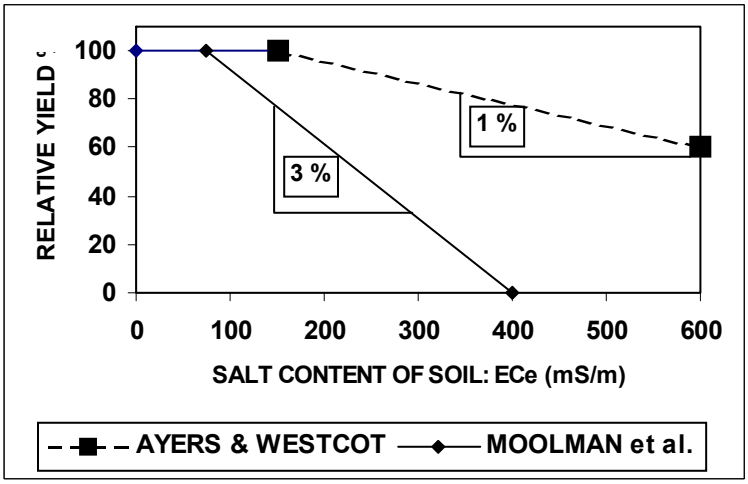


Figure 5.01. The yield response of grapes to soil salinity, as proposed by Ayers and Westcot (1989) and found for the Colombar cultivar by Moolman *et al.* (1999).

Maas and Hoffman (1977) used a two-piece response equation of the following kind to describe grape response (in terms of relative yield RY) to salinity (EC_e):

$$RY = 1+S(EC_e - EC_t) \quad \text{.....(5.01)}$$

The threshold soil salinity below which yield is unaffected is given by EC_t and S is the slope of the response when salinity exceeds the threshold value.

Moolman *et al*. (1999) presented the result shown in Figure 5.01 as a relative yield fraction:

$$RY_{colombar} = 1 - 0.003(EC_e - 75) \quad \text{.....(5.02)}$$

or, when relative yield is expressed as a percentage:

$$RY_{colombar} = 100 - 0.3(EC_e - 75) \quad \text{.....(5.03)}$$

The two response functions in Figure 5.01 have different threshold salinity ($EC_{t)}$ values. Ayers and Westcot (1989) present a threshold value of 150 mS m^{-1} for grapes whereas Moolman *et al*. (1999) found an EC_t of 75 mS m^{-1}, confirming the greater sensitivity to salinity inherent in the steeper slope of their equation.

To further test the effect that treatments and management practices had on yield over all sites and seasons, seasonal mean EC_e values were calculated. From soil data collected at the beginning and end of the irrigation season, averages were used to reflect an overall EC_e for the season. This step produced a better correlation of EC_e with yield components. The way in which the mean values should most appropriately be calculated for the soil profile had also to be found. Depth-weighted means gave the best results. In the ensuing discussion the term EC_e is used to designate seasonal mean values. EC_e in contrast to EC_{sw} gave a better correlation with yield. EC_e has the advantage that it is still easier to acquire than EC_{sw} results and one must bear in mind that the test for EC_e by a farmer will be more accurate, cheaper and easier than EC_{sw}.

EC_e was tested against yield, the number of bunches and shoot mass for all three sites and all three seasons. The data from the main trial and the pilot study at Robertson and the Nietvoorbij trial were analysed separately. Three weighted EC_e means were calculated to generate the variables x_1, x_2 and x_3. The 120cm depth observations were omitted as they were clearly outside the root zone. The following weights were assigned:

x_1 : a weight of 1 for depth 60 cm
x_2 : a weight of 0 for 15 cm, 0.33 each for 30, 60 and 90 cm
x_3 : a weight of 0 for 15 cm, 0.25 for 30, 0.5 for 60 and 0.25 for 90 cm

The correlation matrices are given in Table 5.01and the values of the weighted means in relation to treatments are given for the three trials in Tables 5.02 to 5.04.

Table 5.01. The correlation matrices for the weighted means from R = Robertson main trial, N = Nietvoorbij (Stellenbosch) and L = pilot study ("loodsproef").

	X_2	X_3
X_1	R : 0.917 N : 0.974 L : 0.896	R : 0.952 N : 0.985 L : 0.942
X_2		R : 0.890 N : 0.998 L : 0.993

Table 5.02. The weighted EC_e means (x_1, x_2 and x_3) in relation to treatments in the Robertson main trial.

Treatment	X_1	X_2	X_3
0	60.20	60.04	60.08
2	63.15	62.75	62.86
3	100.06	93.98	95.5
4	139.89	131.77	133.89
5	128.83	122.2	123.86
6(a)	67.23	89.6	84.01
6(b)	78.67	74.19	75.33

Table 5.03. The weighted EC_e means (x_1, x_2 and x_3) in relation to treatments in the Nietvoorbij (Stellenbosch) trial.

Treatment	X_1	X_2	X_3
0	29.55	30.84	30.52
2	44.06	43.86	43.91
3	49.75	50.73	50.22
4	65.98	66.56	66.42
5	75.12	80.39	79.08
6	112.17	113.28	113.03

Table 5.04. The weighted EC_e mean x_3 in relation to treatments in the Robertson pilot study.

	X_3 values
LS1	84.1
LS2	103.4
SL1	90.7
SL2	99.8

The progressive increase in mean EC_e values with increasing EC_i (from treatment 0 to 5 or 6; it should be recalled that 6a and 6b have a fresh water component) is clearly evident in the Nietvoorbij (Stellenbosch) data (Table 5.03) but is not maintained at the highest salinity level (treatment 5) in the Robertson trial (Table 5.02). This inflection in the soil salinity response to irrigation salinity at Robertson can be attributed to the experimental design, entailing an equal water application to all plots based on soil water content in the control treatment. At the highest salinity level this would have resulted in the leaching fraction of the applied water being larger on account of the smaller transpirational water loss associated with more stunted vines.

Regression analyses for the Nietvoorbij data did not reveal a relationship between EC and the variables shoot mass, number of bunches and yield. At Robertson, the regression statistics are shown in Table 5.05.

Table 5.05. P values, F values and regression coefficients for the Robertson main trial as a product of a regression analysis between weighted mean EC_e (X_1, X_2 and X_3) and plant parameters (shoot mass, yield and number of bunches).

		X_1	X_2	X_3
Shoot mass	**P-value**	0.092	0.070	0.056
	b_1	-0.00063	-0.00077	-0.00080
No of bunches	**P-value**	0.022	0.007	0.009
	b_1	-0.055	-0.075	-0.071
Yield	**P-value**	0.011	0.0045	0.005
	b_1	-0.114	-0.0146	-0.0141

The experimental data for the pilot study did not reveal any significant relationships.

The Robertson main trial data in Table 5.05 suggest that the selection of depth increments for calculating a profile mean EC_e value is important. Using only those depth increments that include the root zone achieves the best basis for using EC_e as a predictor of yield. The temporal variation in EC_e is probably also important since, although the Nietvoorbij trial showed relatively high mean EC_e values, these reflect a peaking late in the season and therefore were of less consequence from a yield point of view. A similar situation prevailed in the pilot study, for which, even though there were no significant differences among treatments, an overall higher yield was

obtained than in the Robertson main study. This implies that the level of EC_e in the soil and the duration for which it is sustained is probably more important than the timing of peak EC_e values during the season.

5.1.2 Yield and sodicity

The relationship between yield and SAR (calculated as a depth-weighted seasonal mean analogous to the X2 mean used for salinity evaluation above) in the Robertson main trial is highly significant (Fig. 5.02; Table 5.06). This relationship translates into a yield loss of 2 kg/vine (i.e. about 30% in relative yield terms) for each unit increase in SAR.

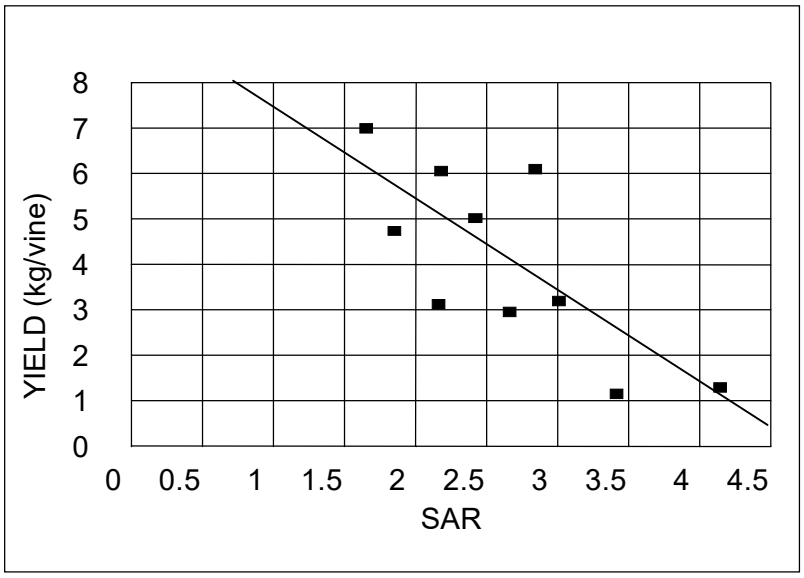


Figure 5.02. Regression analysis of SAR_e of the Robertson main study against yield of the 1996/97 and 1997/98 seasons for treatments one to five (line = predicted values; yield = - 2.04 SAR + 9.45)

Table 5.06. Result of a regression analysis of the Robertson main study between SAR_e and yield of treatments 1 to 5.

Regression analysis	R^2	F	P	X	Intercept
Robertson main study	0.58	10.8	0.0003	-2.04	9.45

The strength of the relationship between yield and SAR_e in Fig. 5.02 highlights the importance of avoiding presumptions of causality, since it suggests that sodicity (nutritional imbalance) and salinity (osmotic effects) cannot easily be separated in considering the influence of saline irrigation water on crops. Other indirect effects are also possible, such as chloride toxicity (see below). For comparison of the yield relationships to EC_e and SAR_e with each other the yield data should be normalised by expressing them as relative yields.

In Figure 5.03 we show a graph of relative yield (treatment means) in each of the six seasons as a function of EC_e. They reveal an interesting change in the slope of the yield response function, intersecting at about the maximum yield (i.e. suggesting a similar threshold salinity each season) but steepening as the experimental seasons progressed to a point in 1997 where the slope of the response had become even steeper (-0.004) than that (-0.003) reported by Moolman *et al.* (1999).

