THE EFFECT OF SALINE IRRIGATION ON SELECTED SOIL PROPERTIES, PLANT PHYSIOLOGY AND VEGETATIVE AND REPRODUCTIVE GROWTH OF PALSTEYN APRICOTS (*Prunus armeniaca* L.)

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Theresa Volschenk

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Promoter:
DR W.A.G. KOTZÉ

Co-promoter:
DR M.D. CRAMER

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DECLARATION

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:.....……..

Date:…….....…….…… …….

SUMMARY

Approximately 45% of apricot tree plantings in South Africa are centered on Montagu, Koo and Barrydale in the Little Karoo. Below average production in this area could be ascribed to the deteriorating water quality of the Breede River and highly saline groundwater from boreholes which provide this area with irrigation water. Profit margins for farmers are such that decreased yields cannot be tolerated. Correct management of low quality water could improve production and net farm income and could decrease irrigation return flow into the river system. The objective of this work was to establish whether international water quality guidelines for apricot are applicable under a different set of climatic conditions for a locally important cultivar and to revise guidelines if necessary for the management of irrigation with saline water. A drainage lysimeter was used to evaluate the effect of saline irrigation on apricot (*Prunus armeniaca* cultivar Palsteyn) trees over a period of four years at Stellenbosch (S33˚ 55'; E18˚ 53') in the Western Cape. Water salinity levels included a control (municipal water) and target levels of 0.7, 1.0, 2.0, 3.0 and 4.0 dS m^{-1}. Saline solutions were obtained by mixing different volumes of a $CaCl_2$:NaCl (1:1 molar) stock solution with control treatment water. The effect of saline irrigation water on soil water salinity as well as sodium, calcium and chloride content, vegetative growth, reproductive growth and some physiological processes of trees were monitored. Dispersed clay in leached water at the control treatment was related to low salinity levels and a sodium adsorption ratio (SAR) of less than, or about 1, in the soil. The salinity and SAR in the soil of treatments receiving irrigation water of 1 to 4 dS m^{-1} remained above 0.8 dS m^{-1} and below 10 respectively. Leaf water potential, leaf osmotic potential and relative water content of leaves decreased significantly with increased irrigation water salinity. Sodium increased significantly in above-ground woody tree parts in the 2 and 3 dS m^{-1} saline irrigation treatments. Chloride was correlated with foliar damage at irrigation water salinities exceeding 1 dS m^{-1} and leaf area duration decreased with increased salinity. The reduced canopy area in the higher salinity irrigation water treatments intercepted less light and, in combination with lower stomatal conductance and decreased net photosynthesis rate of leaves, led to reduced water consumption and final fruit size. Irrigation water salinity levels of 1.0 dS m^{-1} or higher, with an applied leaching fraction of 0.1, led to salinity in the saturated soil water extract that exceeded the locally determined salinity threshold value of 1.7 dS m^{-1} in the root zone for potential growth and yield decrement. This value is similar to the internationally recommended value of 1.6 dS m^{-1} and growers were advised not to use irrigation water with salinity exceeding an electrical conductivity of 0.82 dS m^{-1} for irrigation of Palsteyn apricot on Marianna rootstock where a leaching fraction of 0.1 was applied. The irrigation water salinity that could be used without yield loss at leaching fractions of 0.15 to 0.2 was estimated as 1.08 dS m^{-1} and 1.33 dS m^{-1}. The effect of rainfall on the allowed irrigation water salinity was not taken into account by this recommendation.

OPSOMMING

Ongeveer 45% van die appelkoosbome in Suid-Afrika is in die area rondom Montagu, Koo en Barrydale in die Klein Karoo aangeplant. Laer as verwagte produksies van boorde in hierdie area kan moontlik toegeskryf word aan die verswakkende waterkwaliteit van die Breederivier en uiters brak water vanaf boorgate wat besproeiingswater aan hierdie gebied voorsien. Winsmarge vir produsente is egter so kritiek dat ‘n verlaging in opbrengs nie ‘n opsie is nie. Korrekte bestuur van lae kwaliteit water kan produksie en netto plaasinkomste verbeter en terugvloei in die rivierstelsel verminder. Die doelwit van die studie was om vas te stel of internasionale riglyne vir waterkwaliteit vir appelkoosbome van krag is onder ander klimaatstoestande vir ’n plaaslik belangrike kultivar en om riglyne vir besproeiing met water van hoë soutgehalte daar te stel. Die effek van brak besproeiing op appelkoosbome (*Prunus armeniaca* cultivar Palsteyn) is oor ‘n periode van vier jaar geëvalueer in ‘n dreineringslisimeterfasiliteit te Stellenbosch (S33˚ 55’; E18˚ 53’) in die Wes-Kaap. Die behandelings het ‘n kontrole (munisipale water) asook water met teiken-soutgehaltes van 0.7, 1.0, 2.0, 3.0 en 4.0 dS m^{-1} ingesluit. Die soutoplossings is verkry deur verskillende volumes van ‘n $CaCl_2$:NaCl (1:1 molaar) voorraadoplossing met water van die kontrolebehandeling te vermeng. Die effek van die sout besproeiingswater op die soutgehalte van die grondwater asook die natrium, kalsium en chloried-inhoud, vegetatiewe groei, reproduktiewe groei en fisiologie van die bome is gemonitor. Die teenwoordigheid van gedispergeerde klei in logingswater van die kontrolebehandeling is in verband gebring met lae soutkonsentrasies en ‘n natriumadsorpsieverhouding (NAV) van ongeveer 1 in die grond. Die soutgehalte en NAV in die grond van behandelings wat 1 tot 4 dS m^{-1} water ontvang het, het respektiewelik bo 0.8 dS m^{-1} en onder 10 gebly. Waterpotensiaal, osmotiese potensiaal en relatiewe waterinhoud van blare het betekenisvol afgeneem met toename in die soutinhoud van die besproeiingswater. Natriumkonsentrasies in bogrondse houtagtige boomdele was betekenisvol hoër in bome van die 2 en 3 dS m^{-1} behandelings. Chloriedinhoud van blare is gekorreleer met blaarbrand waar beproeiingswater van meer as 1 dS m^{-1} toegedien is en blaarareaduurte het afgeneem met toename in soutinhoud van die besproeiingswater. Die verlaagde blaararea in behandelings met hoë soutgehalte besproeiingswater het minder lig onderskep en, in kombinasie met laer huidmondgeleiding en verminderende netto fotosintesetempo van blare, gelei tot verlaagde waterverbruik en kleiner finale vruggrootte. Besproeiingswater van 1 dS m^{-1} of hoër, met ‘n logingsfraksie van 0.1 toegepas, het gelei tot soutinhoude in die versadigde grondwaterekstrak wat die plaaslik-bepaalde drumpelwaarde van 1.7 dS m^{-1} vir potensiële groei- en produksieverlaging oorskrei het. Hierdie waarde is soortgelyk aan die internasionaal aanbevole waarde van 1.6 dS m^{-1}. Produsente is dus geadviseer om nie besproeiingswater met ‘n geleidingsvermoë van meer as 0.82 dS m^{-1} te gebruik vir besproeiing van Palsteyn appelkoosbome op Marianna onderstam waar ‘n logingsfraksie van 0.1 toegepas word nie. Die

soutgehalte van besproeiingswater wat gebruik kan word sonder om produksie in te boet indien logingsfraksies van 0.15 en 2.0 toegepas word, is beraam as 1.08 en 1.33 dS m^{-1}. Die effek van reënval op die toegelate soutinhoud van die besproeiingswater is buite rekening gelaat met hierdie aanbeveling.

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LIST OF ABBREVIATIONS AND SYMBOLS

ARC	Agricultural Research Council
C_i	Substomatal cavity carbon dioxide concentration ($\mu L\ L^{-1}$)
Cl_e	Chloride concentration in the saturated soil water extract (mmol dm^{-3})
Cl_{iw}	Chloride concentration in the irrigation water (mmol dm^{-3})
Cl_{sw}	Chloride concentration in the soil water (mmol dm^{-3})
DFPT	Deciduous Fruit Producers' Trust
DW	Dry weight (g)
EC	Electrical conductivity (dS m^{-1})
EC_e	Electrical conductivity in the saturated soil water extract (dS m^{-1})
EC_e'	Depth-weighted seasonal average electrical conductivity in the saturated soil water extract (dS m^{-1})
EC_{iw}	Electrical conductivity of irrigation water (dS m^{-1})
EC_{sw}	Electrical conductivity of soil water (dS m^{-1})
EC_t	Threshold salinity (dS m^{-1})
E_p	American Class-A pan evaporation
ESP	Exchangeable sodium percentage
ET	Evapotranspiration (mm)
FAO	Food and Agriculture Organization of the United Nations
FC	Field water capacity measured as volumetric soil water content (%v/v)
FM	Fresh mass (g)
FN	Fruit number
HC	Hydraulic conductivity
LAI	Leaf area index
LR	Leaching requirement
LOP_{pd}	Pre-dawn leaf osmotic potential (MPa)
LSD	Least significant difference
LWP_{pd}	Pre-dawn leaf water potential (MPa)
PPECB	Perishable Products Export Control Board
RDI	Regulated deficit irrigation
RuBPcase	Ribulose bisphosphate carboxylase
RET	Relative evapotranspiration
RY	Relative yield
S	Slope of the salinity-yield response curve, indicating the rate of yield decline
SAR	Sodium adsorption ratio

SAR_{iw}	Sodium adsorption ratio for irrigation water
SAR_{sw}	Sodium adsorption ratio for soil water
SAR_{sw}'	Depth-weighted seasonal average soil water sodium adsorption ratio
SE	Standard error
SPM	Summer pruning mass
TCC	Total cation content
Y_m	Non-saline control yield (kg)
Y_r	Relative growth or yield
$\Psi_{o,FC}$	Osmotic potential of soil water at field capacity (MPa)

CHAPTER 1

INTRODUCTION

South Africa has for more than a century supplied deciduous fruit to the Northern Hemisphere, primarily the United Kingdom and Europe, and is still a major Southern Hemisphere exporter of fresh fruit (Huyshamer, 1997). The turnover of the deciduous fruit industry currently amounts to more than nine billion rand annually, with the contributions of pome fruit, table grapes and stone fruit being *c.* 4.5, 3.8 and 0.9 billion rand, respectively (Deciduous Fruit Producers' Trust [DFPT], 2002). Deciduous fruit production is, however, becoming increasingly difficult due to the collective effect of several constraints. Such restraining factors include competition from other Southern Hemisphere suppliers (e.g. Chile, Argentina), high interest rates, lower internal rate of return and meeting the specific requirements of European markets that has stringent quality standards and demand an increasing variety of cultivars to select their products from (Huyshamer, 1997). In order to meet these market demands, producers adjust orchard planting density, cultivar combinations, rootstocks, training systems as well as other production techniques. Growers also strive to limit environmental constraints related to climate, soils, water and wind as far as possible by integrating their choice of cultivar, rootstock and site. It follows that reliable information regarding crops is essential for producers to base their management decisions on and to facilitate economically viable production of these high value crops.

Within South Africa, more than 80% of all pome and stone fruit is produced in the Western Cape region (Huyshamer, 1997) (Fig.1.1) and nearly the entire fruit industry of the region is dependent on irrigation (Dept. Water Affairs, 1986). Irrigation utilizes more than 40% of the limited water resources of the Western Cape (Dept. Landbou: Wes-Kaap & Dept. Waterwese & Bosbou, 2003) and water restrictions are enforced in summer whenever winter rains do not adequately meet the water demand. Limited water resources and increasing soil salinisation in arid and semi-arid regions are universally considered to be important limitations for agricultural production (Abrol *et al*., 1988; Orcutt & Nilsen; 2000; Rosegrant, Cai & Cline, 2002). Salinisation of semi-arid areas throughout the world is accordingly seen as a threat to long-term production of perennial deciduous, and especially stone fruit, that is particularly sensitive to salinity and ion toxicities (Bernstein, 1980).