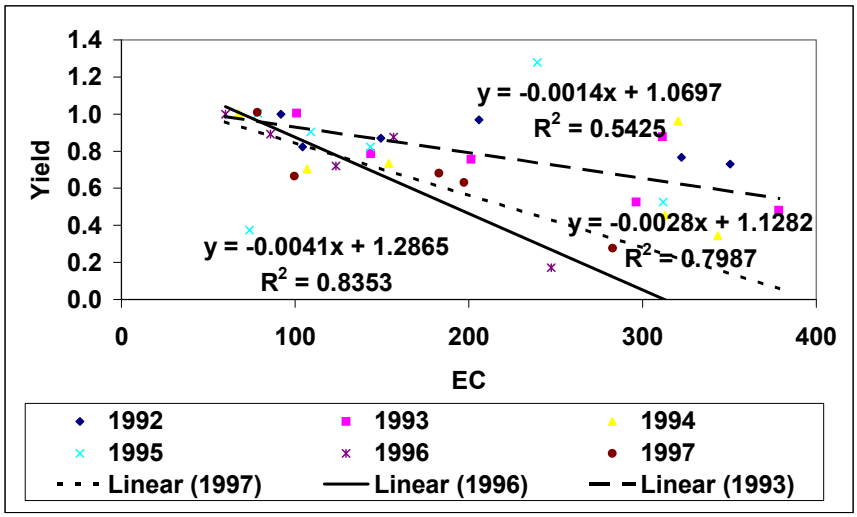


Figure 5.03. Relationship between relative yield and EC_e in relation to season in the Robertson main study 1992-1997.

As indicated earlier, 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). 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 $CaCl_2$-NaCl solution used for salinity treatments was equimolar with respect to Na and Ca, which means that SAR actually increases with increasing salinity (EC_i) in all these trials.

Not surprisingly then, the general pattern of seasonal crop response to soil conditions is much the same in Figure 5.04 whether either SAR or EC is chosen as the independent variable. These graphs summarise probably the most important results from this long-term study and a brief explanation of their construction is warranted. First of all, besides being in keeping with past practice, relative yield was employed to eliminate the effect of a general yield decline across all treatments during the course of the experiment. (This has been attributed to the age of the vineyard). Secondly, the yield data for two plots (15 and 16) were ignored. They showed a tendency to continue yielding exceptionally well before declining a little in the penultimate season despite receiving moderately high salinity water. That they were anomalous is confirmed by their rough coincidence with a large termitarium (heuweltjie). These mounds are known to produce quite different edaphic conditions from those of surrounding areas. The effect of including data from these plots in Fig. 5.04 would have been to intensify the trend evident in the graphs. Thirdly, the EC and SAR values used were profile means from samples taken at the end of the season.

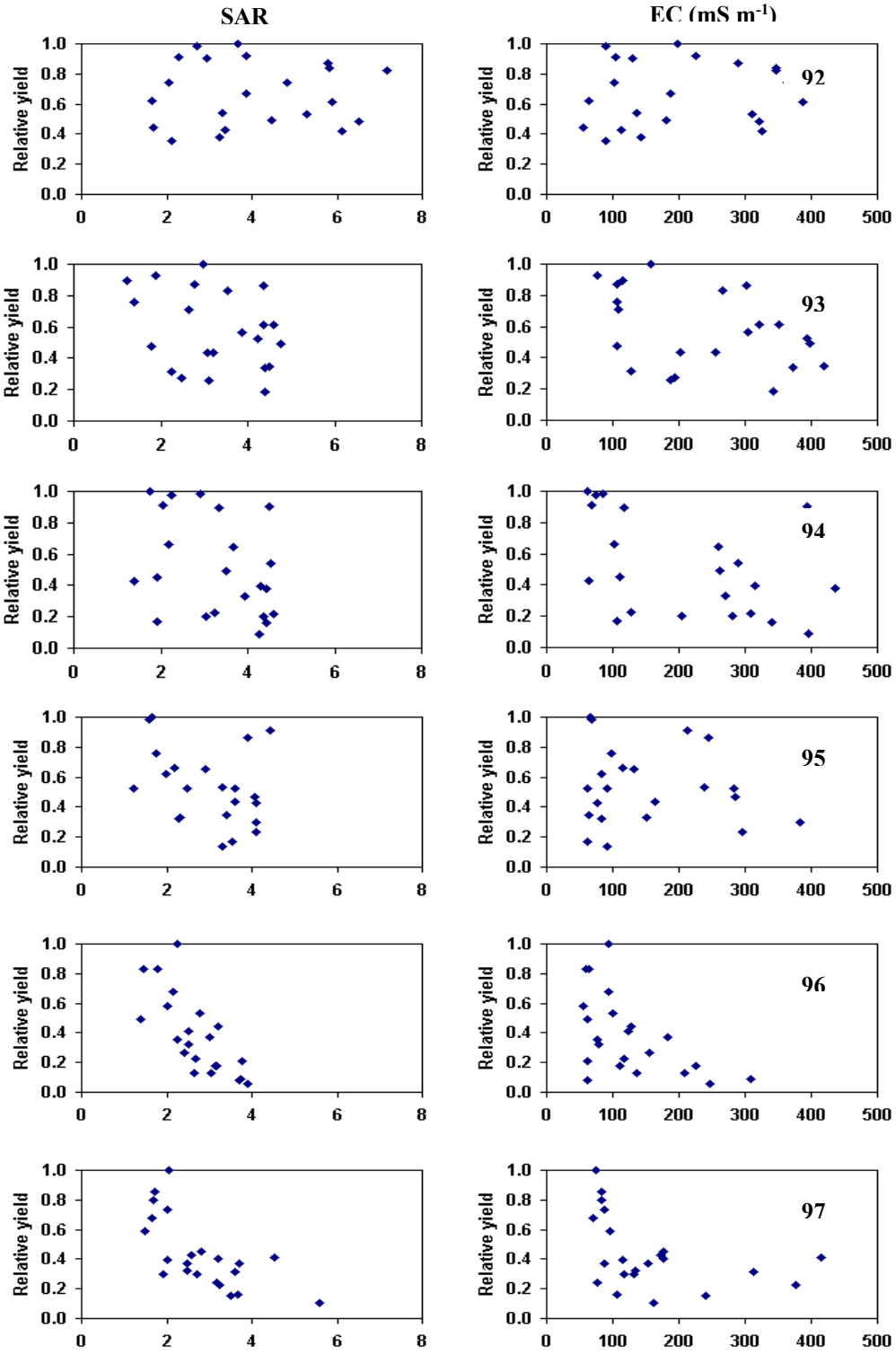


Figure 5.04. Grape yield response to soil sodicity (SAR_e) and salinity (EC_e) in the Robertson main experiment, 1992 – 1997. These data represent the individual plot yields as opposed to treatment means plotted in Figures 5.02 and 5.06.

It should be pointed out that SAR and EC_e are closely correlated in this experiment (Figure 5.05; a similar regression was also evident between soil Cl level and SAR) and it is therefore not surprising that a very similar trend to that in Figure 5.03 is apparent in the way the relationship between yield and SAR_e changed as the experiment progressed (Figure 5.06).

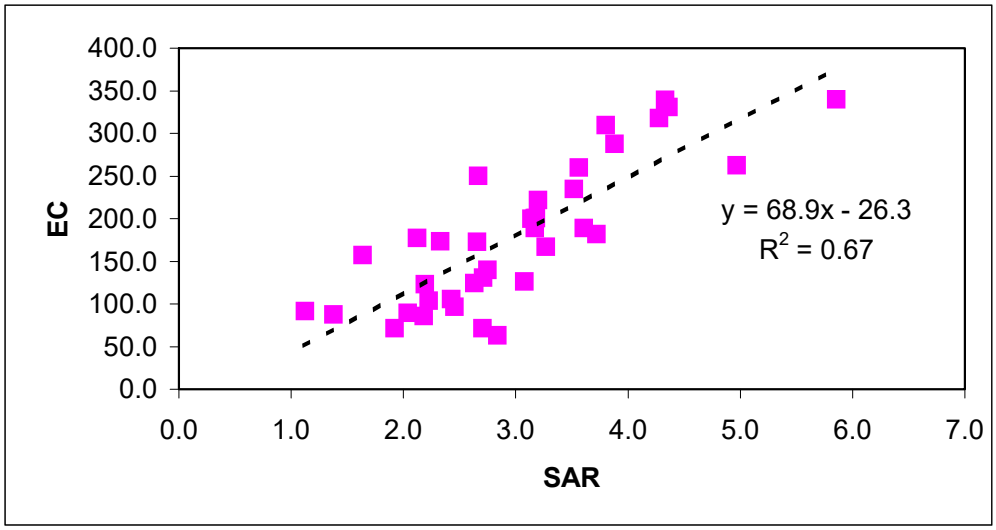


Figure 5.05. Relationship between mean EC_e and SAR_e in soils sampled annually from the Robertson main study 1992-1997.

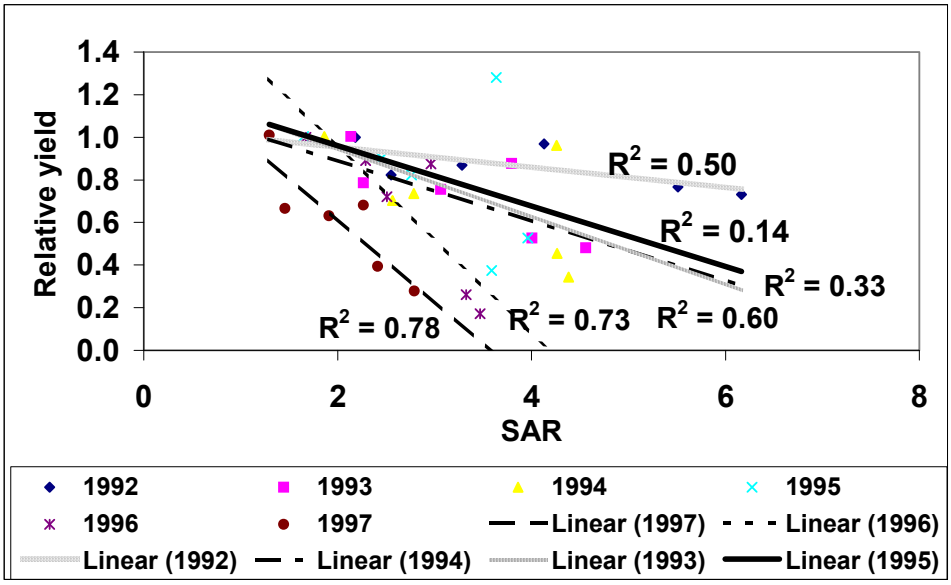


Figure 5.06. Relationship between relative yield and SAR_e calculated for each season in the Robertson main study 1992-1997.

A pattern seems to have emerged from these newer results, which could not have been picked up during the initial trial period. The essence of the pattern is 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 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 on the vines is cumulative. This result has enormously 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 cumulatively debilitating effect on growth and yield leading ultimately to premature economic failure of the vineyard.

5.1.3 Plant chloride level

Chloride content was tested in the must from all sections of the study and in the plant organs from the Stellenbosch site only, the remaining sites having been addressed in this respect by Moolman *et al*. (1999). An intensive salt balance study in relation to all the various plant organs was carried out during the first five years of the project and it was concluded by Moolman *et al*. (1999) that the elements associated with negative plant response were primarily Na and Cl. Although there was no clear threshold, it was determined that the Cl content of the leaves should not exceed 1.2 g kg^{-1}.