The majority of apricots produced in South Africa originate from the Western Cape (85%) and approximately 75% of this is from trees planted in semi-arid areas (DFPT, 2002) with the possibility of salinisation. It is estimated that 9% of the irrigated land in the Western Cape is severely affected by salinity or waterlogging, while an additional 15% is moderately affected by these phenomena (Water Research Commission, 1996, cited in Backeberg, 2000). Problems

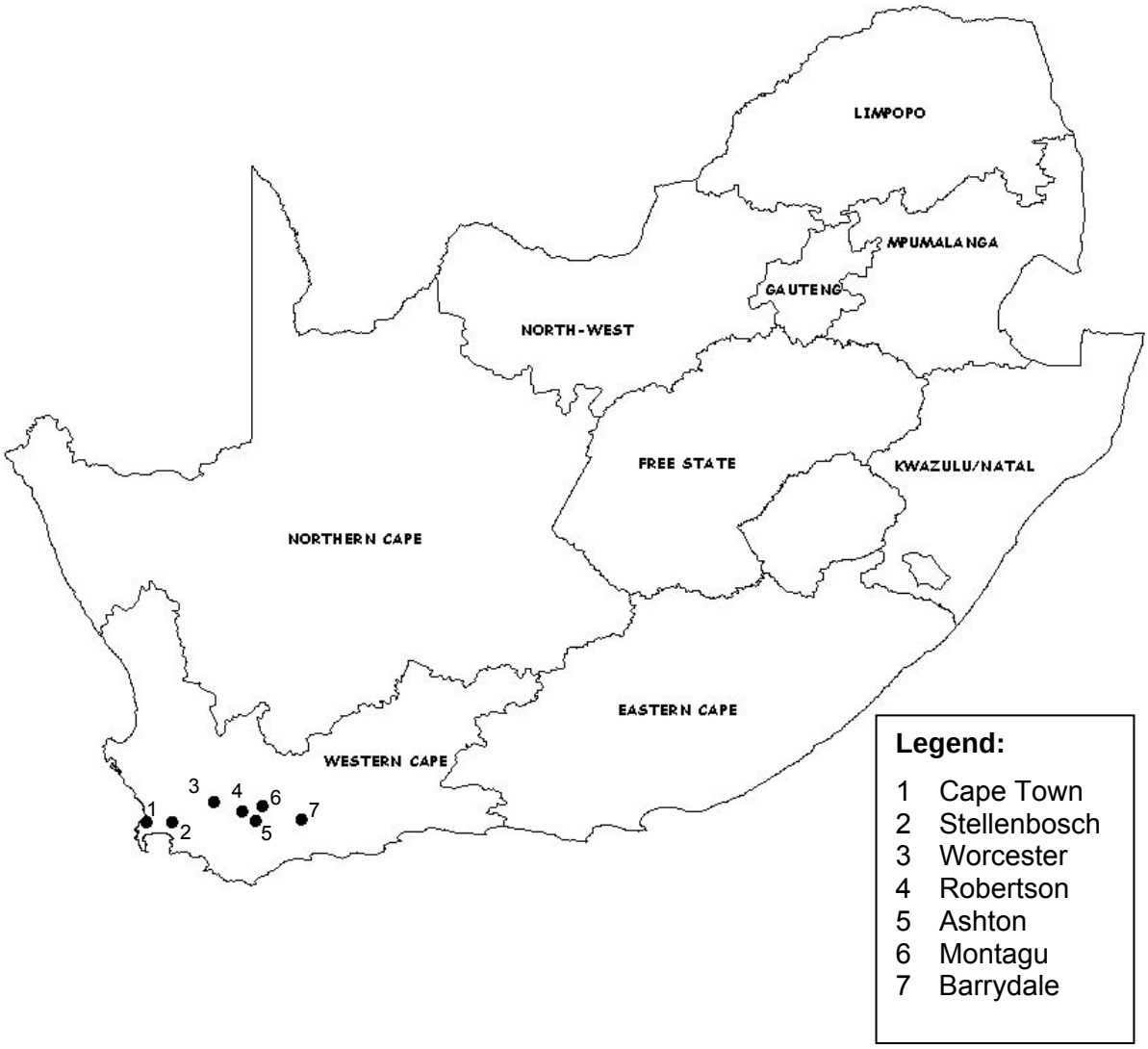


Figure 1.1 Map of the Republic of South Africa illustrating the locality of the Western Cape and towns relevant to the study.

associated with salinity such as decreases in crop yield and quality have already been encountered in a number of rivers and irrigation schemes in South Africa (Fourie, 1976; Du Preez *et al*., 2000; Hall, 1985; Moolman *et al*., 1999) and salinisation of the Breede River in the Western Cape continued during the past few decades (Moolman *et al*., 1999).

The lower Breede River area is an important fruit and vegetable producing area under intensive irrigation and contributes significantly to the national agricultural output. According to Moolman *et al*. (1999) wine grapes extend over 65% of the Breede River Valley area while 13% of the crops produced are peaches and apricots. Approximately 45% of apricot plantings in the Western Cape are centered on Montagu, Koo and Barrydale in the Little Karoo (DFPT, 2002) where saline irrigation water is a problem. The Brandvlei dam is the main source of irrigation water for the Robertson, Bonnievale and Ashton regions and one of the main sources for the Worcester and Montagu regions (Fig. 1.2). A low average rainfall of 200 to 300 mm per annum, hot dry summers and seasonal water requirements cause water shortages during the peak summer months. Canals that form a part of the water works infrastructure, have a constant flow rate and cannot provide in the peak demands, accentuating this problem. Pollution and salinisation occur because the Breede River serves as the drainage canal as well as the water supplier.

The Department of Water Affairs manage water releases from the Brandvlei dam to control the irrigation water quality according to criteria that would prevent substantial yield losses of the main crop produced. The EC_e (electrical conductivity of the saturated soil extract) threshold value of Maas & Hoffman (1977) of 1.50 dS m^{-1} in the rootzone was used as basis for the criteria for the management of the Breede River water quality. These criteria for grapevine response to salinity and specific ion concentrations were recently tested by Moolman *et al*. (1999) in order to contribute to improved salinity management of the Breede River. Their results indicated that grapevines are more sensitive to salinity and that yield decreased progressively above an EC_e of 0.75 dS m^{-1} at a rate three times faster than the value reported by Maas & Hoffman (1977). According to Ayers & Westcot (1985), apricot trees are also sensitive to salinity and a decrease in vegetative growth is expected at an EC_e value of 1.6 dS m^{-1}. Profit margins for farmers, however, are such that decreased yields cannot be tolerated and in view of the findings of Moolman *et al*. (1999), it is important to establish whether the international guideline for apricots is applicable to local conditions.

Approximately five years ago farmers in South Africa were cautioned to expect water quality to deteriorate and water to be in short supply (Du Plessis, 1998). Irrigated agriculture in South Africa is furthermore expected to become subject to increasing pressure from government to

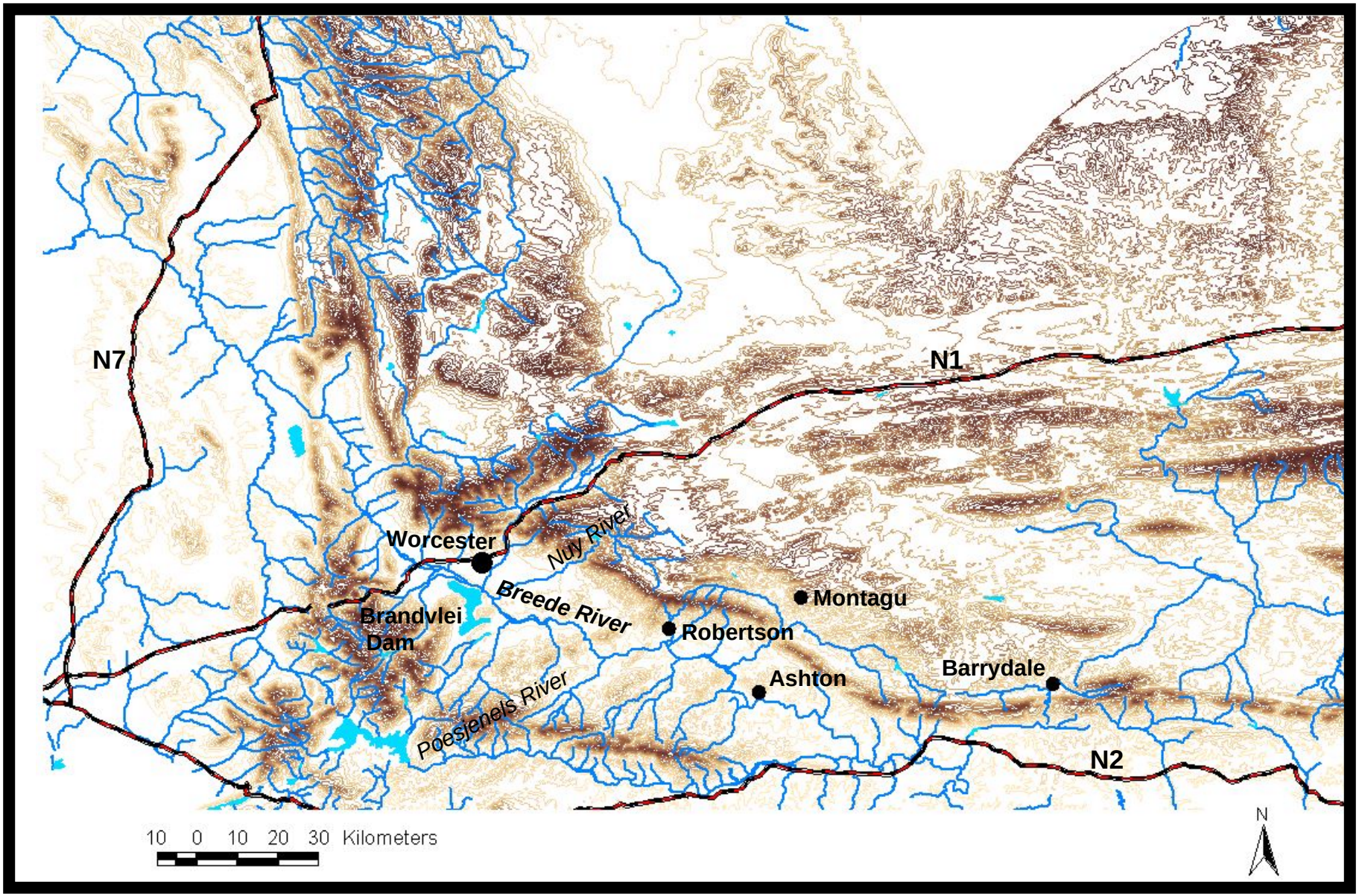


Figure 1.2. Map of a section of the Breede River in the Western Cape.

reduce the salt load resulting from its operations. Correct management of low quality water could improve production and net farm income and could decrease saline return flow into the river system by restriction of excessive leaching. The objective of this work was to establish the response of a locally important apricot cultivar to salinity and to provide guidelines for irrigation management with saline water to aid in appropriate on-farm decisions for sustained and profitable production of crops.

The specific objectives for the study were:

- To assess the effect of saline irrigation of apricot trees on changes in salinity and sodicity of the soil profile over time.
- To determine the effect of irrigation with water of varying salinity on the evapotranspiration of apricot.
- To assess the viability of irrigation of an apricot cultivar with saline irrigation water by evaluating the accumulation and distribution of sodium, calcium and chloride in trees at the end of a four year irrigation period.
- To describe the response of selected plant physiological processes, vegetative and reproductive growth and the resulting fruit quality of apricot trees to saline irrigation and to identify causal factors contributing to the response.
- To compare the locally determined salinity threshold value for yield decrease with the internationally published threshold value for salinity management purposes.

The study intended to derive these answers by researching the effect of saline irrigation on *Prunus armeciaca* L. cultivar Palsteyn (alias Imperial) on Marianna rootstock in a drainage lysimeter facility in Stellenbosch. Imperial apricot forms part of the deciduous fresh fruit export pallete and comprised on average *c.* 55% of the total volumes of apricot exported during the past three seasons (2000/01 to 2002/03). Apricots are mainly exported to the United Kingdom (49%), Europe (36%) and Middle East/ Mediterranean (15%) countries (Perishable Products Export Control Board, 2003). Marianna rootstock is used on some apricot cultivars in South Africa (Huyshamer, 1997) and is known for its salt exclusion characteristics (Bernstein, Brown & Hayward, 1956).

A study necessitating frequent sampling and plant physiological measurements before dawn posed a logistical problem if conducted in the remote Little Karoo. The long-term atmospheric evaporative demand measured by Class-A pan evaporation (E_p) and averaged for September until April, is similar for Stellenbosch to the average of that of the Robertson, Ashton, Montagu and Barrydale apricot production areas (E_p = 7.3). For the warmest months (i.e. December, January and February) the E_p of Stellenbosch is higher than the average of that of the Robertson, Ashton, Montagu and Barrydale apricot production areas (E_p = 9.6 compared to 9.1)

and exceeds that of Robertson (E_p = 9.5), which is the warmest of the Little Karoo areas mentioned above. The long term maximum temperature of Stellenbosch is 2.8°C lower than that of the Little Karoo average for December to February. Based on the favorable comparison of the evaporative demand between Stellenbosch and the Little Karoo production areas and the availability of three-year-old Palsteyn apricot trees on Marianna rootstock in a drainage lysimeter facility at Stellenbosch, it was decided to conduct the study in Stellenbosch.

A study on the effect of saline irrigation on the soil and the concurrent response of mature apricot trees in the lysimeters was considered to provide the necessary information to reach the objectives of the study.

REFERENCES

Abrol, I.P., Yadav, J.S.P. & Massoud, F.I., 1988. Salt-Affected Soils and Their Management. FAO Soil Bulletin, No. 39. Rome: FAO.

Ayers, R.S. & Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: FAO.

Backeberg, G.R., 2000. Planning of research in the field of agricultural water management. Water Research Commission, PO Box 824, Pretoria, 0001, South Africa.

Bernstein, L., 1980. Salt tolerance of fruit crops. *USDA Agric. Inf. Bull*. 292: 1-8.

Bernstein, L., Brown, J.W., & Hayward, H.E. 1956. The influence of rootstock on growth and salt accumulation in stone fruit trees and almonds. *Proc. Am. Soc. Hort. Sci*., 68: 86-95.

Department of Water Affairs, 1986. Managing the water resources of South Africa. Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001, South Africa.

DFPT, 2002. Key deciduous fruit statistics 2002. Paarl: Deciduous Fruit Producers' Trust.

Departement Landbou: Wes Kaap & Departement van Waterwese en Bosbou, 2003. Verslag: Wes-Kaapse Waterberaad. Stellenbosch: Stellenbosch Lodge: p.1.

Du Plessis, H.M., 1998. Water quality and irrigation in South Africa. *S.A. Irrigation*, October/November: 3-11.

Du Preez, C.C., Strydom, M.G., Le Roux, P.A.L., Pretorius, J.P., Van Rensburg, L.D. & Bennie, A.T.P., 2000. Effect of water quality on irrigation farming along the Lower Vaal River: The influence on soils and crops. WRC Report No. 740/1/00. Pretoria: Water Research Commission.