Chloride content of the leaves, petioles and shoots was tested at Stellenbosch only and at no stage during the project did it reveal a treatment effect, confirming that the site at Stellenbosch had no carry-over effect between growing seasons probably as a result of effective leaching during winter.

5.1.4 Water relations

The physiological response of the grapevine to salinity takes the form of a reduction in transpiration and stomatal conductance, which is related to the osmotic pressure in the plant. Transpiration was tested on a plant in treatment one (fresh water) and treatment 6 (500 mS m^{-1}) at Stellenbosch. Plants similar in size were chosen.

Transpiration was measured before and after an irrigation event. This clearly showed the plant response, with the vine in treatment 1 using 17% more water than the vine in treatment 6. This difference would probably have been even greater had similar tests been done at Robertson.

Currently transpiration measurements are not a cost-effective way of determining plant reaction to salinity but can make a large contribution toward understanding response mechanisms.

5.1.5 Visual symptoms

The higher levels of salt in the irrigation water increased plant susceptibility to other illnesses. Increased occurrence was well correlated with increased soil salinity and reduced yield. This was done in terms of a scoring procedure and was reported fully by Moolman *et al.* (1999).

5.1.6 Conclusions

The aim of this study was to show whether the farmer can cope with poor quality water. Therefore, to test yield and reproductive growth, from one season to the next, of plants subjected to various levels of saline water, and to relate these to soil water conditions, would be a reasonable way of achieving that objective. Soil water status, depth weighted mean EC_e and SAR, were all linked to the performance of the plant and provided a suitable basis for explaining why a significant response to saline irrigation treatments was obtained in the Robertson main study. A cumulative effect of saline water on reducing the resistance of the vines to saline-sodic-chloride-rich soil conditions is apparent from the long-term trends in the Robertson main trial and deserves further investigation.

5.2 METHODS BY WHICH IRRIGATION WATER CAN BE EVALUATED FOR LOCAL CONDITIONS

5.2.1 Introduction

The quality of irrigation water can best be evaluated in terms of both soil and plant response. Plant response is linked to salt tolerance and EC_{sw}. EC_{sw} is linked to the soil's capacity to retain salt from the irrigation water. Therefore, guidelines for the successful application of saline water will differ according to the crop type, soil type and irrigation method combination.

Salinity problems are normally related to the amount of sodium chloride in the irrigation water and therefore in the soil. The plant reaction to saline irrigation water is a reflection of how well the soil responds to the saline water or how effectively the situation is managed by the farmer. The capacity of the soil to retain salt is primarily determined by soil texture and structure. The effect of this capacity can conventionally be modified by over-irrigation, by adding gypsum or certain acids (only in Ca rich soils) and by tillage techniques to enhance infiltration and leaching. One principle that is usually ignored and that is well demonstrated by this study relates to the fact that EC_e and SAR of the soil were employed as indices of salinisation of the whole volume of soil beneath the wetted surface. However, since both drip irrigation and micro sprinkler irrigation were used, different volumes of wetted soil need to be considered in each case. When different volumes of soil are being wetted with a given amount of water (applied on the basis of plant requirements), the salt retention capacity and the rooting volume of the plant can both be expected to produce a different plant response to salinity of the irrigation water.

5.2.2 Results and discussion

This project provided an opportunity for comparing drip and micro sprinkler irrigation effects in the same environment and soil type. Both systems were characterized by the same water demand and therefore received similar amounts of water over the season (Table 5.07). Although the average yield among treatments differed slightly in the drip-irrigated study, these differences were found to be statistically non-significant.

Drip irrigation was superior in terms of both yield and the number of bunches (Table 5.07). The harvest and bunch numbers were also best correlated with EC_e when calculated as a weighted mean over the whole season (Table 5.07). This implies that EC_e must be kept as low as possible throughout the season. If so, the capacity of the soil to retain salt should play an important role. This capacity is linked to the texture and structure of the soil and the fraction of applied water that drains below the root zone. Therefore, if the volume of soil that is wetted by irrigation is kept to a minimum, the water holding capacity of the wetted soil volume relative to the volume of irrigation water applied during the season becomes more favourable. This further implies that there would have to be an optimum combination identified in terms of the volume of irrigation water applied over the season, the EC_i, the rooting volume and the water holding capacity of the soil. A smaller wetted soil volume entails a smaller capacity to retain salt. The EC_e and SAR of this smaller volume should be easier and more cost effective to manipulate.

Figure 5.07 shows the difference in soil response rates to saline irrigation in the Robertson main study and in the pilot study. Figure 5.07(a) shows a sharp decline in EC_{sw} between days 25 and 50 which constitutes the reduction in EC_{sw} as a result of over-irrigation with fresh water at the start of the season. After treatments had commenced the EC_{sw} stabilized at about 300 mS m^{-1}. After the veraison changeover the EC_{sw} of treatments SL1 and SL2 dropped at about the same rate. The LS1 and LS2 treatments received saline water and reacted more sharply and stabilised at about 500 mS m^{-1} (EC_i target values for treatments LS1 and LS2 were accidentally set to the 350 mS m^{-1} treatment of the previous project by the irrigation controller). After day of season 150, relatively less water for leaching was available as a result of the high ET during this time of the season and later because of reduced irrigation to aid ripening of the grapes.

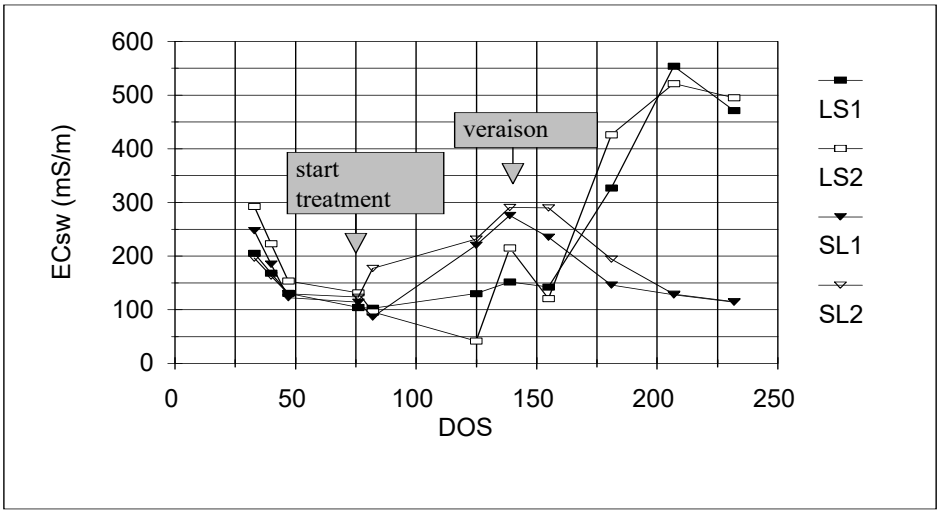
Table 5.07. Comparison between drip and micro irrigation in terms of soil volume, amount of water received and plant performance for the Robertson drip and micro irrigated vineyards that were subjected to saline irrigation.

Irrigation		Wetted surface per plant (m^2)	Wetted soil volume per plant (m^3)	Amount of water received (mm)	EC_e at end of season** (mS m^{-1})	Mean of bunches/ plant**	Mean yield/ plant (kg)**
Drip *	Fresh water	0.3	0.27	659	111	39	5.2
	150 mS m^{-1}	0.3	0.27	659	104	37	5.1
Micro	Fresh water	3	2.7	624	65.1	44	5.4
	150 mS m^{-1}	3	2.7	624	117	30	3.4

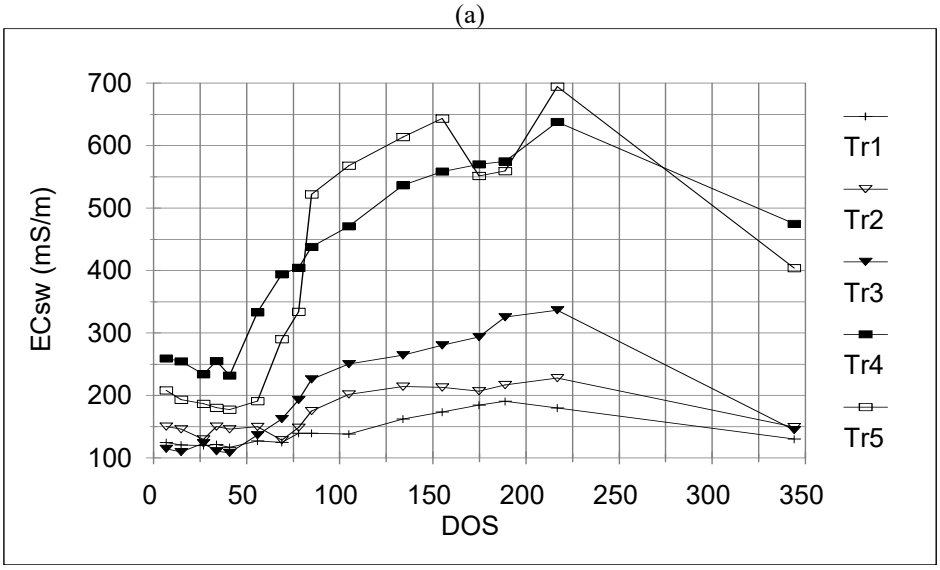
* *Tthe mean of treatments SL1 and SL2 is given in drip with fresh water, and the mean of treatments LS1 and LS2 is given in drip with 150 mS m^{-1} . The reason is that the first combined treatment ended the season with fresh irrigation water and the latter ended the season with 150 mS m^{-1} water.*

** = *the means at the end of season over the three seasons were used.*

Three features that are critical to this study must be kept in mind when evaluating the drip irrigation data relative to those of the micro-sprinkler irrigated main study. The first is the fact that in both cases the irrigation was applied without any fertiliser other than that sprayed on the leaves. The second is that the drip irrigation did not create a mist that might cause leaf damage under windy conditions. Lastly, the drip irrigation site was irrigated whenever a 4 mm deficit was predicted from the weather station data in comparison to the micro-irrigated study, where the weekly soil water deficit was applied. This may have influenced the comparability of EC_{sw} samples since the two irrigation types did not allow us to sample at the same time after an irrigation event. In Table 5.08 the response rates for EC_{sw} are given, calculated as the inclination of the lines shown in Figures 5.07 (a) and (b). They are presented in order to indicate what rate of change is possible in the EC_{sw} for both irrigation types. The rates of salinisation and desalinisation in a micro-irrigated vineyard are higher with water of a higher EC_i.