Fourie, J.M., 1976. Mineralization of Western Cape Rivers: An investigation into the deteriorating water quality related to drainage from cultivated lands along selected

catchments, with special reference to the Great Berg River. Ph.D. (Agric) Thesis, University of Stellenbosch, Stellenbosch, South Africa.

Hall, G.C. (ed.), 1985. Studies of mineralization in the Great Fish and Sundays Rivers. Water Research Commission Working group for mineralization: Summary report. Pretoria: Water Research Commission.

Huyshamer, M., 1997. Integrating cultivar, rootstock and environment in the export driven South African deciduous fruit industry. *Acta Hort*., 451: 755-760.

Maas, E.V. & Hoffman, G.J., 1977. Crop salt tolerance-current assessment. *J. Irrig. Drain Div. ASCE,* 103:115-134.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J. & Moolman, C.G., 1999. The Use of Saline Water for Irrigation of Grapevines and the Development of Crop Salt Tolerance Indices. WRC Report No. 303/1/99. Pretoria: Water Research Commission.

Orcutt, D.M. & Nilsen, E.T., 2000. Physiology of plants under stress. New York: John, Wiley & Sons, Inc.

Perishable Products Export Control Board [Online], 2003. Available: http://www.PPECB.com. [2003, November 3].

Rosegrant, M.W., Cai, X. & Cline, S.A., 2002. World water and food to 2025: Dealing with scarcity. Washington, D.C.: International Food Policy Research Institute.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Soil salinisation is the most prevalent and widespread problem limiting crop production in irrigated agriculture (Shalhevet, 1994). Irrigated agriculture, including that in South Africa, will in future be faced with the challenge of using less water, in many cases of poorer quality, to provide food and fibre for an expanding population (Oster, 1994; Moolman *et al*., 1999). Use of poor quality water requires modification of standard irrigated agriculture practices. This includes the selection of appropriately salt-tolerant crops, improvements in water-management, and in some cases, adoption of advanced irrigation technology and maintenance of soil physical properties to assure soil tilth and adequate soil permeability to meet crop water and leaching requirements (Oster, 1994). Present knowledge, if judiciously applied, is adequate for coping with many of the salinity problems resulting from mismanagement of irrigation and drainage. This is despite the fact that there are still many aspects of salinity which are obscure and misunderstood and many of the required technological solutions are yet to be developed (Shalhevet, 1994).

Sustained and profitable production of crops on salt-affected soils is possible if appropriate on-farm management decisions are made. In order to be successful, producers require an understanding of how plants respond to salinity, the relative tolerances of different crops and their sensitivity at different stages of growth, and how different soil and environmental conditions affect salt-stressed plants (Francois & Maas, 1994). The recent increase in the number of publications on the response of mature trees and vines to salinity indicate the worldwide trend of increased exposure of fruit trees and vines to salinity (Van Zyl, 1997; Moolman *et al*., 1999; Storey & Walker, 1999). Among the first crops to suffer yield reductions if irrigation water becomes more saline will be deciduous fruit trees (Hoffman *et al*., 1989). Due to their perennial nature, these high-value crops are a long-term investment for producers and it is therefore important to establish the effect of prolonged exposure to salinity on the growth, production and longevity of the trees.

The current review includes a synopsis of the effect of saline irrigation on soil properties as related to leaching. The review focuses on literature regarding the long-term effect of salinity on deciduous, as well as non-deciduous perennial fruit tree crops and grapevine. Short-term studies and literature on annual crops were consulted to clarify mechanisms of salt injury where

necessary. In some of these studies, sodium chloride is used as the sole salinising agent to assess plant response to extreme ion concentrations or ion relations in the substrate. The use of salinising compositions that are not representative of that in the field, however, limits the extent to which the results can be interpreted. The short-term studies are informative, despite the fact that effects on potted trees differ from effects of salinity on orchard-grown trees. The mechanisms of salt injury, its effect on plant physiology and subsequently on factors determining the economical yield and evapotranspiration of selected perennial fruit crops are discussed. Literature on salt tolerance and selected factors that may modify it concludes the review.

2.2 THE EFFECT OF SALINE IRRIGATION ON SOIL PROPERTIES

2.2.1 Irrigation water quality considerations

Where saline water is the only available water source for irrigation, the question frequently arises as to whether this water could or should be used for crop production purposes. The quality of irrigation water has been discussed in several papers and reviews (Ayers & Westcot, 1985; Department of Water Affairs and Forestry, 1993; Rhoades & Loveday, 1990; Richards, 1954; Shainberg & Letey, 1984). To evaluate the suitability of water for irrigation, one should consider the specific conditions under which the water is to be used. Factors to be taken into account include soil properties, crop species, irrigation technology and management, cultural practices and climate (Rhoades, 1972). The South African Water Quality Guidelines for Irrigation (Department of Water Affairs and Forestry, 1993) considered the effect of irrigation water quality on profitability (crop yield, crop selection and crop acceptability), soil degradation and sustainable production as well as the extent to which different management options need to be employed to alleviate undesirable effects to categorise the quality of irrigation water. However, the main criteria used to establish if irrigation water has potential to cause soil conditions injurious to crop growth are specific ion concentrations, salinity and sodicity (Shainberg & Letey, 1984). Salinity refers to total salt concentration and is most commonly measured and reported as electrical conductivity (EC), while the sodium adsorption ratio (SAR = $Na^{+}/(Ca^{2+} + Mg^{2+})^{½}$ with Na^{+}, Ca^{2+} and Mg^{2+} in mmol dm^{-3}) is frequently used to quantify the irrigation water sodium hazard.

2.2.2 The process of salinisation and salinity control by leaching.

One of the major factors responsible for formation of salt-affected soils is the use of saline groundwater for irrigation purposes, as high salinity of the irrigation water can cause accumulation of salts in the rootzone, particularly if the internal drainage of the soils is restricted and leaching, due to rainfall and/or irrigation water is inadequate (Abrol, Yadav & Massoud, 1988). Leaching may be considered to be the key to successful cultivation with brackish water

irrigation (Oster, 1994; Shalhevet, 1994). As water is taken up by the crop or evaporates from the soil surface, salts are left behind and accumulate. Each plant has a maximum soil salinity level that can be tolerated without negatively influencing yield or crop quality due to osmotic and/or specific ion effects (Maas, 1987; Maas & Hoffman, 1977). High salt concentrations in the soil solution and toxic salt levels, respectively, do not damage or affect the physical properties of the soil (Shainberg & Letey, 1984). Leaching should be applied to the soil, however, to remove salts from the root zone of plants and thus prevent accumulation of salt in excess of the crop salt tolerance levels.

The leaching requirement can according to Rhoades and Merrill (1976), cited in Ayers and Westcot (1985), be estimated as LR = EC_{iw}/ ($5EC_e$ - EC_{iw}) where EC_{iw} and EC_e refer to irrigation water salinity and the crop tolerance to soil salinity respectively. The water salinity can be obtained from laboratory analysis while the EC_e should be obtained from tolerance data for the crop concerned (Maas, 1987; Maas & Hoffman, 1977). The amount of additional water to be applied in excess of crop water use to prevent damaging salinity levels increases as the salinity of the irrigation water increases. In addition, the amount of leaching water depends on the initial salt content of the soil, required level of soil salinity after leaching, the depth to which reclamation is required, soil characteristics (Abrol *et al*., 1988) and the amount of effective rainfall (Ayers & Westcot, 1985; Hoffman & Durnford, 1999). It is, however, not necessary for leaching to be achieved with every irrigation event and leaching is only needed once the levels of soil salinity approach hazardous levels (Oster, 1994). Requirements for effective leaching to occur are soil physical properties that will allow adequate water infiltration and movement through the soil profile enabling excess salt removal (Oster, 1994) and preferably a low soil moisture content and the absence of a shallow water table, the latter of which can serve as a secondary source of salinisation (Abrol *et al*., 1988; Ayers & Westcot, 1985). According to Abrol *et al*. (1988), excessive leaching can contribute to root zone salinisation in the event that it causes a rise in the water table. Once the water table is within 1 to 2 m below the soil surface, it can contribute significantly to evaporation from the soil surface and movement of salts from the water table to the root zone can occur.

2.2.3 Soil properties that affect leaching

A prerequisite for the use of leaching to effectively control salinisation is that the applied water can readily infiltrate and move through the soil to produce the drainage necessary for the removal of excess salts (Oster, 1994). Infiltration rate and hydraulic conductivity are the two main processes determining water movement through the soil (Shainberg & Letey, 1984). If these processes are significantly adversely affected by irrigation water quality, it could reduce the effectivity of the leaching process and interfere with the water supply and aeration required for normal tree growth. Changes in soil pore structure are important for water and air movement

into and through the soil. These changes are brought about by clay swelling and dispersion resulting from changes in soil chemistry, aggregate disintegration (slaking) upon wetting, root growth and decay, vehicle and animal traffic, tillage and cropping (Oster & Shainberg, 2001). The extent of slaking, swelling, and dispersion and the relative importance of the processes governing them were found to depend on the salinity and sodicity of the soil (Shainberg & Letey, 1984; Abu-Sharar *et al*., 1987) and will be discussed in more detail below.

The mutual effect of exchangeable sodium and the total salt concentration on the permeability of the soil is strongly influenced by other factors such as the intrinsic properties of the soils (Oster & Shainberg, 2001). The soil properties concerned include for example texture, mineralogy, pH, CaCO3, sesquioxides, organic matter content and the amount of exchangeable potassium and exchangeable magnesium. The effects of these properties were discussed in detail by Shainberg and Letey (1984) and Sumner (1993) and a synopsis thereof was included in the current review. Soil, water and crop management factors such as cultivation, irrigation method and wetting rate, previous water content and time since cultivation are other factors that can either alleviate or aggravate the effects of sodicity and salinity on soils. These are beyond the scope of this review, but are discussed by Mamedov *et al*. (2001), Shainberg *et al*. (2001) and Oster & Shainberg (2001).

2.2.3.1 Infiltration rate

Infiltration rate measures the rate at which water enters the soil at the soil-atmosphere interface. Infiltration rate is high during the initial stages of infiltration but decreases exponentially with time to approach a constant rate. Mainly two factors effect the reduction in infiltration rate: 1) a decrease in the matric potential gradient that occurs as infiltration proceeds; 2) the formation of a crust or seal at the soil surface (Shainberg & Letey, 1984). Soil surface sealing and the resulting reduction in water infiltration are considered to be a problem in many vineyard soils of the Western Cape region in South Africa (Louw & Bennie, 1992). The nature of the soil surface effects the infiltration rate and the result of the interaction of the applied water with the surface soil structure becomes crucial in determining the final infiltration rate. The presence of a crust or seal at the soil surface will appreciably decrease the final infiltration rate compared to when it is absent (Sumner, 1993).

Crust formation at the soil surface can be ascribed to two processes. The first process is physical disintegration of soil aggregates (slaking) and their compaction caused by the impact of rain or irrigation water droplets. The second, is physicochemical dispersion and movement of clay particles and the resultant plugging of conducting pores (Agassi, Morin & Shainberg, 1981). The infiltration rate is more sensitive than hydraulic conductivity to the SAR and the total salt content, quantified by the electrical conductivity (EC), of the irrigation water (Shainberg & Letey,

1984). This is due to the mechanical impact of the water drops and the relative freedom of particle movement at the soil surface (Oster & Schroer, 1979). Stirring of the soil surface by drop impact and irrigation water flow enhances the rate of clay dispersion and crust formation (Shainberg & Letey, 1984). According to Sumner (1993) even soils with very low levels of exchangeable sodium can exhibit sodic behaviour in the presence of low salinity water and mechanical energy. Research of Du Plessis and Shainberg (1985) with a rainfall simulator on infiltration rates of South African soils confirmed that some of these soils are very susceptible to crust formation at exchangeable sodium percentages as low as 1. Very low salinity water (less than 0.2 dS m^{-1}) almost always results in water infiltration problems, regardless of the SAR (Ayers & Westcot, 1985). The EC_{iw} values for irrigation water which are needed to prevent the detrimental effect of sodium on infiltration rate into the soil as proposed by Ayers and Westcot (1985) in their table of guidelines for interpretation of water quality for irrigation, are presented as an excerpt in Table 1. The more recent South African Water Quality Guidelines for Irrigation (Department of Water Affairs and Forestry, 1993) proposed even stricter guidelines to ensure prevention of infiltration problems on South African soils (Table 2). The guidelines should, however, be adjusted and made more site-specific, depending on the specific soils involved, the availability of information on their permeability, SAR-EC relationships, and the rainfall patterns in the area.

Table 2.1. Excerpt of guidelines for interpretation of water quality for irrigation (Ayers & Westcot, 1985). The sodium adsorption ratio (SAR) and electrical conductivity (EC_{iw}) of the irrigation water are considered together to assess potential soil infiltration problems

	Degree of restriction on irrigation water use		
	None	Slight to moderate	Severe
SAR	EC_{iw} (dS m^{-1})		
0 - 3	>0.7	0.7 - 0.2	< 0.2
3 - 6	>1.2	1.2 - 0.3	<0.3
6 - 12	>1.9	1.9 - 0.5	<0.5
12 - 20	>2.9	2.9 - 1.3	<1.3
20 - 40	>5.0	5.0 - 2.9	<2.9

The predictive capacity of the SAR of the irrigation water (SAR_{iw}) for soil exchangeable sodium percentage (ESP) and SAR of the soil solution (SAR_{sw}) is complicated by evapotranspiration that concentrates the salts in the applied irrigation water. The SAR equation does not account for changes in calcium solubility in the soil water that take place due to precipitation or

Table 2.2. Summary of South African irrigation water quality classes as determined by salinity, sodicity effects on sodicity induced infiltration rate and leaching fraction (Department of Water Affairs and Forestry, 1993). The salinity of the water is expressed in terms of electrical conductivity

Class	Water quality constituent		Management option	Fitness for use[1]	Soil permeability
	Salinity (dS m^{-1})	Sodicity (SAR)	Leaching fraction no more than		
I	0 – 0.4	0 – 1.5	0.10	Suitable for even most sensitive soils.	SAR of water will not induce a soil-ESP which reduces infiltration rate of sodium sensitive soils.
II	0.4 – 0.9	1.5 – 3.0	0.10	Suitable for all but most sensitive soils.	SAR of water will not induce a soil-ESP which reduces infiltration rate of moderately sodium sensitive soils.
III	0.9 – 2.7	3.0 – 5.0	0.15	Some special management practices are implemented.	The infiltration rate of sodium sensitive soils can be maintained with special but economical management practices.
IV	2.7 – 5.4	5.0 – 10.0	0.20	Special management practices are such that economic viability becomes questionable.	The infiltration rate of sodium sensitive soils cannot be maintained economically with special management practices.

[1] Limitation imposed on allowable choices in soil sodicity-induced infiltration rate by the definition of the particular fitness-for-use class.

dissolution during or following irrigation (Ayers & Westcot, 1985). The adjusted SAR according to Suarez (1981; 1982) improved the estimation of the tendency of $CaCO_3$ to dissolve or precipitate following irrigation and has increased the ability to quantify the relationships between the SAR_{iw} and soil ESP. This change in electrolyte concentration of the applied water and in the soil solution during the growing season are more important parameters than soil ESP in predicting the effect of sodicity damage to the soil (Shainberg & Letey, 1984; Rhoades & Loveday, 1990). The permeability hazard can be evaluated by observing whether the adjusted SAR-EC_{iw} combination is likely to pose problems according to a relationship described by Rhoades & Loveday (1990) between the SAR in the topsoil and the EC of the infiltrating water.

Clay dispersion, governed by the relative balance between exchangeable sodium and total salt content of the soil water, was considered by several researchers to be the prime factor in the hardsetting behaviour of some soils (Sumner, 1993). The surface of hardsetting soils is compact, hard and apedal on drying. Crust or seal formation occurs especially in soils low in organic matter and with unstable structure (Oster, 1994). The structure of hardsetting soils is highly unstable and even wetting causes aggregate breakdown and clay movement within the entire Ap horizon, whereas in crusting, clay mobility is manifest only in the top few millimeters of soil. In addition to the effect of exchangeable sodium and total salt content on dispersion of the soil, several other factors can result in hardsetting behaviour of soils and is described in detail by Sumner (1993).

Several inherent soil properties may affect the infiltration rate (Shainberg & Letey, 1984). Only a small amount of dispersed clay is needed to clogg soil pores and consequently soil texture is not expected to affect infiltration rate markably. More recent research (Mamedov *et al*., 2001), however, showed that soils with intermediate clay content (22.5 to 40.2% clay) were more susceptible to seal formation compared to soils with low (8.8%) or high (>52.1%) clay content. The role of exchangeable sodium levels in determining sealing decreased with an increase in clay content and in wetting rate.

Behaviour of soils with respect to crusting is strongly influenced by the mineralogy of the clay fraction (Shainberg, 1992 and Van der Watt and Valentin, 1992 cited in Sumner, 1993). Smectitic and illitic clays were more prone to dispersion than kaolinites (Frenkel *et al*., 1978; Goldberg & Glaubif, 1987) and soils in which sesquioxides are present, with crust formation resulting in lower infiltration rates (Van der Watt and Valentin, 1992, cited in Sumner, 1993). In contrast, low shrink/swell potential is a prerequisite for hardsetting soils. Aggregate disintegration took place more rapidly in kaolinitic than in smectitic soils (Sumner, 1993). Furthermore, precipitation of cementing agents such as amorphous silica, imogolite-like

aluminosilicates, felspathoid minerals and silica-Fe complexes could be involved in the phenomenon of hardsetting (Chartres, Kirby & Raupach, 1990).

The mineral weathering process is not important as far as infiltration rate is concerned as the kinetics of dissolution are usually too slow to supply sufficient electrolyte to prevent crust formation (Sumner, 1993). Increasing levels of exchangeable potassium have a detrimental effect on infiltration rate, although, substantially less than that of equivalent levels of sodium, whereas increasing levels of exchangeable magnesium do not affect infiltration rate (Sumner, 1993).

2.2.3.2 Soil hydraulic conductivity

The hydraulic conductivity of a soil is a measure of its ability to transmit water (Klute & Dirksen, 1986). A 50% decrease in soil HC relative to normal HC could be regarded as critical and will result in poor soil permeability (Shainberg & Letey, 1984). The "threshold concentration" concept of Quirk & Schofield (1955) was therefore redefined by Shainberg & Letey (1984) as the combination of salt concentration and ESP required to cause a 50% change in HC. The primary mechanisms responsible for degradation of hydraulic conductivity are slaking in addition to clay swelling and dispersion (Quirk & Schofield, 1955; Shainberg & Letey, 1984; Sumner, 1993). The permeability of soils is determined by the amount and continuity of interaggregate pores larger than 30 μm in the soil, with a large amount of these transmitting pores resulting in high hydraulic conductivity (Kay & Angers, 1999, cited in Shainberg *et al*., 2001). On wetting, disintegration of macroaggregates (>250 μm) into microaggregates (20 - 200 μm) diminish the number of macropores, thereby decreasing soil permeability and thus hydraulic conductivity. Slaking depends on agreggate stability in addition to the effect of soil sodicity and low salinity (Abu-Sharar *et al*., 1987). Soil aggregates may disintegrate as a result of the development of internal swelling pressure or of local shearing stresses which deform the weakened aggregates (Waldron & Constantin, 1968). The development of internal swelling depends on the difference between the concentration of ions within the aggregate and the bulk solution (Shainberg, Bresler & Klausner, 1971) while expansion of diffusive double layers on the clay surfaces within the aggregates could result in shearing stresses that cause their breakdown (Abu-Sharar *et al*., 1987).

The mechanism of swelling and dispersion according to the diffuse double layer between the clay colloidal material and surrounding soil solution was previously described in detail (Quirk & Schofield, 1955; Quirk, 2001; Shainberg & Letey, 1984 and Sumner, 1993) and concisely summerised by Halliwel, Barlow and Nash (2001). Swelling reduces radii of the larger water-conducting pores with concurrent reduction in hydraulic conductivity. Dispersion (deflocculation) is considered to occur when charged clay plates which are separating during swelling, have

reached such a distance apart that the attractive forces are no longer enough to oppose the repulse between colloidal particles (Quirk & Schofield, 1955). Clay movement and deposition within the soil pores may further deteriorate soil hydraulic permeability (Oster & Shainberg, 2001; Quirk, 2001).

Swelling and dispersion increase due to larger repulsion forces between clay particles with an increasing ratio of sodium to calcium and magnesium or SAR and decreasing salinity, thereby influencing the physical properties of each soil in a unique manner (Oster, 1994; Oster & Shainberg, 2001). Soils begin to swell as the total cation concentration of the soil solution is reduced but it becomes only substantial at SAR values above 10 (Sumner, 1993). This swelling process is more or less reversible when the total salt content is increased. Clay dispersion however, occurs when the total cation concentration of the soil solution decreases below the turbidity concentration, the concentration at which the electrolyte concentration is too low to maintain clay – soil particle interactions (Quirk & Schofield, 1955; Quirk, 2001). Below the turbidity concentration the soil microstructure is progressively dismantled as the electrolyte concentration decreases and the process is not reversible. The turbidity concentration is much lower than, and not synonymous to the flocculation concentration. The flocculation concentration is the concentration of electrolyte needed to develop a clear supernatant for a dispersed soil or clay suspension, in a specified time (Quirk, 2001) or according to Sumner (1993), the electrolyte concentration at which the attractive force between colloidal particles is more than the repulsive force in the diffuse double layer, causing particles to flocculate.

The effects of salinity and sodicity on the soil hydraulic conductivity are also affected by inherent soil properties such as texture. Soils containing more clay will be more susceptible than others to exchangeable sodium provided that swelling is the main mechanism in reducing hydraulic conductivity at progressively decreasing salt levels (Shainberg & Letey, 1984). Shainberg *et al*. (2001) found neglible effects of exchangeable sodium in a loamy sand (9% clay) on reference hydraulic conductivity and concluded that no macroscopic swelling took place in soils used in their study with less than 22% clay. For a loam soil (22% clay) though, exchangeable sodium levels of between 9.3% and 10.5% reduced reference hydraulic conductivity values to approximately a third of that found at exchangeable sodium percentage values of between 1 and 2.2. Both swelling and aggregate slaking affected the hydraulic conductivity values of the loam soil. In lighter sandy soil clay dispersion and movement may predominate resulting in irreversible sealing of pore space (Shainberg & Letey, 1984). In very sandy soils (± 3% clay) the relative degree of dispersion as determined by the exchangeable sodium percentage and total cation content can determine the deteriorating effect of these parameters on hydraulic conductivity. A higher degree of dispersion may prove beneficial as, after an initial reduction in hydraulic conductivity, removal of suspended clay from the soil profile in effluent could improve

hydraulic conductivity. Less efficient dispersion at intermediate exchangeable sodium percentage levels could deter subsequent clay removal and hydraulic conductivity of the soil will decline steadily (Pupisky & Shainberg, 1979).

Differences in mineralogy are important as the interaction of the same level of sodium with different minerals will result in different physical behaviours. Soil pore stability to changes in solution composition when irrigated with water of different quality, are considerably lower for soils dominated by montmorillonite, vermiculite or illite (mica), than for soils in which kaolinite and iron oxides are the dominant minerals (Sumner, 1993). At decreasing total cation content and variable sodium adsorption ratios, soils which clay fractions are dominated by montmorrilonite and mica are particularly sensitive to reductions in total salt content, whereas soils dominated by kaolinite and haematite only show appreciable hydraulic conductivity reductions at electrical conductivities less than 0.3 dS m^{-1} (concentrations below 3 mmol dm^{-3}), with kaolinitic iron-rich soils also being quite stable (Hensley, 1969; Johnston, 1975). Although calcium clays, as a general rule swell less than sodium clays, swelling of both increases as salinity decreases (Shainberg & Letey, 1984).

Organic matter can have both positive (Emerson, 1954; Emerson, Foster & Oades, 1986, cited in Sumner, 1993; Rengasamy & Olsson, 1991) and negative (Alymore & Sills, 1982; Gupta, Bhumbla & Abrol, 1984) effects on the ability of soils to resist dispersion induced by the presence of sodium. Bruce, Langdale & West (1990), cited in Sumner (1993), found a strong positive relationship between the amount of organic carbon in the top 15 mm of soil and infiltration rate for highly dispersive soils which indicated that the presence of organic matter can mitigate dispersion. Organic compounds such as polysaccharides can reduce clay dispersion in dispersive soils by bonding particles together to form water stable aggregates and to resist sensitivity to dispersion induced by the presence of sodium (Emerson *et al*., 1986, cited in Sumner, 1993; Rengasamy & Olsson, 1991; Warrington *et al*., 1991). Organic bonds between clay particles may be broken when soils are continually cultivated and eventually result in a decrease in organic matter level. This could in turn decrease structural stability, with the remaining organic fragments attaching to colloid particles and as such contributing mainly to the negative charge that enhances dispersion (Emerson, 1992, cited in Sumner, 1993). Any increases in exchangeable sodium and decreases in electrolyte concentration would tend to increase the repulsive forces in the double layer, further contributing to clay dispersion. Furthermore, organic matter has a greater preference for calcium compared to that of clay minerals (Black, 1968). According to Sumner (1993), the sodium levels in the inorganic fraction could increase compared to that in the organic fraction if organic matter in the bulk soil acts as a sink for calcium. High exchangeable levels of sodium and low cation concentrations could promote dispersion of the inorganic fraction. The extent to which organic matter acts as a sink

for calcium due to specific adsorption has not been investigated at all in relation to the resulting effect on the cation composition of inorganic colloids (Sumner, 1993).

The type of minerals and degree of weathering in the soil profile also determines the effect of increasing exchangeable sodium levels on soil physical degradation through its contribution of salt to the soil. Soils that contain substantial amounts of readily weatherable minerals such as lime and gypsum which can dissolve continuously to sustain appreciable salt levels in solution (>3-5 mmol dm^{-3}), may be less prone to clay dispersion compared to other soils. Also, in some soils weathering rates may be too slow to prevent a reduction in hydraulic conductivity. In more highly weathered soils, low salt concentration often enhances the effects of small increases in exchangeable sodium on swelling and clay dispersion, thereby reducing hydraulic conductivity. In areas where irrigation water is moderately saline, problems may be experienced during periods of rainfall which may reduce the total cation concentration sufficiently for clay dispersion to occur. Even soils which do not swell or contain spontaneously dispersible clay, exhibit hydraulic failure even at very low exchangeable sodium levels. The only plausible explanation is that there is sufficient disturbance of the clay within the soil matrix during passage of water for dispersion to take place (Sumner, 1993).