(a)



(b)

Figure 5.07. (a) EC_{sw} response to irrigation water with EC_i of ~30 mS m^{-1} and 150 mS m^{-1} in a drip irrigated vineyard and (b) comparable EC_{sw} response in the micro irrigated vineyard

Furthermore, the rates of salinisation and desalinisation in the drip experiment both appear to be much greater than in the micro sprinkler irrigated system. In reality the differences between the drip- and micro sprinkler-irrigated experiments are probably too complex as a result of their design to draw simple conclusions about the superiority of one method over the other for irrigating vines in this environment.

Table 5.08. Rates of change in the EC_{sw} (mS m^{-1} per day) for the Robertson main study (5 treatments separately) and the Robertson pilot study (all 4 treatments combined).

	ROBERTSON MAIN STUDY TREATMENTS				
	1	**2**	**3**	**4**	**5**
MAX RATE OF SALINISATION	1.62	3.79	4.72	6.74	7.6
MAX RATE OF DESALINISATION	-0.67	-1.64	-1.8	-3.3	-4.57
ROBERTSON PILOT STUDY : ALL TREATMENTS COMBINED					
MAX RATE OF SALINISATION	12.4				
MAX RATE OF DESALINISATION	-13.03				

5.3 ALTERNATIVE ON-FARM MANAGEMENT STRATEGIES AND IRRIGATION WATER QUALITY GUIDELINES TO ENHANCE THE USE OF SALINE WATER FOR IRRIGATION PURPOSES

The irrigation scenarios provided in this project are summarised in Table 5.09. Obviously there were numerous possibilities that could not be tested. Wide application of the findings does therefore not follow automatically.

The most important feature of the experiments is that they represent an attempt to manipulate water quantity, water quality during the season and frequency of application. The results were to some extent buffered by soil physical properties. It was virtually impossibly to alter the state of salinity of both the soil and plant within the irrigation season at the micro irrigated sites, whereas this was possible at the drip irrigated site. The only way in which the soil could be rid of the salt load was through supplementing winter rainfall with winter irrigation. This was done at both the Robertson main (micro-) and pilot (drip-irrigation) study sites. This may have had a negative effect in stripping the soil of nutrients. The practice in certain regions of the Breede River valley of treating the soil with chicken manure before bud break is therefore probably very sensible. In soils with a high sodicity potential, gypsum should nevertheless be prescribed. In this experiment, no gypsum was used to alter soil chemistry because $CaCl_2$ was included in the irrigation water during the summer

and the SAR of the irrigation water was consequently maintained at a reasonably low level.

Table 5.09. The experimental layout of the whole project since 1995.

Site	Irrigation type	Water quality	Water volume	Frequency
Robertson (implies full scale irrigation)	Micro (main study)	Fresh water ~30 mS m^{-1}	Deficit replacement + 10% measured with neutron probe in the fresh water treatment	Weekly
		75 mS m^{-1}		
		150 mS m^{-1}		
		250 mS m^{-1}		
		350 mS m^{-1}		
		Fresh to 150 mS m^{-1} change after full bloom		
	Drip : subsurface (pilot)	150 mS m^{-1} and change to fresh at veraison	Deficit replacement calculated from Penmann-Monteith evapotranspiration using an on-site weather station	Daily
		Fresh and change to 150 mS m^{-1} at veraison		
	Drip : surface (pilot)	150 mS m^{-1} and change to fresh at veraison		
		Fresh and change to 150 mS m^{-1} at veraison		
Stellenbosch (implies supplementary irrigation)	Micro	Fresh water ~40 mS m^{-1}	Deficit replacement + 10% measured with neutron probe in the fresh water treatment	Three to four irrigation events during season only in peak demand period
		75 mS m^{-1}		
		150 mS m^{-1}		
		250 mS m^{-1}		
		350 mS m^{-1}		
		500 mS m^{-1}		

What is clear from this report, however, is that the drip-irrigated vineyard was less affected by saline irrigation than its micro irrigated counterpart.

The salt balance of the soil is of prime importance. A build up of salt must be avoided. By using high frequency irrigation, salts can be kept out of the root zone. This irrigation technique, however, does require a higher level of skill but it becomes easier to manipulate soil EC_e. This can only be done by careful measurement of the water and soil salinity. Frenkel and Meiri (p.333, 1985) also stated that monitoring soil salinity is an essential basis for management decisions and the identification of best growing conditions. Suction cup lysimeters were used with great success in this project. The technology was developed to such an extent that use of the system could be commercialised and can be integrated with any irrigation controller.

Because the research sites are in a predominantly winter rainfall area, the abundant fresh water for leaching during winter months must be born in mind. Winter leaching by irrigation need not necessarily be planned for, in contrast with areas that are subject to mainly summer rainfall.

The larger the capacity of the soil to accumulate salt, the smaller is the effect on yield of applying a leaching fraction during the season. The amount of water needed in the Robertson main experiment to reduce soil salinity by 66 % during winter was 500 mm. Total irrigation during the growing season came close to this amount. Of the 500 mm total irrigation, 100 mm took the form of a leaching fraction. Bresler and Yaron (1972) contended that it is more effective to increase irrigation frequency and thus allow more water for increased evapotranspiration and total soil water potential, than to allocate extra water for leaching at extended intervals. This rationale is exactly that of the drip irrigated pilot study at Robertson. From the results of this study since 1990, it is evident that the concentration of Na and Cl in the irrigation water, the volume of irrigation water, the sodicity of the soil and the rooting depth of the crop, are all important in determining the extent to which the farmer is able to cope with water of varying quality. It is also worth remembering that the quality of the soil water is always worse than that of the irrigation water.

The transpiration study at Stellenbosch showed that more frequent irrigation intervals have the added benefit of reducing transpiration. This will result in smaller salt uptake by the plant.

A proper formulation of irrigation water quality guidelines should consider the following questions:

– How much irrigation water is available?
– Is there enough water for leaching?
– Is the quality of EC_i and EC_{sw} being monitored?
– Is it good practice to leach during summer or winter?
– Will leaching have an effect on the water supply?
– Does the farmer use refined scheduling techniques?

- Do the advantages of partial wetting of the soil apply?
- What is the salt tolerance of the crop?
- Does the salt content of the marketable product matter?
- What is the length of season for the crop?
- What is the typical rooting volume of the crop?
- Under saline conditions, should crops be selected with the smallest possible rooting volume?

The Robertson area, which is characterised by predominantly winter rainfall, does have winter leaching as an option. However, if leaching is applied during the last month before budbreak throughout the valley, the quality of the water in the river will certainly receive a large salt pulse just at or after budbreak. It would be preferable to apply leaching irrigation during winter just after each rainfall event. By irrigating with slightly saline water after rainfall, the infiltration rate is improved and consequently the effectiveness of the rainwater.

Partial wetting of the soil has the advantage that the remaining soil acts as a capillary salt buffer during the summer and the leaching fraction can be reduced. Irrigation water quality in the river will benefit by even a marginal decrease in leaching during summer.

The key to sustainable use of saline water for irrigation is to avoid salt input due to unnecessary irrigation, and to prevent the rapid build-up of salinity by means of effective leaching at the appropriate time. This will result in an optimal compromise between salt concentration in the drainage water, magnitude of the leaching fraction and extent of salinity damage to the crop (Moolman *et al.*, 1999). What has become apparent from the full period of the main trial at Robertson is that the salinity treatments could have influenced the performance of the vines in more than one way: besides the osmotic effect of the salinity, there is a real possibility that Na and/or Cl toxicity are also involved. The combined effect of these factors in aggravating yield appears to be a cumulative one, resulting in a situation where it is impossible to stipulate a threshold water quality without considering the desired longevity of the vineyard.

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6. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 SOIL WATER STATUS

6.1.1 Irrigation amounts

The irrigation operation in the main study was well satisfactorily controlled and the management aspects of irrigation with saline water can therefore be satisfactorily evaluated. The amount of water applied during each irrigation in the Robertson main study was designed to include a 20% leaching fraction before full bloom period and thereafter a 5 % over-irrigation. The outcome of this is addressed in the section below dealing with soil salinity response.

With regard to the main study, it is also important to note that irrigation scheduling was done by neutron probe measurement in the fresh water treatment (treatment 1). The soil water deficit was calculated and a percentage was added to compensate for system ineffectivity. As a result of smaller canopies in the more saline treatments and therefore smaller plant water consumption, these sites were therefore consistently over-irrigated.

The volume of water needed in the Robertson main experiment and in the pilot study differed as a result of both management practices and differences in canopy. In all treatments of the main study the plant size and canopy development showed a progressive decline during the last three years. This implies a concomitant decline in water consumption.

6.1.2 Soil water levels and treatment effects

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 with an excessive 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.

At Stellenbosch the season in which saline irrigation was started earlier (i.e. before the soil water deficit was deemed large enough) was the only season in which treatment effects became visible. Therefore supplementary irrigation was, during the last two seasons, applied after the veraison period when it had a negligible effect on the plants compared with that resulting from saline irrigation applied earlier in the season. No treatment effect was detected, however, as a result of the soil water differentiation effect that soil water quality would have had on the vines. During all irrigation events at Stellenbosch at least 30 percent of the drains flowed after irrigation.

The measures we took in regard to altering the crop factors for the pilot study ensured that we could manage the soil water status for both subsurface and surface irrigation at similar levels. This is very important with regard to management options and the comparison of treatment effects in this study.

6.2 SALINITY AND SODICITY

Soil and plant responses to manipulation of the irrigation salinity (EC_i) were the main focus of the follow-up investigation. Therefore in the Robertson main study, treatments 1, 3, 6(a) and 6(b), are important and are amenable to comparison with all treatments in the pilot study as well as with treatments in the Stellenbosch trial.