Soil pH affects the net negative charge on the soil components and thus the dispersion/ flocculation behaviour of clay systems (Rengasamy & Olsson, 1991; Sparks, 1986; Sumner, 1993). The soil solution is in contact with a wide variety of surfaces which can exhibit both constant and variable charges of both polarities. The internal crystal lattice structure of the clay minerals carry negative charges (constant charge), while their edges and the surfaces of the sesquioxides can carry either charge, depending on conditions in the equilibrium solution (variable charge). For variable charge surfaces the charge and its sign are entirely dependant on the pH and total cation concentration of the ambient solution. Increasing pH and the total cation concentration above the pH value at which there is equal numbers of positive and negative charges on the particle surface, increase negative charge and decrease the forces that are facilitating flocculation (Sumner, 1993).

Ions other than sodium also affect the permeability of soils. Increasing levels of exchangeable potassium or magnesium have a detrimental effect on hydraulic conductivity, although substantially less compared to that of equivalent levels of sodium (Sumner, 1993). Sumner (1993) summarized the effect of inherent soil properties on the total cation content threshold needed to prevent dispersion of soils at various exchangeable sodium levels: the threshold would increase with an increase in mechanical energy input, negative charge, smectite or illite, K and Mg, anion adsorption and exposure of new surfaces and/or a decrease in partial CO_2 pressure, organic matter, positive charge, sesquioxides, kaolinite and salt from weathering.

2.3 RESPONSE OF PERENNIAL FRUIT CROPS TO SALINITY

Most fruit trees are relatively sensitive to salinity (Bernstein, 1980; Francois & Maas, 1994; Maas, 1987) and deciduous fruit trees will be amongst the first crops to suffer yield reductions if irrigation water becomes more saline (Hoffman *et al*., 1989). *Prunus* species are generally considered to be more sensitive to salinity than most other fruit crops (Maas, 1987) and apricot considered to be less tolerant compared to other *Prunus* species (Bernstein, Brown & Hayward, 1956). The effect of salinity on crops is influenced by several factors: ion concentrations and relations in the substrate, duration of exposure, plant species, cultivar and rootstock, stage of plant development, plant organ (e.g. leaves vs. fruit) and environmental conditions (Marschner, 1995). The specific combination of the above-mentioned factors will determine the main mechanisms of salt injury that operate and the relative contribution to growth inhibition and decreased yield.

2.3.1 Mechanisms of salt injury

Growth inhibition and yield reduction may be the result of osmotic inhibition of water absorption, oxidative stress and specific ion effects on key physiological processes. The effect of soil salinity is the result of a decreased availability of water through a decrease in the osmotic potential component of the total soil water potential (Dudley, 1994). Soil osmotic potential and matric potential, both components of total soil water potential, are similar and additive in their effect on water availability which caused reductions in both evapotranspiration and yield (Du Plessis, 1985; Shalhevet, 1994). Oxidative stress inhibits photosynthetic performance under conditions of high salinity, high light intensity and low stomatal aperture through reactive oxygen species disrupting enzyme activity and membranes associated with photosynthesis (Orcutt & Nilsen, 2000).

Specific ion effects may involve direct toxicity or nutritional disturbances (Bernstein & Hayward, 1958; Orcutt & Nilsen, 2000). The detrimental direct effects of ions can be observed at the level of enzyme activity, membrane function and several important metabolic processes, including photosynthesis and respiration (Orcutt & Nilsen, 2000). Toxic chloride, sodium and boron are of specific importance in the case of deciduous fruit trees (Bernstein, 1980; Hoffman *et al*., 1989). Under saline conditions, which are characterised by low nutrient ion activities and extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+} and Cl^-/NO_3^-, nutritional disorders can develop and crop growth may be reduced. Nutrient imbalance may result from the effect of salinity on nutrient availability, competitive ion uptake, transport of or partitioning of ions within the plant or may be caused by physiological inactivation of a given nutrient, resulting in an increase in the internal requirement of the plant for that essential element. Excessive amounts of Na^+ salts in soil water reduces Ca^{2+} availability as well as transport and mobility of Ca^{2+} to growing regions of the

plant. Salinity can also directly affect ion uptake due to competition for uptake through cell membranes as Na^+ decrease K^+ and Cl^- reduce NO_3^- uptake (Grattan & Grieve, 1994).

The relative contribution of water deficit, ion toxicity and nutritional imbalances to salt injury is not always discernable. The effect of salinity induced water deficit on relative yield or the growth responses of several perennial fruit crops were previously documented by Maas and Hoffman (1977) for conditions where rootstocks deter rapid accumulation of sodium and chloride and when these ions do not predominate in the soil. Bernstein (1980) reported on research where tree growth and fruit yield of stone fruits, citrus and avocado was decreased by both the accumulation of harmful levels of sodium and chloride and by osmotic stress. Bernstein *et al*. (1956) attributed half of the total reduction in growth of saline irrigated stone fruit trees to specific ion toxicity and the other half to additional effects, particularly osmotic stress under the conditions of their experiment which lasted three years. The relative contribution of ion toxicity and osmotic stress was ascertained by comparison of growth and chloride content of the trees on Lovell rootstock with trees on three different commercial rootstocks of which some rootstocks restricted chloride accumulation more than others. Growth and yield reduction may occur with woody fruit species in the absence of specific ion toxicity, but once salts have accumulated to toxic levels, growth and yield are suppressed by the additive effects of osmotic stress and ion toxicity (Bernstein, 1980).

Munns (1993, 2002) proposed a two-phase growth inhibition model; an initial osmotic response to salt outside the plant followed by a salt specific response due to salt inside the plant. The time scale of this response is between weeks and months, depending on the level of salinity and the sensitivity of the species. In the model, growth is first reduced by a decrease in soil water potential due to salt accumulation outside the plant during which the plant responds to a water stress. This plant-response to water stress is regulated by phytohormone signals from the roots. The salt specific effect appears later as salt injury in old leaves, which later die due to a rapid rise in salt concentrations in cell walls or cytoplasm when the vacuoles can no longer sequester incoming salts. If the rate of leaf death approaches the rate of new leaf production, there is eventually a substantial drop in the supply of assimilates to growing leaves, or a change in the supply of growth regulators, and growth is further reduced. The increasing sensitivity and development of toxicity symptoms of perennial fruit crops as time of exposure to salinity increases support this hypothesis (Bernstein, 1980; Catlin *et al*., 1993; Boland, Mitchell & Jerie, 1993; Moolman *et al*., 1999). Catlin *et al*. (1993), based on the response of mature plum trees to different levels of saline irrigation applied over a period of six years, hypothesized that irrigation with lower salt concentrations would ultimately lead to responses similar to those obtained with shorter periods of time and higher salinity water. However, such extended

exposure to low salinity water will not result in a specific ion effect if the sodium and chloride levels in leaves remain below the threshold for reduction of vegetative growth and leaf toxicity.

It is thought that sodium is initially retained in the sapwood of the tree and subsequently, with the conversion of sapwood to heartwood, is released and then translocated to the leaves causing leaf burn (Bernstein *et al*., 1956). With succeeding years, the chloride and sodium accumulate more rapidly in the leaves, causing leaf burn to develop earlier and more severely. Sodium is apparently excluded from the leaves until the leaf membranes are damaged from chloride accumulation, and then sodium moves into the leaves and accumulates (Hoffman *et al*., 1989). Sodium can, however, also gain access to the xylem at sites of secondary root emergence or the apical region of the roots by means of apoplastic bypass flow, which seems to increase under conditions of stress damage (Jacoby, 1994). Tozlu, Guy & Moore (2002) found that accumulation of sodium is as injurious as chloride to 12 to 18 month old citrus plants in pots, with a different probable site of toxicity. While chloride appeared to be most harmful in leaf tissue, sodium appeared more injurious in root tissues.

Thus the time-scale for salt injury to appear on perennial fruit crops varies (Boland *et al*., 1993; Catlin *et al*., 1993; Myers *et al*., 1995; Moolman *et al*., 1999) as a function of specific mechanisms which include that of salt injury and crop-specific adaptation to salinity. Mechanisms of adaptation to salinity include salt exclusion, reabsorption, retranslocation, extrusion, dilution, compartmentation and tissue salt tolerance (Orcutt & Nilsen, 2000).

2.3.2 Factors influencing economic yield of (deciduous) fruit trees

The factors that influence the economic yield of apple production systems were reviewed by Wünsche (1993) and are applicable to most deciduous fruit production systems and will be used as point of departure for this study. Productivity in crops is generally limited by light availability, light interception, photosynthesis and respiration. Light availability is mainly influenced by climate, while light interception is a function of orchard design factors (planting system, tree density, tree shape, tree height, alley width and row orientation) as well as leaf area index and length of growing season. Total photosynthesis depends on photosynthetic rates as well as light interception and leaf area index. Respiration of healthy, well supplied fruit trees requires close to 50% of all carbohydrates produced during the light period (Faust, 1989).

2.3.2.1 Light interception

Salinity can be detrimental to production through its effects on growth and net photosynthesis rates per unit leaf area. The damaging effects of salinity on perennial crops are cumulative and it might take several years before the real effects become visible. Such cumulative effects of salinity have been reported for plums after three (Hoffman *et al*., 1989) and six (Catlin *et al*.,

1993), pears after seven (Myers & West, 1989) and for vines after four (Moolman *et al*., 1999) years of saline irrigation under field conditions. Shoot growth may be an earlier, or more sensitive indicator of salt stress, as was found for plum trees (Hoffman *et al*., 1989) and salinised field-grown grapevine (Prior, Grieve & Cullis, 1992b). However, the effects of salinity on vegetative growth have only an indirect effect on reduced yield in cultivars where fruit are borne primarily on the spur branches (Catlin *et al*., 1993), as the shoot growth of plum trees was significantly reduced at low salinity levels (1 and 2 dS m^{-1} treatments) without any detrimental effect on yield.

Indicators of the detrimental effects of salinity on vegetative growth in several perennial fruit crops and in vines have been identified in previous studies to include: root length, shoot growth, trunk growth, top growth, trunk cross sectional area, pruning mass, unit leaf area, total leaf area, leaf area index, new leaf production, leaf number per plant, individual leaf weight or petiole fresh weight and individual leaf dry weight or petiole dry weight (Boland *et al*., 1993; Catlin *et al*., 1993; Francois & Maas, 1994; Hoffman *et al*., 1989; Lloyd & Howie, 1989; Myers & West, 1989; Moolman *et al*., 1999; Ruiz, Martínez & Cerdá, 1997; 1999). For grapevines (cultivar Columbar) irrigated with water of between 0.25 and 5 dS m^{-1}, shoot length, the length and number of nodes per shoot, as well as fresh and dry mass per internode decreased with increasing salinity during the second to fourth seasons of saline irrigation (Moolman *et al*., 1999). According to Munns & Termaat (1986), the earliest response of a non-halophyte exposed to salinity is that its leaves grow more slowly, with root growth almost always being less affected than shoot growth.

Salinity resulted in significantly smaller individual leaf area and reduced lateral shoot growth, measured during the seventh season of irrigation, of 40-year-old Williams Bon Cretien pear trees irrigated with 2.1 dS m^{-1} irrigation water compared to that of trees receiving irrigation water with an EC of 0.2 dS m^{-1} (Myers *et al*., 1995). Salinity likewise reduced individual leaf area of 24-year-old Washington Navel citrus trees on sweet orange (*C. sinensis*) rootstock that was irrigated for 5 years with water containing either 5 (control treatment) or 20 mol NaCl m^{-3} prior to measurements (Lloyd & Howie, 1989). Prior to imposition of the salinity treatments the orchard was irrigated with water drawn from the River Murray which contained on average 5 mol NaCl m^{-3}. However, salinisation did not affect the number of leaves per unit canopy volume of these trees. In contrast, significant decreases in leaf number per plant and leaf dry weight was observed for citrus rootstock *Citrus macrophylla* Wester seedlings grown for two months in nutrient solutions containing 40 mM NaCl (Ruiz, Martinez & Cerdá, 1999). Shoot length of these plants were reduced by 29% compared to that of the control treatment.

The total leaf area of the NaCl-salinised Washington Navel citrus trees on sweet orange (*C. sinensis*) rootstock amounted to only 40% of those of the controls with correspondingly

lower leaf area indexes (Lloyd & Howie, 1989). Leaf area index of 3-year-old peach trees (cultivar Golden Queen) in drainage lysimeters subjected to irrigation water salinity levels of 0.1, 0.25, 0.5 and 1 dS m^{-1} in combination with regulated deficit irrigation (RDI), decreased with increasing water salinity during the second year of saline irrigation (Boland *et al*., 1993). Regulated deficit irrigation is a practice whereby plant water deficits are manipulated by applying less water through irrigation than the trees would have used under normal conditions to obtain optimum tree growth and optimum water utilisation (Mitchell, Jerie & Chalmers, 1984). Leaf area index of the peach trees decreased by *c*. 55% at the 1 dS m^{-1} treatment compared to that of the 0.1 dS m^{-1} channel water treatment.

Salinity induced premature leaf senescence in pears (Myers *et al*., 1995), plums (Hoffman *et al*., 1989) and grapes (Yunusa, Walker & Blackmore, 1997), thereby reducing leaf area duration and thus the total amount of assimilates produced during the growing season. Leaf fall occurred earlier in the latter part of the seventh season of irrigation for mature Williams Bon Cretien pear trees that received 2.1 dS m^{-1} irrigation water compared to that for the 0.2 dS m^{-1} treated trees. Effects of salinity on tree foliage can also be assessed by measuring the proportion of solar radiation passing through the canopy (Hoffman *et al*., 1989). Measurements taken for mature plum trees (cultivar Santa Rosa) during the fourth month of the third season of saline irrigation indicated that 85%, 79%, 78%, 76%, 62% and 48% of the total incoming solar radiation was intercepted by the trees for the 0, 1, 2, 4, 6 and 8 dS m^{-1} treatments respectively. This could indicate an increase in the degree of leaf senescence as irrigation water salinity increased since severe salinity-related leaf damage of the plum trees was accompanied by defoliation. Irrigation water salinity of 3.6 dS m^{-1} likewise significantly reduced the green area index (the ratio of leaves, shoots and fruit, when present, to the unit of land area allocated to each vine) and fraction of photosynthetically active radiation intercepted by eight-year-old Sultana grapevines (Yunusa *et al*., 1997). Irrigation water with salinity of 0.4 and 1.8 dS m^{-1} did not decrease the vegetative growth of the vines significantly. Only 15% of spring flush leaves of salinised Washington Navel orange trees survived to winter and, although the abscission of leaves was offset to some extent by greater production of off-season vegetative flushes, it was not sufficient to completely offset the high spring flush abscission rate on trees (Lloyd & Howie, 1989).

Specific ion toxicity can reduce the effective leaf area available for photosynthesis through foliar damage. The initial symptoms of excess chloride accumulation in fruit crops are leaf tip necrosis, developing into marginal necrosis, premature leaf drop, complete defoliation, twig and shoot dieback, and in extreme cases death of the tree or vine (Bernstein, 1980; Hayward, Long & Uhvits, 1946, cited in Francois & Maas, 1994). Characteristic injury symptoms for sodium include tip, marginal and/or interveinal necrosis (Bernstein *et al*., 1956). Foliar damage was

observed on peach (Boland *et al*., 1993), plum (Hoffman *et al*., 1989), pear (Myers *et al*., 1995), grapevine (Moolman *et al*., 1999) and citrus (Rasmussen, Furr & Cooper, 1969; Ruiz *et al*., 1999; Storey & Walker, 1999) irrigated with saline water.

Observations on the extent and duration of foliar damage and leaf senescence were made in most of the above-mentioned studies. The extent of foliar damage on these woody fruit crops generally increased as the concentration and duration of exposure to salinity increased. It was previously noted that fruit trees, especially stone fruit trees, become more sensitive to salinity after 2 or 3 years, with leaf burn developing earlier in the season and with increasing severity (Bernstein, 1980). Chloride toxicity generally shows up earlier, is more severe and is observed on a wider range of woody fruit crop species than sodium toxicity (Bernstein, 1980; Boland *et al*., 1993; Francois & Maas, 1994; Hoffman *et al*., 1989; Moolman *et al*., 1999). With plum trees, the lower salinity level irrigation water of 1 dS m^{-1} and 2 dS m^{-1} caused none or limited leaf burn, respectively, during the fourth year of saline irrigation. Foliar damage at the 2 dS m^{-1} treatment did not increase from Year 4 to Year 6 of the experiment, with no reduction in yield. Apparently, chloride in leaves of trees had reached an equilibrium or maximum level by the fourth year of treatment (Catlin *et al*., 1993).

Salinity decreases the quantity of light energy intercepted by orchard systems and interferes with the conversion of energy through photosynthesis into available carbohydrate for partitioning to vegetative and reproductive sinks. Net carbon dioxide fixation per unit leaf area may decline, while dark respiration increases, leading to a drastic reduction in net carbon dioxide assimilation per unit leaf area per day (Marschner, 1995).

2.3.2.2 Photosynthesis

Sodium chloride decreased carbon dioxide assimilation in peach (Boland *et al*., 1993), apple (Dinkelberg & Lüdders, 1990), grapevine (Downton, 1977a), pears (Myers & West, 1989), citrus (Storey & Walker, 1999 and references therein) and plum (Ziska, Seemann & DeJong, 1990). Water deficit and partial stomatal closure, loss of turgor of mesophyll cells through salt accumulation in the apoplasm, or direct toxic effects of ions can decrease rates of net carbon dioxide fixation during the light period (Marschner, 1995). The water stress effects of salinity on plants occur ahead of the salt-specific effects (Munns, 1993, 2002). Excessive salt accumulation in the apoplasm or direct toxic effects of ions in the cytoplasm becomes only important when the storage capacity of the vacuoles in leaf cells is exceeded (Flowers & Yeo, 1986). The time scale for excessive salt accumulation in the apoplasm or cytoplasm of leaf cells depends on the the salt exclusion mechanisms of the plant concerned, the prevailing salinity and environmental conditions (Munns, 2002).

In potted (Downton, 1977a) and field-grown (Prior *et al*., 1992b) grapevines subjected to saline irrigation, the reduction in carbon dioxide assimilation was more strongly related to leaf chloride than leaf sodium concentrations. The reduction in assimilation was due to a uniform decrease in stomatal conductance up to tissue concentrations of 165 mM chloride, while non-uniform stomatal closure was observed in leaves with chloride levels exceeding these levels (Downton, Loveys & Grant, 1990). The non-uniform stomatal closure across the leaf surface might be due to the response of stomata to irregular distributed salts in leaves. Water deficit and stomatal closure as well as direct adverse effects of chloride contributed to an approximately 50% to 60% reduction in carbon dioxide assimilation of leaves of peach trees receiving saline irrigation (1.0 dS m^{-1}) after a period of RDI, compared to the control treatment (0.1 dS m^{-1}) which received adequate irrigation throughout the season (Boland *et al*., 1993). The decline in photosynthesis rate of plum leaves after three years of saline irrigation (7, 14 and 28 mM; 1:1 NaCl:$CaCl_2$ ratio) was mainly attributed to direct effects of increasing leaf chloride on the mesophyll conductance (Ziska, Seemann & DeJong, 1990). Ziska, Seemann & DeJong (1990) related reduced assimilation capacity to a decline in the activity of the ribulose-1,5-bisphosphate carboxylase and the pool size of triose phosphate and phosphoglycerate with increasing salinity. Continued photosynthesis requires efficient regeneration of the carbon dioxide acceptor (ribulose-1,5-bisphosphate) and recycling of the phosphate incorporated into the triose phosphate, with the rate of photosynthesis being inhibited by deviations from an optimum concentration of inorganic phosphate in the external medium (Quick & Neuhaus, 1997). In plum leaves with excessive levels of chloride, an initial decline in ribulose 1,5-bisphosphate and organic phosphate regeneration capacity was followed by a decrease in the initial activity of ribulose-1,5-bisphosphate carboxylase (Ziska, Seemann & DeJong, 1990), thereby inhibiting the rate of photosynthesis. The measurement of the response of carbon dioxide assimilation to substomatal cavity carbon dioxide concentration (C_i) made *in situ* and the *in vivo* measurement provided independent estimates of the decline in ribulose-1,5-bisphosphate carboxylase activity associated with salinisation. In addition, approximately 10% of the decline in carbon dioxide assimilation in the plum leaves could be attributed to an increase in leaf dark respiration. No significant increase in the stomatal limitation was found with increased salinity and non-uniform stomatal closure was associated only with leaves of the 28 mM salinity treatment. Non-uniform distribution of stomatal pore size across the leaf surface could result in overestimation of C_i and underestimation of the initial response of carbon dioxide assimilation to C_i (Ziska, Seemann & DeJong, 1990).

Carbon dioxide assimilation rate and stomatal conductance decreased under conditions of sodium chloride salinisation of the root zone of potted citrus plants from several experiments. The majority of evidence from studies on citrus does not implicate water deficit, but rather high sodium and/or chloride levels in leaves in the salinity-induced reduction in assimilation rates.

However, there are examples where high concentrations of these ions occur in leaves without reducing carbon dioxide assimilation (Storey & Walker, 1999). For example, Walker, Törökvalvy and Downton (1982) found that eight-month-old Etrog citron (*C. medica* L.) plants in pots treated with 50 mM NaCl for 70 days under glasshouse conditions returned to normal carbon dioxide assimilation rates following removal of the salt treatment. This recovery in carbon dioxide assimilation rate was not due to major changes in leaf turgor pressure immediately upon stress relief, as photosynthesis rate did not completely recover even after leaf water potential returned to near control values and permitted full stomatal opening. Photosynthetic recovery corresponded with the eventual return of internal resistances to control values and occured despite chloride concentrations in leaves being approximately six-fold of that in the control. Such photosynthetic recovery in the absence of a definite change in leaf chloride levels may indicate some change in cellular solute distribution, for example an enhanced ability for chloride compartmentation after removal of the salt treatment (Walker *et al*., 1982).

According to Orcutt & Nilsen (2000), the relative control of mesophyll and stomatal conductance by salinity varies among species. Storey & Walker (1999) reviewed the effect of salinity on citrus trees. They proposed that the contrasting responses in photosynthesis shown by various rootstock-scion combinations, trees of different age and size, and different salinisation treatments could be attributed to differences in the rate of chloride or sodium entry into leaves and subsequent charge compensation or compartmentation of ions for normalisation of key physiological processes, provided that osmotic stress remains absent in the root medium. Salt tolerance is associated with the ability to maintain a homeostatic ion concentration in the cytoplasm (Orcutt & Nilsen, 2000). The control of ionic balances at cellular level and the distribution of essential elements throughout the plant are considered pivotal to maintain equilibrium in plants, as mineral elements are required for structural, biochemical and osmotic functions. Maintenance of homeostasis extends to the intracellular level where each of the cellular compartments, for example the cytoplasm, vacuole, mitochondrion and chloroplast as well as other membrane-bound organelles, each has its own unique metabolic role(s) and specific mineral element requirements that are vital to its proper functioning. Under saline conditions the continued cellular function of ions depends upon osmotic adjustment with more ions (Flowers & Yeo, 1986). If the additional ions exceed the capacity of the vacuoles where they are sequestered, the cell dies due to dehydration by excess salt effluxed to the cell walls or excessive salt accumulation in the cytoplasm that inhibits enzyme activity (Flowers & Yeo, 1986; Munns & Passioura, 1984).

It follows that the intensity (concentration and duration of exposure) of salinity and the effectivity of the species-specific mechanisms of adaptation to salinity will finally determine the primary effect of salinity on photosynthesis.

2.3.2.3 Assimilate allocation

Apart from the amount of light intercepted by the canopy and leaf photosynthesis rate, the allocation of assimilates to fruits controls the actual fruit yield of orchards. Fruit yield is a function of fruit number and fruit size. Salinity reduced yield in pear (Myers *et al*., 1995), plum (Hoffman *et al*., 1989), peach (Boland *et al*., 1993) and citrus (Storey & Walker, 1999) by reducing fruit number and/or fruit size. Fruit bud formation and fruit set are the main factors determining fruit number.

The partitioning of assimilates to fruit as opposed to partitioning to vegetative sinks is strongly dependent on canopy microclimate and crop load (Wünsche, 1993). Canopy microclimate variables include amongst others, light distribution in the canopy. Advanced foliar damage and/or leaf senescence caused by high salinity levels could have the same limiting effect as shade within the canopy, which limits carbohydrate availability for growth and development, which in turn has an adverse effect on fruit bud formation, fruit set and fruit size (Wünsche, 1993), thereby affecting crop load. Flowering intensity, fruit set and final fruit numbers of 24-year-old Washington navel oranges on sweet orange rootstock, were reduced by salt stress following irrigation with 20 mM NaCl for 5 years. Diminished flowering and fruit set are attributed to significant leaf drop and resultant low carbohydrate reserves (Howie & Lloyd, 1989).

The critical processes to achieve the yield potential of the current year are initial and final fruit set as well as fruit growth, assuming adequate fruit bud formation and flower density (Wünsche, 1993). Salinity increased blossom density (Myers *et al*., 1995) and lowered fruit set (Myers & West, 1989) of pear trees. High salinity caused many potential fruiting buds of plum trees not to form, or not to develop and toxicity to flowers resulted in few fruit and smaller fruit than that at less saline treatments (Hoffman *et al*., 1989). Salinity may thus affect productivity through increased or reduced fruit bud initiation. Reduced fruit set and/or smaller fruit may be due to the effect of salinity on fruit growth early in its development.

2.3.2.4 Quality

Economic yield is defined as the proportion of fruit yield which meets the commercially acceptable quality standards in terms of exterior and interior fruit characteristics (Wünsche, 1993). Literature on the effect of salinity on fruit quality of fruit trees from long-term studies is limited. Indices of fruit quality are crop-specific, but fruit size, maturity and internal disorders are

generally important quality parameters for deciduous fruit. Final fruit size of plum (Hoffman *et al*., 1989) and peach (Boland *et al*., 1993) was reduced by salinity. Saline irrigation in general caused an increase in the proportion of pear fruit in the smallest size class (Myers *et al*. 1995), while size distribution of Valencia orange was not affected (Francois & Clark, 1980).

Maturity of fruit is important due to its effect on cold storage potential and timeous delivery to markets. Salinity hastened maturity in grape (Downton & Loveys, 1978), plum (Hoffman *et al*., 1989) and guava (Walker, Kriedemann & Maggs, 1979), but delayed maturation of Valencia orange with 2 to 4 weeks (Francois & Clark, 1980). Hastened maturation could decrease the already short, effective cold storage period for plums, while the delay in maturation of oranges could have serious economic consequences on the price the grower receives for his crop. Grapes from long-term salinised vines contained less sugar (Prior, Grieve & Cullis, 1992a) and accumulation of sodium and chloride in Cabernet Sauvignon grapes influenced the concentrations of these ions in wine (Downton, 1977b). Valencia orange rind thickness was significantly reduced by salinity compared to the control, but the length to width ratio of the fruit and rind color was not significantly affected (Francois & Clark, 1980). Salinity-induced foliar damage and leaf senescence can promote the development of sun-scald through reduced shading of the fruit by the leaf canopy which results in markedly lower fruit quality, especially for grapes (Bernstein, 1980).