From the Robertson micro-irrigated main study and the drip-irrigated pilot study, the following observations can be highlighted:

a) Treatments 1 and 3 of the micro-irrigated site produced the expected response and therefore are in line with trends from the previous seasons.

b) Treatment 6(a)(fresh water) went through an initial stage of slowly reducing EC_e over the first year. Treatment 6(b)(150 mSm^{-1}) adapted relatively quickly to the new EC_i and its EC_e stabilised almost in line with that of treatment 3.

c) SAR_e was positively correlated with yield in the Robertson main study. SAR also showed a remarkable treatment effect. The SAR in the pilot study showed, in

relation to EC_e, a more gradual response to the irrigation quality changeover in the middle of the season.

d) The soils of treatment 3 of the Robertson main study and all treatments of the drip-irrigated pilot study responded rapidly to the saline treatment and the salinity stabilised at high levels early in the season. In response to the fresh water treatment in the main study, EC_e decreased to about 40% of the rate observed in the drip-irrigated pilot study. This implies that the process of salinisation was much faster than desalination in the micro-irrigated vineyard and needs more water to desalinise than under drip irrigation.

e) The rate of salinisation and desalination of the drip-irrigated experiment in comparison to the micro-irrigated experiment is much more conspicuous. This implies a greater opportunity for salinity control. One must bear in mind that both irrigation types received the same amount of water. The drip application was applied to a much smaller soil surface and thus soil volume. Since the volume in the drip- irrigated experiment is smaller, a more dynamic system is created in terms of EC_e. This constitutes an important concept in later discussion regarding irrigation management strategies.

f) In the drip irrigated pilot study, due to winter rain, the soil volume that was normally wetted by irrigation became more saline and sodic during winter. This is because a redistribution of salt took place from the drier zone, between the vine rows, which was never wetted during the irrigation season. This zone became more saline as a result of, among other factors, the evaporation from the soil surface, as was reported by Moolman *et al*. (1999). With drip irrigation, it was found that full-scale winter irrigation designed to leach as much salt as possible did not produce a better result than by commencing with fresh water irrigation about five weeks before bud break. This is possibly due to the effect of winter rain and the time available to redistribute salt in the soil water towards the normally drip-wetted soil zone. This redistribution process appeared to take place more rapidly when no winter drip irrigation had been applied (as shown by winter suction cup EC_{sw} measurements). The amount of salt that was leached using the latter approach is thus greater although not necessarily optimal.

g) Drip irrigation with saline water appeared to lead to more saline soil conditions outside the wetted perimeter than did micro-jet applied saline water. Because of better management of the subsurface drip irrigation during the last two seasons, a different salt gradient pattern emerged. Soil immediately above the dripper line became far more saline than before. This had two implications. Firstly, the fact that the soil surface was nowhere wetted by irrigation meant that plant nutrients were not leached from the soil surface. Secondly, the salt load in the soil above the irrigation line could create problems when it rains.

h) Another advantage of sub-surface irrigation worth mention is the fact that fewer weeds germinate as a result of the drier soil surface. This implies less competition for water and nutrients.

i) With sub-surface drip irrigation, approximately one-third less water was needed to maintain the same soil water level than was the case with surface irrigation systems during the last two seasons.

j) One disadvantage of subsurface irrigation is the problem of blocked emitters. However, with the type of dripper that was used, very few irregularities were experienced. Once an emitter or two adjacent emitters had become blocked, the plant soon started to show severe salt stress symptoms or completely died back before the problem could be rectified. The soil responded with a sharp intensification of the salt gradient within the vine row.

k) At Stellenbosch the rate of salinisation and desalination of the soil in this micro-irrigated experiment is likely to have played a large role in determining plant response to the treatments. Most salts were retained high in the soil profile. As a result of the irrigation pattern, the root zone extends beyond a depth of 70cm. The salts in this deeper zone were to a large extent minimised by the buffering effect of the upper horizons. This suggests that drip irrigation might not be the best option for supplementary irrigation.

l) At the Stellenbosch site, SAR_e did not differ significantly between treatments and there was also no correlation between SAR_e and yield.

m) In the pilot study, there were differences between treatments. Firstly, the differences between the Chenin Blanc section and the Colombar section could

have resulted from the fact that the two cultivars have different season lengths. The irrigation system unfortunately did not make provision for this fact since both vine cultivars were linked to the same system. The change between treatments had to be made when the Colombar was at veraison, which left the Chenin Blanc with a shorter period of saline and fresh water irrigation after that. This is an important consideration since it implies that when saline water is used for irrigation, cultivars that have a shorter seasonal length or ripen earlier should be given preference. By using this approach, less saline water will be used and therefore a smaller salt build-up in the soil will result.

6.3 PLANT RESPONSE

6.3.1 Plant size

With full-scale irrigation at Robertson the plants continued their decline. It is clear that the Robertson main study suffered a severe decline over the duration of the study. The question remains: what is the significance of this decline and how does it relate to treatment and management decisions made during this study?

With a change in treatment during the season (i.e. a change in water quality at Robertson), the plants in treatment 6(a) reacted moderately to the fresh water but it appeared as though the vines would not retain their vigour. Treatment 6(b) received fresh water up to full bloom and thereafter 150 mS m^{-1} water. These old plants showed almost no response to the new treatment possibly because of lack of vigour.

6.3.2 Yield

At the Robertson main study, we managed to improve the yield of treatment 6 which, as a split-plot experiment, received fresh water and 150mSm^{-1} of water. The two plots that received fresh water performed even better. With almost 25% of the vines in these plots having died as a result of the previous treatment, the yield can be seen in an even more positive light.

6.3.3 Number of bunches

At Stellenbosch, the effect of saline irrigation on the vines was smaller than at Robertson. The number of bunches appeared to be affected the most. These results were subjected to detailed statistical analysis in Chapter 3.

6.3.4 Transpiration and LAI

With the transpiration measurements at Stellenbosch, the fact that the same method was applied between the fresh water treatment and the 500 mSm^{-1} treatment makes these findings particularly relevant. The response of grapevines to salinity and the different water consumption over the duration of one day was very clear from this study. The plant response after a single irrigation was also readily apparent.

It was thus necessary to model the leaf area in an effort to get a better LAI for the plants than were measured for transpiration since other methods failed to be exact. The method worked well but it was more time consuming than remote methods. It also had the benefit that measurements could be repeated and was therefore considered the best approach for following transpiration during the season, when only selected plants need to be monitored.

With transpiration measurements we had no other method in the field for calibration except the weather station and soil moisture depletion. The transpiration method, if applied correctly, does not need calibration. The method applied by Savage *et al.* (1993) is based on the accountability of the total heat flux in the area of measurement. Because maximum precaution was taken to account only for energy loss through sap flow, we believe the sap flow method to have been accurate. The crop factor for this time of year is 0.4. Our estimate from T and ET was 0.42.

6.4 QUALITY OF FRUIT AND WINE

The wine from treatment 6 was judged to be significantly more salty to taste than that from the control and treatment 3 ($P = 0.05$). When the wines were ranked, the quality of the wine made from treatment 3 was significantly lower than that from the other two treatments. The wine made from the untreated grapes (control) showed more fruit

and flavour and was given a median score of 14 on a 20-point scale. None of the wine possessed a typical Weisser Riesling character.

From these results it aws evident that although the treatments had no marked effect on the sugar, acidity and pH levels of the juice after crushing, the effect of saline irrigation became more pronounced in the quality of the final wine. Wine made from high salinity treatments showed a significant, detectable saltiness and was ranked lower in sensory quality than the corresponding wine made from the control treatment. Unfortunately none of the wines had the typical cultivar character, an aspect that cannot be related to irrigation only but to the overall quality of the grapes as a result of experimental constraints on the timing of the harvest.

6.5 MANAGEMENT OPTIONS

6.5.1 Drip irrigation with a change in water quality during the season

Saline irrigation in the semi-arid Robertson region, where full-scale irrigation is important, had larger effects on the plant than did supplementary irrigation at Stellenbosch. However, the pilot study at Robertson, where irrigation water quality was switched from good to poor or *vice versa* during the season, the results were insufficiently clear for definite conclusions to be drawn about the superiority of one practice over another. This was partly due to problems with the control of the irrigation supply but perhaps more so to the experimental design which failed at the outset to properly accommodate cultivar differences. The overall yields were better in the pilot study than in the Robertson main study, however, and these may be related to the less debilitating effect of salinity under drip irrigation compared with micro sprinkler irrigation.

6.5.2 Full scale saline irrigation with different levels of salinity

The Main trial at Robertson has been most illuminating with respect to the effects of saline irrigation on vineyard performance. Although it should be remembered that the vineyard was an old one and that the vines may have had an inherently greater susceptibility to the saline water treatments, the progressive decline in yield over the period of the experiment could largely be eliminated as a confounding factor in

making seasonal comparisons by expressing yield on a relative basis within each season. (Almost invariably, the control treatment produced the highest yield). Having done this, we found (a) that the response to saline water is about equally strongly related to salinity, sodicity and chloride level in the soil and it would be speculative to focus the blame on only one of these factors as the cause of adverse yield; and (b) the response seems to change with each successive season of saline irrigation, conforming to the same quality threshold each time but showing an increased sensitivity to the saline-sodic condition. The salinity and sodicity of the soil did **not** increase over the same period, which suggests that the effect of the treatments is cumulative, rather like an allergic reaction. 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. Certainly the implications could be serious for irrigation farmers in the Breede River valley in terms of the expected lifetime of their vineyards.

6.5.3 Saline supplementary irrigation

At Stellenbosch, it was concluded that supplementary irrigation had no significant effect on yield or quality parameters partly because the application of water is too late in the season to affect the vines and partly because the soil structure combined with winter rainfall allowed the effects of the previous season to effectively be wiped out by the time the new season commenced.

6.5.4 Time

The long-term, detrimental effects of salinity on wine grapes were demonstrated with treatment 4 at Robertson. For the first time in five years, there was a significant decrease in yield in the 95/96 season. The 96/97 season showed a further decline of treatment 4 but also a relative increase in yield for treatment one. Plants from treatment 5 at Robertson also began to die. In general, the seasonal plots of yield vs. salinity and SAR_e at Robertson (discussed above) have confirmed the cumulative nature of vineyard response to saline irrigation and the fact that the life span of the vineyard may be under threat even though the short-term resistance of the vines appears to be adequate for obtaining an economic yield. We recommend that further long-term experiments with saline irrigation water be conducted on vines and other

woody perennials in order to find out whether there is an effect on longevity of the crop separate from that which is commonly ascribed to a deterioration in soil quality. Sites such as that at Stellenbosch would be ideal for this purpose because, apart from the well developed infrastructure, the soil is physically more resilient and amenable to being regularly desalinised by winter irrigation.

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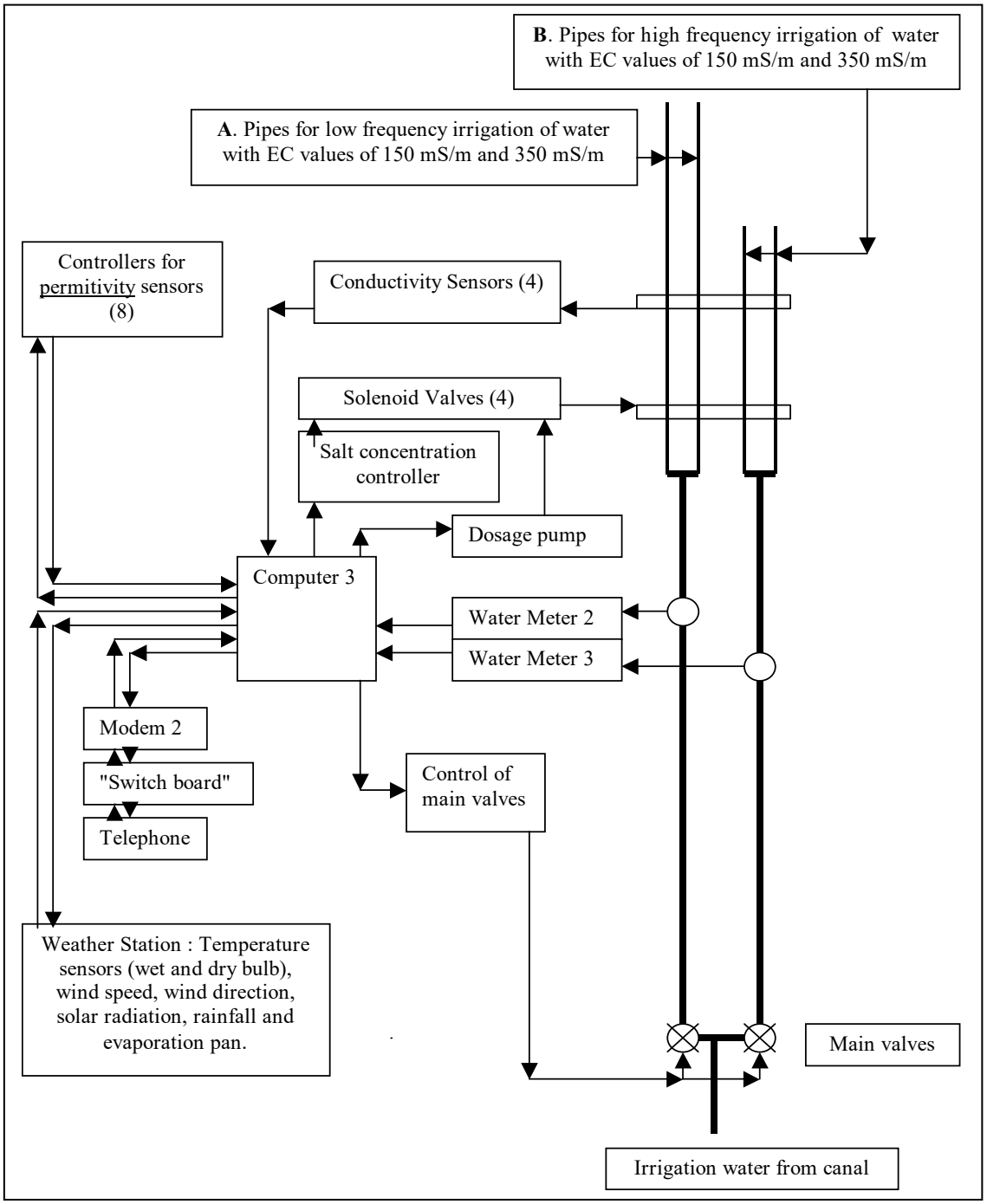
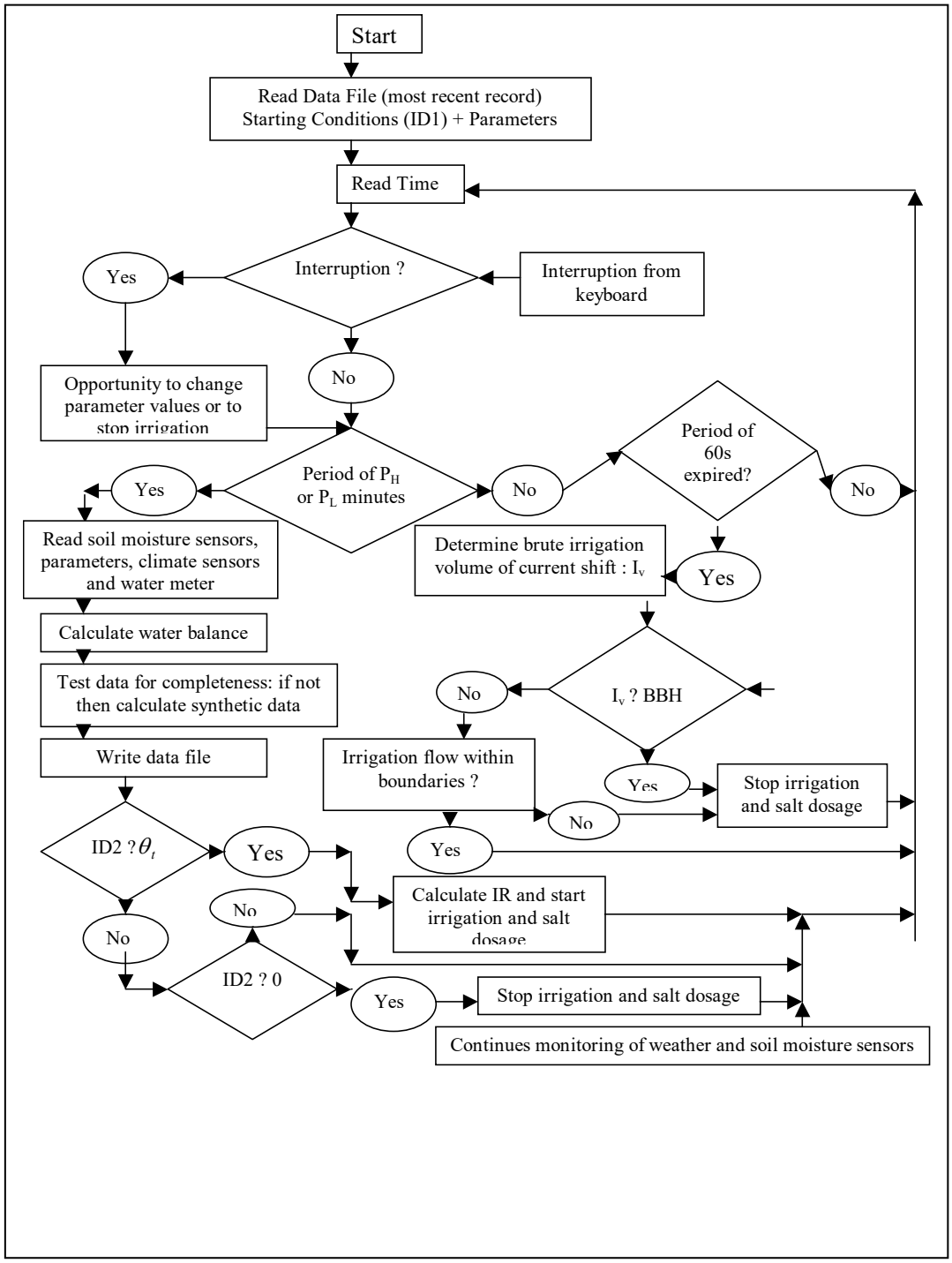
APPENDICES

APPENDIX A Diagram : Apparatus and their placement for data gathering and control of the irrigation and salt dosage systems.



APPENDIX B Diagram : Flow diagram for the data acquisition and irrigation system control.



APPENDIX C Irrigation management

1 METHODOLOGY

In practice, to be able to apply high frequency irrigation, decisions must be made in terms of how irrigation volumes, as well as irrigation starting times are going to be handled. Three options exist:

a) irrigate using water loss data determined by a sensitive weighing lisimeter;

b) irrigate using calculated water consumption, typically calculated as potential evapotranspiration (PET) and crop factors;

c) irrigate using soil water measurement data, typically from neutron probe, tensiometer or matric potential readings.

Option a) is probably the most appropriate and accurate method, but also the most expensive. Therefore, this method was not considered since it is the least likely to be used commercially.

Option c) has merit in terms of practical acceptability, but the accurate measurement of soil water content differences of 1 to 2 mm water per 1 m soil profile, using commercially available measuring equipment, is not currently possible.

It was therefore decided to use option b) in which the applied irrigation is based on evapotranspiration calculated for immediate afore going period. An inherent problem of this method is that any measured or calculated PET values must be converted to actual evapotranspiration for use in irrigation management. In order to achieve this, crop factors (also known as crop coefficients) are required. Crop factors are normally determined through plant water usage as dictated by atmospheric conditions and growth stage of the plant, as well as surface evaporation (again influenced by irrigation method and frequency). Current available factors developed for grapevines did not necessarily consider high frequency irrigation and definitely not sub-surface irrigation. This project was therefore started at a time where these factors had to be developed from experimental data and therefore this became one of the management

options investigated in the project. It was decided to calculate potential evapotranspiration (PET) using climatic data gathered by an automatic weather station, where the Penman-Van Bavel formula (E_P) (Jensen, 1974) was calculated in real time and initial assumptions were made in terms of the crop factors used to describe irrigation systems. Crop factors were adjusted in an iterative manner using frequent measurements of soil water content.

A second problem encountered using the automatic control system for irrigation was that eight possible combinations of water quality, method of irrigation and frequency of application were studied. The rate of evapotranspiration was not constant for each of these combinations and it was therefore theoretically necessary to be able to switch the irrigation on or off for each possible combination using calculated actual evapotranspiration (AET) data. In this event provision would have had to be made to accommodate eight sets of crop factors.

The initial irrigation system was therefore designed to accommodate all the above-mentioned combinations individually. Initially, only a number of options were selected and built into the control system. For example, assuming that for high frequency surface and sub-surface drip irrigation, the value of AET was identical (identical crop factors for both situations), then in the initial control system not all eight combinations were used. This initial assumption suggested that any calculated soil water deficit needed to be controlled between prescribed limits.

2 IRRIGATION MANAGEMENT 1993-1995

2.1 CALCULATION OF WATER BALANCE

2.1.1 Original approach (1992/93)

The irrigation was controlled by means of a time series of water deficits in the root zone calculated one step at a time, every hour and every quarter of an hour for the low and high frequency cases, respectively. The procedure will be explained by using general equations, which are applicable to both cases.

At the end of each time interval the latest deficit was calculated by means of Equation (1):

$ID2 = ID1 + ET - I - XP$ ....(1)

with:

ID2 = latest soil water deficit (mm)

ID1 = soil water deficit at the end of the previous time interval (mm)

$ET = K_C \times f_w \times E_P$ ....(2)

with:

ET = calculated evapotranspiration for the interval (mm)

K_C = the chosen crop factor,

f_w = an "area factor" (f_w=1 was used initially),

E_P = calculated potential evapotranspiration for

the interval (mm), and

$I = I_V \cdot I_E \cdot (1-LR_P)/2025$ ....(3)

with:

I = average depth of irrigation water that entered the root zone during the interval (mm), and

I_V = gross volume of irrigation water applied during the interval (m^3), and

I_E = prescribed irrigation and leaching application efficiency (fraction of the total volume of water used during the interval)

LR_P = prescribed leaching as a fraction of I, and

2025 = the total irrigated area (m^2).

The leaching was calculated by

$DP = I_V \times I_E \times LR_P/2025$ ....(4)

with:

DP = the average depth (mm) of water allocated to leaching during the interval;

and:

XP = rainfall during the interval (mm).

The gross volume of irrigation water needed for an irrigation shift was calculated according to Equation (6) whenever Equation (5) was found to be satisfied:

ID2 = θ_t ....(5)

with:

θ_t = prescribed maximum deficit allowed (mm)

The total volume of water (IR) required for an irrigation shift is calculated by means of Equation (6) as soon as Equation (5) is satisfied.