2.3.3 Evapotranspiration

The literature regarding evapotranspiration is discussed under the heading of perennial fruit crop response to salinity (Section 3), although it is partially a soil-related process. The term evapotranspiration represents water losses from soil and plant surfaces (evaporation) as well as water loss through plant transpiration. Knowledge of evapotranspiration is essential for irrigation management purposes, to prevent water stress due to under-irrigation on the one hand, or excessive leaching due to over-irrigation on the other. Evaporation is mainly influenced by the irrigation frequency and the amount of solar energy that is not intercepted by the crop. The main impact of salinity on evapotranspiration is expected from its effect on plant response.

As plants transpire, the remaining soil water becomes more concentrated and the additive effect of increased salt stress as well as water stress impacts on transpiration when soil water is depleted (Maas, 1987; Shalhevet, 1994). Increased metabolic energy expenditure by osmotic adjustment processes to enable water uptake as well as reduced stomatal conductance could indirectly influence transpiration by reducing plant growth and thus ground cover (Allen *et al*., 1998). The rapid closure of stomata after exposure to excessive salinity could be due to a short-term response to the low water potential of the root medium, a specific effect of sodium on

guard cell wall plasticity, or an increase in a root hormonal signal, most likely abscisic acid (Orcutt & Nilsen, 2000). A further decrease in transpiration could be attributed to depressed root hydraulic conductivity, which could be caused by a sodium chloride-induced increase in root diameter and fewer fine roots (Storey & Walker, 1999), increases in suberisation of the root system or changes in the properties of membranes (Ramos & Kaufmann, 1979; Syvertsen, 1985; Zekri & Parsons, 1989). Research on root hydraulic conductivity for perennial fruit crops is, however, limited.

Total water uptake of grapefruit was reduced as salt concentration in the soil increased (Bielorai, Shalhevet & Levy, 1978). Whole plant transpiration rates of citrus are generally reduced by salinity through lower stomatal conductance (Howie & Lloyd, 1989) as well as depressed root hydraulic conductivity. The transpiration rate may decline linearly with time, or display a rapid decrease during initial exposure to salinity and then stabilize at a lower rate (Storey & Walker, 1999). Salinity reduced evapotranspiration of peaches as a result of lower stomatal conductance and reduced canopy size and density (Boland *et al*., 1993). In the case of field-grown grapevines with similar size, leaf colour, overall leaf condition, leaf area index and soil water status, transpiration of the salinised vines (5 dS m^{-1}) was approximately 50% of that of non-salinised vines (0.4 dS m^{-1}) in very dry soil before irrigation. Transpiration of salinised vines increased to only 56% of that of non-salinised vines after irrigation (De Clercq *et al*., 2001). The limited increase in transpiration of vines in the saline treatment relative to that in the non-saline irrigation treatment after being irrigated can probably be attributed to the water deficit only being partially alleviated. The contribution of salts to the osmotic potential component of soil water potential most likely did not decrease after irrigation. The osmotic potential of the soil solution at field capacity was estimated according to Maas (1987) from depth-weighted salinity of the saturated soil paste extract (EC_e) for the 0.9 m soil depth to be -0.028 MPa and -0.068 MPa at field capacity for the 0.4 and 5 dS m^{-1} treatments respectively.

It is clear that the decrease in evapotranspiration due to salinity could strongly decrease the amount of water that is used by plants from that supplied through irrigation and thus cause increased leaching of salts, soil microelements and agro-chemicals if irrigation scheduling is not adjusted accordingly. Irrigation return flows resulting from overirrigation, with water of poor quality are a source of pollution of surface water bodies downstream of drainage outlets and deep percolation could contaminate groundwater. Consequently, the sustainable use of saline water in irrigated agriculture requires the control of soil salinity at the field level, a decrease in the amount of drainage water, and disposal of irrigation return flows in such a manner that it minimizes the side effects on the quality of downstream water resources (Beltrán, 1999).

2.3.4 Salt tolerance

When saline water is used for irrigation of agricultural crops, three important factors should be taken into account: 1) the selection of appropriate crops and cropping systems based on their salt tolerance; 2) prevention of salt accumulation in the soil through management practices and; 3) use of advanced irrigation and drainage technology (Shalhevet, 1994). Salt tolerance of the crop must be known in order to estimate the leaching requirement for prevention of salt accumulation in the soil to levels that can cause yield reducing stress (Ayers & Westcot, 1985).

Plant tolerance to salinity can, amongst other factors, be appraised as the relative growth or yield on a saline soil compared with that on a non-saline soil. Maas and Hoffman (1977) used a two-part response function to describe the response of fruit and vine crops to total salinity. The mathematical equation used was as follows: $Y_r = 100-(EC_e-EC_t)*S$, where (EC_t) is the threshold salinity where yield just begins to decline and (S) is the slope of the response (rate of yield decline) when salinity exceeds the threshold value. Y_r is the relative yield in percent and EC_e is the mean soil salinity expressed as the conductivity of the soil saturation extract. Salt tolerance is characterised by values of both the threshold and slope. Tolerant crops are characterized by a high threshold value and small slope, while sensitive crops are characterized by a low threshold and large slope (Shalhevet, 1994).

The growth or yield response to total salinity does not account for the effect of specific toxic effects on the particular crop. The sensitivity of perennial woody crops to specific ions, however, necessitates that not only total salinity, but also the effects of specific ion concentrations be considered in salt tolerance evaluation (De Clercq *et al*., 2001; Maas, 1987; Moolman *et al*., 1999). Irrigation water salinity, soil water salinity, SAR of the soil and ionic composition of selected plant organs have been used as indices of salinity hazard for deciduous fruit trees and grapevines (Boland *et al*., 1993; De Clercq *et al*., 2001; Moolman *et al*., 1999; Myers *et al*., 1995). De Clercq *et al*. (2001) found a high degree of covariance between EC, SAR and Cl as indices of salinity for grapevine and concluded that the adverse effect of irrigated salts on the crop should not be attributed to any one of these factors individually.

The appropriate time scale for evaluation of salt tolerance for perennial fruit crops is complicated by the cumulative effect of salinity and the fact that it might take several years before the real effects become visible (Boland *et al*., 1993; Catlin *et al*., 1993; Hoffman *et al*., 1989; Myers *et al*., 1995; Moolman *et al*., 1999). The time-scale for salt injury to manifest on perennial fruit crops differs between species as a function of specific mechanisms of salt injury and crop-specific adaptation to salinity (see section 3.1). Hoffman *et al*. (1989) found that three years of saline irrigation is the minimum time scale to correctly quantify the impact of salinity on plum yield. Myers *et al*. (1995), however, found that mature pear tree yield decreased for the

first time after 7 years of saline irrigation. The yield-response function could not be successfully applied, because the eventual decrease in yield occurred without a concurrent change in soil salinity.

In conclusion, many environmental, soil and management factors interact with salinity to influence crop salt tolerance (Maas, 1987; Moolman *et al*., 1999; Shalhevet, 1994). These factors include amongst others climate, steady state versus transient salinity, soil properties and waterlogging, soil fertility, irrigation method and frequency and chemical composition of the soil water. Factors that may modify salt tolerance were discussed in detail by Moolman *et al*. (1999) and Shalhevet (1994) and readers are referred to their papers for further information on the topics not included in the current review.

2.4 REFERENCES:

Abrol, I.P., Yadav, J.S.P. & Massoud, F.I., 1988. Salt-Affected Soils and Their Management. FAO Soil Bulletin, No. 39. Rome: FAO.

Abu-Sharar, T.M., Bingham, F.T. & Rhoades, J.D., 1987. Stability of soil aggregates as affected by electrolyte concentration and composition. *Soil Sci. Am. J.*, 51: 309-314.

Agassi, M., Morin, J. & Shainberg, I., 1981. Effect of electrolyte concentration and soil sodicity on infiltration rate and soil crust formation. *Soil Sci. Soc. Am. J*., 45:848-851.

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M., 1985. Crop evapotranspiration. FAO Irrigation and Drainage Paper No. 56. Rome: FAO.

Ayers, R.S. & Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: FAO.

Aylmore, L.A.G. & Sills, I.D., 1982. Charaterization of soil structure and stability using modulus of rupture-exchangeable sodium percentage relationships. *Aus. J. Soil Res.*, 20:213-224.

Beltrán, J.M., 1999. Irrigation with saline water: benefits and environmental impact. *Agric. Water Man.* 40: 183-194.

Bernstein, L., 1980. Salt tolerance of fruit crops. *USDA Agric. Inf. Bull*., 292:1-8

Bernstein, L. & Hayward, H.E., 1958. Physiology of salt tolerance. *Ann. Rev. Plant Physiol*., 9: 25-46.

Bernstein, L., Brown, J.W., & Hayward, H.E., 1956. The influence of rootstock on growth and salt accumulation in stone fruit trees and almonds. *Proc. Am. Soc. Hort. Sci.*, 68: 86-95.

Bielorai, H., Shalhevet, J. & Levy, Y., 1978. Grapefruit Response to Variable Salinity in Irrigation Water and Soil. *Irrig. Sci.,* 1:61-70.

Black, C.A., 1968. Soil-Plant relationships. New York: John Wiley.

Boland, A.M., Mitchell, P.D. & Jerie, P.H., 1993. Effect of saline water combined with restricted irrigation on peach tree growth and water use. *Aust. J. Agric. Res*., 44: 799-816.

Catlin, P.B., Hoffman, G.J., Mead, R.M. & Johnson, R.S., 1993. Long term response of mature plum trees to salinity. *Irrig. Sci.*, 13:171-176.

Chartres, C.J., Kirby, J.M. & Raupach, M., 1990. Poorly ordered silica and aluminosilicates as temporary cementing agents in hard-setting soils. *Soil Sci. Soc. Am. J.*, 54: 1060-1067.

De Clercq, W.P., Fey, M.V., Moolman, J.H., Wessels, W.P.J., Eigenhuis, B. & Hoffman, J.E., 2001. Experimental irrigation of vineyards with saline water. WRC Report No. 522, 695/1/01. Pretoria: Water Research Commission.

Dinkelberg, W. & Lüdders, P., 1990. Influence of Seasonally Different Sodium Treatment on Photosynthesis and Transpiration of Apple Trees. *Gartenbauwiss.*, 55(3): 130-135.

Downton, W.J.S., 1977a. Photosynthesis in salt-stressed grapevines. *Aust. J. Plant Physiol*., 4: 183-192.

Downton, W.J.S., 1977b. Salinity effects on the ion composition of fruiting Cabernet Sauvignon vines. *Am. J. Enol. Vitic*., 28: 210-214.

Downton, W.J.S. & Loveys, B.R., 1978. Compositional changes during grape berry development in relation to abscisic acid and salinity. *Aust. J. Plant Physiol*., 5: 415-423.

Downton, W.J.S., Loveys, B.R. & Grant, W.J.R., 1990. Salinity effects on the stomatal behavior of grapevine. *New Phytol.*, 116: 499-503.

Dudley, L.M., 1994. Salinity in the Soil Environment. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 13-30.

Du Plessis, H.M., 1985. Evapotranspiration of Citrus as Affected by Soil Water Deficit and Soil Salinity. *Irrig. Sci.*, 6: 51-61.

Du Plessis, H.M. & Shainberg, I., 1985. Effect of exchangeable sodium and phosphogypsum on the hydraulic properties of several South African soils. *S. Afr. J. Plant Soil*, 2: 179-186.

Emerson, W.W., 1954. The determination of the stability of soil crumbs. *J. Soil Sci.*, 5: 233-250.

Faust, M., 1989. Physiology of temperate zone fruit trees. New York: Wiley-Interscience.

Flowers, T.J. & Yeo, A.R., 1986. Ion relations of plants under drought and salinity. *Aust. J. Plant Physiol*., 13: 75-91.

Francois, L.E. & Clark, R.A., 1980. Salinity effects on yield and fruit quality of 'Valencia' orange. *J.Am.Soc.Hort.Sci*, 105(2): 199-202.

Francois, L.E. & Maas, E.V., 1994. Crop Response and Management on Salt-Affected Soils. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 149-181.

Frenkel, H., Goertzen, J.O. & Rhodes, J.D., 1978. Effects of clay type and content, exchangeable sodium percentage and electrolyte concentration on clay dispersion and soil hydraulic conductivity. *Soil Sci. Soc. Am. J.*, 42: 32-39.

Goldberg, S. & Glaubig, R.A., 1987. Effect of saturating cation, pH, and aluminum and iron oxides on the flocculation of kaolinite and montmorillonite. *Clays Clay Min.*, 35: 220-227.

Grattan, S.R. & Grieve, C.M., 1994. Mineral nutrient acquisition and response by plants grown in saline environments. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 203-226.

Gupta, R.K., Bhumbla, D.K. & Abrol, I.P., 1984. Effect of sodicity, pH, organic matter and calcium carbonate on the dispersion behavior of soils. *Soil Sci.*, 137: 245-251.

Halliwel, D.J., Barlow, K.M. & Nash, D.M., 2001. A review of the effects of wastewater sodium on soil physical properties and their implications for irrigation systems. *Aust. J. Soil Res*., 39: 1259-1267.

Hensley, M., 1969. Selected properties affecting the irrigable value of some Makatini soils, M.Sc. Agric Thesis, University of Natal, Pietermaritzburg, South Africa.

Hoffman, G.J., Catlin, P.B., Mead, R.M., Johnson, R.S., Francois, L.E. & Goldhamer, D., 1989. Yield and foliar injury responses of mature plum trees to salinity. *Irrig. Sci.*, 10: 215-229.