IR = ID2 x (1+LR_P) x 2025 ....(6)

(Note: ID2 ¸ Sum(ET) ¸ Sum(I) for an irrigation shift).

with:

IR = gross volume of water required for the shift (P) (m^3)

With θ_t = 25 mm irrigation was initiated whenever ID2 = 25 mm for the low frequency case according to Equation (5), and stopped whenever the soil water deficit was reduced to 0 or less as expressed by Equation (7) **and** the volume of water applied satisfied Equation (6):

ID2 <= 0 ....(7)

An irrigation shift was therefore stopped only when Equations (6) and (7) were satisfied simultaneously.

Scheduling of the irrigation by means of these calculations implies that the leaching requirement will also be satisfied according to Equation (4).

2.1.2 New Approach (1993/95)

A new method of calculation was adopted during 1994 for the following reasons:

1. Calculation of the soil water deficit by means of Equations (1), (3), (4), and (6) implies that leaching is taking place during each interval with I_V > 0 irrespective of

the soil water content of the root zone. Part of the **calculated** volume of leachate therefore accrued when the calculated soil water deficit was positive. Since the assumption that leaching occurs while the soil water deficit is positive, is in conflict with the concept of soil water deficit (which is based on the concept of field capacity), this method of calculating leaching cannot be expected to yield realistic or practical results. When this problem was realised, the calculation method for soil water deficit and drainage was changed so that calculated leaching accumulates only when the calculated deficit is less than zero. This was achieved by calculating I by means of Equation (2.8) for use in Equation (2.1) to obtain the changes in soil water deficit:

$$I = I_V \,.\, I_E/2025 \quad \text{.....(8)}$$

and with I_E defined as

$$I_E = (1 - E_I - RO - DP) \quad \text{.....(9)}$$

with:

I_E = Efficiency of Irrigation and Leaching water application, with the following water losses occurring while irrigating, expressed as fractions of the gross water volume used;

E_I = Direct evaporation when irrigating;

RO = Runoff;

DP = Deep percolation past the root zone.

Only when ID2 becomes negative, when calculated by means of Equations (1) and (2.8), is the absolute value of ID2 considered as representing potential leaching.

2. Originally the soil water deficit was sometimes changed manually (through the computer keyboard) in order to change the irrigation regime, or to start or stop water application indirectly when repairs or servicing of the irrigation system became necessary while it was operating. This was achieved by forcing the condition ID = 25 mm (or = 2 mm for the high frequency irrigation treatment) for starting, or ID <= 0 for stopping the irrigation.

Increasing the deficit manually for this purpose without decreasing it again soon enough after the irrigation was stopped or started, and continuing the application of

irrigation water accordingly, amounted to increasing the field capacity of the crop root zone, which increases the actual physical leaching in practice (provided that the originally chosen field capacity was realistic) without the calculations reflecting it. In order to stop this undesirable practice, the irrigation control program was changed during 1994 so that irrigation could be started and stopped manually and independently from the calculated value of the soil water deficit.

At the same time the new variable DP was defined as the leaching requirement (mm per calculation interval) which was used together with LR_P (the actual leaching in mm per calculation interval) to determine whether the leaching requirement had been met at any particular time. An irrigation shift is now terminated when both the following conditions:

(ID2 <= 0), and (the accumulated LR_P = the accumulated DP), are satisfied.

3. During the 1994/5 irrigation season it was decided to aim for zero leaching. This was done by setting $LR_P = 0$. In practice it is impossible to guarantee zero leaching by this means, due to the fact that leaching can take place during an irrigation interval before the next water balance calculation is done. It must therefore be expected that the seasonal average drainage per irrigation shift will be equal to half the difference between the net capacity of the irrigation system and the average evapotranspiration during the calculation interval. Drainage due to rainfall sometimes happens and is also calculated and added to obtain the total drainage as will be explained.

Use of Equations (1), (3), and (6) implies that the irrigation water is uniformly spread over the full irrigated area of 2.025 m^2 for each irrigation frequency. (Each irrigation frequency served by a water meter contains 5 x 90 vines spaced 3 m x 1.5 m.) With the degree of lack of uniformity of the irrigation system used, especially reflected by the fact that it wets only a relatively small fraction of the total area on the surface, it seems better to base the water balance calculations on the estimated effectively wetted area =(f_w * total irrigated area) only, and with $f_w < 2/3$.

The latest method of calculating the water balance will now be presented. The results of these calculations were used to obtain estimates of the soil water deficit and

leaching on which to base the automatic management of the irrigation system. Some of the variables already defined will be used, and new ones will be introduced.

$$IR = I_V / (f_w * 2025) \quad \text{.....(10)}$$

with:

IR = gross water application on the wetted area during the interval (mm) if uniformly spread over an area of $(f_w * 2025)$ m^2,

I_V = gross volume of water used during the interval (m^3), and

f_w = fraction of total area effectively irrigated.

$$TEW = I_V * (I_E/f_w)2025 \quad \text{.....(11)}$$

with:

TEW = total evaporable water; the calculated average depth of water (mm) that infiltrated on the effective area during the interval, and which is allocated to balance the evapotranspiration and/or the leaching required, and with:

Equation (2.12) is used to determine how much water in excess of the evapotranspiration must be applied in order to satisfy the prescribed leaching requirement for the interval, and **never to determine how much leaching has actually taken place in practice**.

$$LD = LR_P * ET \quad \text{.....(12)}$$

with:

LD = the leaching demand (mm) for the interval,

and:

LR_P = the prescribed leaching as a fraction of ET,

with:

$$ET = K_C * E_P \quad \text{.....(13)}$$

where:

K_C = the prescribed crop coefficient, and

E_P = the calculated potential evapotranspiration for the interval.

Note that the area factor f_w is not used in calculating ET as in Equation (2). The latest soil water deficit (ID2) is calculated by means of Equation (14) which is similar to Equation (1) but with TEW and ET calculated differently from their counterparts in Equation (1):

ID2 = ID1 + ET - TEW - XP ....(14)

The actual leaching is now calculated by means of Equations (15) and (16) or (18) and (19) as follows:

If Equation (15) is satisfied:

ID2 <= -1.25 mm ....(15)

then the leaching is calculated with Equation (16):

LR_P1 = -(ID2 + 1.25) ....(16)

with:

LR_P1 = the leaching for the interval (mm),

and:

ID2 = -1.25 ....(17)

If Equation (18) is satisfied,

ID2 > -1.25 mm ....(18)

then:

LR_P1 = 0 ....(19)

The final value of ID2 from Equation (17) or Equation (18) is used as ID1 in Equation (14) as usual.

This procedure implies that the water use capacity of the plant, is field capacity plus 1.25 mm. The amount of water that has to be applied exceeds field capacity and to allow drainage past the root zone, more frequent irrigation applications are needed. No leaching of water past the root zone will take place when the soil water deficit is -1.25 mm or less.

The new variable RLD is defined as follows:

$$RLD = RLD1 + LDI - LR_PI \quad \text{.....(20)}$$

where:

RLD = the residual leaching requirement at the end of the latest calculation interval (mm), and

RLD1 = the residual leaching requirement at the end of the previous calculation interval (mm).

Irrigation is stopped when ID2 <= 0 (Equation (7) and Equation (21) are satisfied simultaneously):

$$RLD <= 0 \quad \text{.....(21)}$$

Since it was decided during 1994 to set $LR_P = 0$ in Equation (10), RLD calculated by means of Equation (16) should ideally never be more than zero, and the use of RLD is not implemented. The actual leaching is now calculated by means of Equations (15) and (16) or (18) and (20) and an irrigation shift is ended by using only the one criterion ID2 <= 0 (as in Equation (7)).

In an attempt to distinguish between leaching due to irrigation and that due to rain the following two components for LRI are defined:

$$LR_PI = LRI + LRP \quad \text{.....(22)}$$

with:

LRI = leaching due to irrigation (mm), and

LRP = leaching due to rain (mm).

2.1.3 In an interval with irrigation and no rain:

LRI is calculated by means of Equations (14) through (22) with LR_PI replaced by LRI and LRP = 0.

2.1.4 In an interval with irrigation and rain:

LRI is first calculated by means of Equation (14) by omitting the rain, followed by Equations (15) to (19), and thereafter LRP is calculated in the same way but by omitting the irrigation on this occasion.

In this case both LRI and LRP may be greater than zero.

2.1.5 In an interval with rain and no irrigation:

All the leaching calculated by means of Equations (14) through (19) is assigned to LRP.

At the end of every calculation interval LR_PI is calculated through Equation (22) and stored on disk with the other water balance data.

2.1.6 Calculation of the soil water deficit

The calculations of the soil water deficit for high and low frequency irrigation are covered in this section. In this subroutine, the most recently calculated soil water deficit as well as the soil water content, weather data, irrigation data and parameters obtained during the previous period for each P (typically each 15 minutes for low and 60 minutes for high) were time and date stamped and stored in two separate data files.

The parameters for the mentioned calculations (formulas following) were read from the most recent entry in the data file. As a matter of interest, it was possible to edit and change any value in any of these files from the keyboard of computer 3 by writing all changes into the most recent record of the relevant data file.

The most recent soil water deficit was calculated using the following equation:

$$ID2 = ID1 + ET - I - XP \quad \text{.....(23)}$$

where:

ID2 = the current deficit (mm)

ID1 = the previous deficit (mm).....

ET = the evapotranspiration (mm) during the relevant time period (for the high frequency irrigation) .....

I = net irrigation (mm) during the specific time period.....

XP = rain (mm) measured during the specific time period.

The initial soil water deficit (time and date stamped) was written into the relevant data file (ID2 in this case) as the first record at the start of a continuous set (real time) of calculations.

2.1.7 Calculation of evapotranspiration

The evapotranspiration (ET, net use) was calculated using the following equation:

$ET = KC * f_w * E_P$ .....(24)

where:

K_C = crop factor for the combination: grapevine, plant spacing, irrigation frequency and method.

f_w = the "area factor" for the irrigation system.

E_P = potential evapotranspiration for the specific period (mm).

2.1.8 Calculation of potential evapotranspiration

The potential evapotranspiration was calculated using the following Penman-Van Bavel equation (Jensen *et al*. 1973):

$$E_p = \frac{\Delta}{\Delta+\gamma}\left(R_n + G\right) + \frac{\gamma}{\Delta+\gamma}\frac{0.27011\lambda\rho k^2}{P}\frac{u_z}{\left(\ln z/z_0\right)^2}\left(e_z^o - e_z\right) \quad \text{.....(25)}$$

where:

E_p = The potential evaporation (mm) for P minutes.

Δ = Slope of saturation vapour pressure-temperature curve, de/dT

Δ = e^0 [-8.2/$T_{(P)}$ + 0.0057113 + 7235.44/$(T_{(P)})^2$] mb.ºC^{-1}

γ = Psychrometric constant, mb.ºC^{-1}

= c_p . P_a / (0.622 . λ) mb.ºC^{-1}

= 1.6027 / λ , mb.ºC^{-1}

c_p = specific heat of air at constant pressure

= 1004.9 J kg^{-1}

R_n = Net radiation received, in MJ m^{-2} P min^{-1}

= (1 - α)R_s - R_b, where (1 - α)R_s is the net short-wave radiation received by the vineyard and typically 77% for vines.

α = albedo

R_s = Solar radiation

Rb = Net outgoing radiation

G = Heat flux density from ground

= σ . T(p)^4

σ = Stefan Boltzmann constant

λ = Latent heat of vaporization, MJ.kg^{-1}

= 0.004182(595 - 0.51.$T_{(P)}$), MJ.kg^{-1}

T_P = average air temperature for specific period P, ºC

ρ = Air density, mb

k = height at which wind speed was measured / roughness factor for vineyards = 2/0.3

u_z = Horizontal wind speed at height z, km.h^{-1}

z = Elevation, cm

z_0 = roughness length, cm

e_z = Water vapour pressure, mb at a specific temperature (T), ºC

e_z^0 = Saturation vapour pressure, mb at a specific temperature (T), ºC

P_z = atmospheric pressure, mb

= (1013 - 0.1055 . height above sea level in mb)

$e_z^0 - e_z$ = d_a Vapour pressure deficit, mb, at a specific temperature (T), ºC

= e_z^0 - (e_z - γ ($T_{(p)}$ - $T_{w(p)}$)

$\ln(e_{T(P)}^0)$ = 72.73784 - 8.2 ln(T) + 0.0057113(T) - 7235.44 / (T)

$\ln(e_{Tw(P)}^0)$ = 72.73784- 8.2 ln(T_w) + 0.0057113(T_w) - 7235.44/(T_w)

$e_{T(p)}^0$ = Saturated vapour pressure at $T_{(P)}$, ºC for period P

2.1.9 Calculation of net irrigation

The net irrigation was calculated using the following equation:

$I = I_V . (1 - RO - E_I - DP) . (1-LR_P) / 2.025$ .....(26)

where:

I = net irrigation applied during the specific period (mm)

L_V = measured volume of irrigation water applied during the specific period (cubic. m)

RO = the fraction of the measured irrigation water that runs off during an irrigation (initially taken as 0)

E_I = the fraction of the measured irrigation water that evaporates during an irrigation (initially taken as 0.05)

DP = the fraction of the measured irrigation water that flows past the root zone (initially taken as = 0.05)

LR_P = prescribed leaching as a fraction of I

2025 = area in square m

LRC = LR_P * I

where:

LRC = the calculated amount of leaching (mm)

2.2 CRITERIA FOR IRRIGATION CONTROL

At the end of the calculation period (every P minutes) the following criteria was validated:

ID2 >= θ_t ..... (27)

where:

θ_t = the maximum allowable soil water deficit (mm).

If Equation (27) was valid, the volume of irrigation water was calculated using Equation (28) and the result used for control of the irrigation system:

IR = (ID2 / I_E).(1 + LR_P) * 2025 ..... (28)

where:

IR = the gross irrigation volume (in cubic meter) required for the irrigation surface area of 2025 m^2

In the event of active irrigation, the irrigation was stopped when the following equation became valid:

ID2 <= 0 .....(29)

2.3 DATA FILES OF IRRIGATION RECORDS: RECORDS OF THE LOW & HIGH FREQUENCY IRRIGATION.

This files contained the following:-

a) The date, time, month, day, hour and minute.

b) All calculations were based on 15 min increments for the high frequency and 1 hour for the low frequency irrigation.

c) All applications and data reflect 2 mm per application for the high frequency and 25 mm for the low frequency irrigation.

d) The values of the following constants and parameters used at the end of the prescribed time period to calculate the water balance (P minutes, Appendix 4):

c_p, I_E, f_w, K_C, LR, θ_t, Rs(1-α), RO, DP, E_I, Z_0 and Z_W

e) The climatic data: (total of average values for the specific period) used to calculate the soil water balance, irrigation data as well as the following elements of the soil water balance:
ET, RH, XP, R_N, T_{dry}, T_{wet}, I_V, u_z, ID1, ID2, DP

f) Values from permitivity sensors: four units with ten sensors each.

2.4 MONITORING OF WEATHER DATA

A locally built logging device was used. The logger acted as a multiplexing device that connected to a special card inserted in the personal computer controlling the irrigation.

2.5 MONITORING OF SOIL WATER CONTENT AND SOIL SALINITY

Each plot was equipped with two neutron access tubes at approximate distances of 0.25 m and 0.5 m from an emitter. Each tube is installed to a depth of 1.4 m, which allows the profile water content to be determined to a depth of 1.2 m. The second access tube, 0.5 m from the emitter, was installed in September 1994 and was used only during the last season of the study. The vineyard is situated on a flat terrain and because lateral flow is unlikely, no provision was made for subsurface drainage.

A permitivity/capacitance based system was planned to record soil water content.

3 IRRIGATION MANAGEMENT 1995-1998

The same system was used as was described above for the previous phase of the study. It was, however, necessary since the retirement of Mr Wessels to adapt to a more “hands on” approach. The controller was placed on manual and the program was rewritten to accept irrigation quantities that were supplied. The main difference in the approach was that an calculated ET value per day was now sufficient whereas in the preceding study ET per 15 minutes and ET per 1 hour was required.

The old weather station was replaced by a new MC Systems weather station and the software supplied by the manufacturer was used to determine ET daily. The software was developed in collaboration with Prof J de Jager of the University of the Free State, making use of a modified Penman-Monteith equation, Equation (30) (Allen *et al.*, 1998). The algorithm of the program is supplied in an addendum to this report. The constants was adapted to account for the global position of Robertson and the height above sea level as well as for Robertson being a predominantly winter rainfall region.

$$E_P = \frac{0.612\Delta(R_n - G) + \gamma \frac{P}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{.....(30)}$$

E_p = Evapotranspiration, mm.day^{-1}

R_n = net radiation at crop surface, MJ.m^{-2}.day^{-1}

G =soil heat flux density, MJ.m-2.day^{-1}

T = mean daily air temperature at 2m height. ºC

u_2 = wind speed at 2m height, m.s^{-1}

e_s = saturated vapour pressure, kPa

e_a = actual vapour pressure, kPa

e_s-e_a= saturated vapour pressure deficit, kPa

Δ = slope vapour pressure curve, kPa.ºC^{-1}

γ = psychrometric constant, kPa.ºC^{-1}

The weather station was interrogated daily, and an ET amount was calculated and supplied to the irrigation controller. Whenever the amount exceeded 4 mm, the amount was divided into more than one irrigation event per day not exceeding 4 mm per event, to prevent water from ponding on the soil surface.

Provision was also made by programming the system to supply an average amount for the next week in case something happened and we were unable to program irrigation for the next days. This procedure worked quite well and assured against untimely maintenance to the system.

APPENDIX D Algorithm of Prof J de Jager, UOVS

```
10 INPUT "What is the mean dry bulb temperature in degrees Celsius"; TD
   INPUT "What is the mean wet bulb temperature in degrees Celsius"; TN
   INPUT "What is the average wind speed in m/s"; WS
   INPUT "What is the total radiation for this hour in MJ/m2/hour"; KIP
   KIP1 = KIP * 277.7777
   QN = (.75 * KIP1) - 72
   HII = .1
   ZO = .13 * HII
   D = .63 * HII
   IF WS = 0 THEN
   WS = .00000001#
   END IF
   RA = (LOG((2 - D) / ZO)) ^ 2 / (.41 ^ 2 * WS)
   CON1 = 1 / RA
   LCON = .03
   E1 = 6.11 * EXP(5347.61 * (1 / 273.16 - 1 / (273.16 + TD)))
   E2 = 6.11 * EXP(5347.61 * (1 / 273.16 - 1 / (273.16 + TN)))
   E3 = E2 - .66 * (TD - TN)
   E4 = E1 - E3
   GAMA = .66 * (1 + CON1 / LCON)
   DELTA = E1 / (273.16 + TD) ^ 2 * (6790.5 - 5.02808 * (273.16 + TD) + 4916.8 *
10 ^ (-.0304 * (273.16 + TD)) * (273.16 + TD) ^ 2 + 174209 * 10 ^ (-1302.88 /
(273.16 + TD)))
   DELT = DELTA / (DELTA + GAMA)
   K = (1710 - 6.85 * TD)
   LE1 = DELT * QN
   LE2 = (K * E4 * CON1) / (DELTA + GAMA)
   EVAP = (LE1 + LE2) * 3600 / 2469150
   IF EVAP < 0 THEN
   EVAP = 0
   END IF
   PRINT "TOTAL EVAPORATION IN mm/HOUR = "; EVAP
   GOTO 10
```

APPENDIX E List of the assembled project data.

The project data include the following:

1) Weather station data.
2) Soil water data from suction cup lisimeters and neutron probe readings.
3) Harvest data, which include harvest per vine, number of shoots, number of bunches and shoot mass per vine.
4) Various plant growth measurements like shoot elongation rates, trunk circumference, leaf size and berry size and weight.
5) Chemical analysis of soil water, soil, leaves, petioles, berries, must and wine.
6) Soil sample data, which include two samplings per year and full chemical analysis.

This electronic version of this report and files with selected relevant data will be made available on CD-ROM at the Department of Soil Science, University of Stellenbosch at a minimal fee to cover costs.

APPENDIX F List of the technology transfer activities, including theses and dissertations, which emanated from this research.

Theses

S.F. du Toit, M.Sc. (Agric.) Subject: Time and spatial changes in the chemical composition of a vineyard soil irrigated with saline water. (Stellenbosch, December 1995)

E. Van Zyl, M.Sc. (Agric.) Subject: The accumulation, distribution and effect of salinity in the organs of grapevine (Vitis vinifera L.) when irrigated with saline water. (Stellenbosch, December 1996)

W.P. de Clercq, M.Sc. (Agric) Subject: Leaf area changes and transpiration in a vineyard under salt stress. (Stellenbosch, December 1999)

Public addresses

De Clercq, W.P. 1996. The effect of saline irrigation water on grapevine success (Robertson ZA 1996)

De Clercq, W.P. 1997. Preliminary results of the reaction of Colombar to saline irrigation water. (Presented at the Vredendal Farmers Information Day, organised by Dept of Agriculture, Western Cape).

De Clercq, W.P. 1998. Response of Colombar Grapes to Saline Irrigation Water and some Managerial Options. (Presented at the Robertson Valley Information Day in Robertson, 9 September 1998).

Articles/papers presented at Congresses.

DE CLERCQ, W.P. 1999. Effect of irrigation water quality on grapevine performance at Robertson and Stellenbosch. *23rd SASEV Congress in Somerset West.*

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