Hoffman, G.J. & Durnford, D.S., 1999. Drainage Design for Salinity Control. *Agronomy,* 38: 579-614.

Howie, H. & Lloyd, J., 1989. Response of "Washington navel" orange *Citrus sinensis* (L) Osbeck to saline water II. Flowering, fruit set and fruit growth. *Aust J. Agric. Res*., 40: 371-380.

Jacoby, B., 1994. Mechanisms involved in Salt Tolerance by Plants. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 97-123.

Johnston, M.A., 1975. The effects of different levels of exchangeable sodium on soil hydraulic conductivity. Proceedings of the South African Sugar Technologists Association, 49: 142-147.

Klute, A. & Dirksen, C., 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. *Agronomy,* 9(1): 687-734.

Lloyd, J. & Howie, H., 1989. Response of Orchard 'Washington Navel' Orange. *Citrus sinensis* (L.) Osbeck to Saline Irrigation Water. I Canopy Characteristics and Seasonal Patterns in Leaf Osmotic Potential, Carbohydrates and Ion Concentrations. *Aust. J. Agric. Res*., 40: 359-369.

Louw, P.J.E. & Bennie, A.T.P., 1991. Water runoff and soil erosion in vineyard soils. *Aus. Grapegrower and Winemaker: Ann. Tech. Issue*, p.110- 113.

Maas, E.V., 1987. Salt Tolerance of Plants. *In*: B.R. Christie (ed.). CRC Handbook of Plant Science in Agriculture – CRC Series in Agriculture Vol. II. Boca Raton, Fla: CRC Press, p. 57-75.

Maas, E.V. & Hoffman, G.J., 1977. Crop salt tolerance-current assessment. *J. Irrig. Drain Div. ASCE,* 103:115-134.

Mamedov, A.I., Levy, G.J., Shainberg, I. & Letey, J., 2001. Wetting rate, sodicity, and soil texture effects on infiltration rate and runoff. *Aust. J. Soil Res*., 39: 1293-1305.

Marschner, H., 1995. Mineral Nutrition of Higher Plants, 2nd Ed. New York: Academic Press.

Mitchell, P.D., Jerie, P.H. & Chalmers, D.J., 1984. The effects of regulated water deficits on pear tree growth, flowering, fruit growth and yield. *J. Am Soc. Hort. Sci.*, 109(5): 604-606.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J. & Moolman, C.G., 1999. The Use of Saline Water for Irrigation of Grapevines and the Development of Crop Salt Tolerance Indices. WRC Report No. 303/1/99. Pretoria: Water Research Commission.

Munns, R., 1993. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell Environ.*, 16: 15-24.

Munns, R., 2002. Comparative Physiology of salt and water stress. *Plant Cell Environ.*, 25: 239-250.

Munns, R. & Termaat, A., 1986. Whole-plant responses to salinity. *Aust. J. Plant Physiol*., 13: 143-160.

Munns, R. & Passioura, J.B., 1984. Effect of prolonged exposure to NaCl on the osmotic pressure of leaf xylem sap from intact transpiring barley plants. *Aust. J. Plant Physiol.*, 11: 497–507.

Myers, B.A. & West, D.W., 1989. Effects of saline irrigation on mature pear trees. *In*: Australian Temperate Fruits Review Conference, Roseworthy, South Australia, 22-27 May 1988. Acta Hort. 240, p. 279 – 282.

Myers,B.A., West,D.W., Callinan,I & Hunter,C.C., 1995. Long term effects of saline irrigation on yield and growth of mature Williams pear trees. *Irrig. Sci.,* 16:35-46.

Orcutt, D.M. & Nilsen, E.T., 2000. Physiology of plants under stress. New York: John, Wiley & Sons, Inc.

Oster, J.D., 1994. Irrigation with poor quality water. *Agric. Water Man.*, 25: 271-297.

Oster, J.D. & Schroer, F.W., 1979. Infiltration as influenced by irrigation water quality. *Soil Sci. Soc. Am*. J., 43: 444-447.

Oster, J.D. & Shainberg, I., 2001. Soil responses to sodicity and salinity: challenges and opportunities. *Aust. J. Soil Res*., 39: 1219-1224.

Prior, C.D., Grieve, A.M. & Cullis, B.R., 1992a. Sodium chloride and soil texture interactions in irrigated field grown Sultana grapevines. I. Yield and fruit quality. *Aust. J. Agric Res*., 43: 1051-1066.

Prior, C.D., Grieve, A.M. & Cullis, B.R., 1992b. Sodium chloride and soil texture interactions in irrigated field grown Sultana grapevines. II. Plant mineral content, growth and physiology. *Aust. J. Agric Res*., 43: 1067-1083.

Pupisky, H. & Shainberg, I., 1979. Salt effects on the hydraulic conductivity of a sandy soil. *Soil Sci. Soc. Am. J.*, 43: 429-433.

Quick, W.P. & Neuhaus, H.E., 1997. The regulation and control of photosynthetic carbon assimilation. *In*: C.Foyer & W.P. Quick (eds.). A molecular Approach to Primary Metabolism in Higher Plants. London:Taylor & Francis, p. 41-62.

Quirk, J.P., 2001. The significance of the threshold and turbidity concentrations in relation to sodicity and microstructure. *Aust. J. Soil Res.*, 39: 1185-1217.

Quirk, J.P. & Schofield, R.K., 1955. The effect of electrolyte concentration on soil permeability. *J. Soil Sci.*, 6: 163-178.

Ramos,C. & Kaufmann, M.R., 1979. Hydraulic resistance of rough lemon roots. *Physiol. Plant.,* 45: 311-314.

Rasmussen, G.K., Furr, J.R. and Cooper,W.C., 1969. Ethylene Production by Citrus Leaves from Trees Grown in Artificially Salinized Plots. *J. Am. Soc. Hort. Sci.*, 94(6): 640-641.

Rengasamy, P. & Olsson, K.A., 1991. Sodicity and soil structure. *Aust J. Soil Res.*, 29: 935-952.

Rhoades, J.D., 1972. Quality of water for irrigation. *Soil Sci*., 113: 277-284.

Rhoades, J.D. & Loveday, J., 1990. Salinity in irrigated agriculture. *Agronomy* 30:1089-142.

Richards, L.A. (ed.), 1954. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No. 60. Washington, DC: USDA.

Ruiz,D., Martínez, V. & Cerdá, A., 1997. Citrus response to salinity: growth and nutrient uptake. *Tree Physiol.*, 17: 141-150.

Ruiz,D., Martinez, V. & Cerdá, A., 1999. Demarcating specific ion (NaCl, Cl^-, Na^+) and osmotic effects in the response of two citrus rootstocks to salinity. *Sci. Hort.,* 80: 213-224.

Shainberg, I. & Letey. J., 1984. Response of soils to sodic and saline conditions. *Hilgardia*, 52: 1-57.

Shainberg, I., Bresler, E. & Klausner, Y., 1971. Studies on Na/Ca montmorillonite systems. I. The swelling pressure. *Soil Sci.*, III: 214-219.

Shainberg, I., Levy, G.J., Goldstein, D., Mamedov, A. I. & Letey, J. 2001. Prewetting rate and sodicity effects on the hydraulic conductivity of soils. *Aust. J. Soil Res*., 39: 1279-1291.

Shalhevet, J., 1994. Using water of marginal quality for crop production: major issues. *Agric. Water Man.*, 25: 233-269.

Sparks, D.L., 1986. Soil Physical Chemistry. Boca Raton, Fla: CRC Press.

Storey, R. & Walker R.R., 1999. Citrus and salinity. *Sci. Hort.*, 78: 39-81.

Suarez, D.L., 1981. Relationship between pHc and SAR and an alternative method of estimating SAR of soil or drainage water. *Soil Sci. Soc. Am. J*., 45: 469-475.

Suarez, D.L., 1982. Graphical calculation of ion concentration in CaCO3 and/or gypsum solutions. *J. Environ. Qual.,* 11: 302-308.

Sumner, M.E., 1993. Sodic soils: New perspectives. *Aust. J. Soil Res*., 31: 683-750.

Syvertsen, J.P., 1985. Integration of water stress in fruit trees. *HortSci.*, 20: 1039-1043.

Tozlu, I., Guy, C.L. & Moore, G.A., 2002. Tolerance Mechanisms to Salinity Stress in *Citrus* and *Poncirus*. *In*: U.Aksoy and S. Anaç (eds.) Proceedings of the International Symposium on Techniques to control Salinisation for Horticultural Productivity. Turkey: Antalya. Acta Hort. 573, p. 271-281.

Van Zyl, E., 1997. Seasonal distribution of salts in the plant organs of *Vitis vinifera* L. (cv. Colombar) irrigated with saline water. M.Sc thesis, University of Stellenbosch, Stellenbosch, South Africa.

Waldron, L.J. & Constantin, G.K., 1968. Bulk volume and hydraulic conductivity changes during sodium saturation tests. *Soil Sci. Soc. Am. Proc.*, 32: 175 – 179.

Walker, R.R., Kriedemann, P.E. and Maggs, D.H., 1979. Growth, leaf physiology and fruit development of salt-stressed guavas. *Aust. J. Agric Res*., 30: 477-488.

Walker, R.R., Törökfalvy, E. & Downton, W.J.S., 1982. Photosynthetic Responses of the Citrus Varieties Rangpur Lime and Etrog Citron to Salt Treatment. *Aust J. Plant Physiol*., 9: 783-790.

Warrington, D., Shainberg, I., Levy, G.J. & Bar-Or, Y., 1991. Polysaccharide and salt effects on infiltration and soil erosion. A rainfall simulation study. *Soil Tech.*, 4:79-91.

Wünsche, J., 1993. The basis of productivity in apple (Malus domestica Borkh.) production systems: the role of light interception by different shoot types. Dr. agric. diss., Bonn: Rheinischen Friedrich-Wilhelms-Universität.

Yunusa, I.A.M., Walker, R.R. & Blackmore, D.H., 1997. Characterisation of water use by Sultana grapevines (Vitis vinifera L.) on their own roots or on Ramsey rootstock drip-irrigated with water of different salinities. *Irrig. Sci.,* 17: 77-86.

Zekri, M. & Parsons, L.R., 1989. Growth and root hydraulic conductivity of several citrus rootstocks under salt and polyethylene glycol stresses. *Physiol. Plant.,* 77: 99-106.

Ziska, L.H., Seemann, J.R. & DeJong, T.M., 1990. Salinity-induced limitations on photosynthesis in Prunus salicina, a deciduous tree species. *Plant Physiol.*, 93(3): 864-870.

CHAPTER 3

The effect of saline irrigation water on soil salinity and sodicity

3.1 INTRODUCTION

Economic fruit production in the South Western Cape, South Africa, is only possible under irrigation, but in many of the more arid areas water quality is deteriorating at an alarming rate (Du Plessis & Van Veelen, 1991). To evaluate the suitability of water for irrigation, one should consider the specific conditions under which the water is to be used. Factors to be taken into account include soil properties, crop species, irrigation management, cultural practices and climate (Rhoades, 1972). The main criteria used to establish irrigation water quality is salinity, specific ion concentrations and sodicity (Shainberg & Letey, 1984). Salinity refers to total salt concentration and is most commonly measured and reported as electrical conductivity (EC). The sodium adsorption ratio (SAR= $Na^+/((Ca^{2+} + Mg^{2+})^{½})$ with Na^+, Ca^{2+} and Mg^{2+} in mmol dm^{-3}) is frequently used to quantify the irrigation water sodium hazard. The predictive capacity of the SAR of the irrigation water (SAR_{iw}) for soil exchangeable sodium percentage (ESP) and SAR of the soil solution (SAR_{sw}) is complicated by evapotranspiration that concentrates the salts of the applied irrigation water.

The SAR equation does not account for changes in soluble calcium in the soil water that take place due to precipitation or dissolution during or following irrigation (Ayers & Westcot, 1985). The adjusted SAR, according to Suarez (1981; 1982), improved the estimation of the tendency of $CaCO_3$ to dissolve or precipitate following irrigation and has increased the ability to quantify the relationships between the SAR_{iw} and soil ESP. Changes in electrolyte concentration of the applied water and in the soil solution during the growing season are more important parameters than soil ESP in predicting the effect of sodicity damage to the soil (Shainberg & Letey, 1984; Rhoades & Loveday, 1990).

Rhoades & Loveday (1990) described a method to assess the suitability of water for irrigation. The basic approach was to predict the salinity, sodicity and toxic-solute concentration of the soil water within a simulated crop root zone from use of the particular irrigation water of a given composition at a specified leaching fraction. The effect of this salinity level or solute concentration on crop yield and the sodicity level on soil permeability was then evaluated. This scheme has been simplified by Rhoades for steady-state conditions by using a water-uptake-weighted EC under frequent irrigation conditions (matric stress insignificant) and average profile EC for conventional or infrequent (significant matric stress) irrigation management scenarios.

The likelihood of salinity related problems is determined after soil water compositions are predicted. According to Shalevet (1994), the arithmetic mean salinity within the rooting depth integrated over time may be considered as the effective salinity for estimating crop response, while the water uptake weighted salinity may be more representative than a simple average when salinity develops prior to root system establishment or when the salinity level at the bottom of the root zone is very high.

A soil salinity problem is expected if the predicted root zone salinity exceeds the tolerance level of the crop to be grown (Ayers & Westcot, 1985). The permeability hazard can be evaluated by observing whether the adjusted SAR-EC_{iw} combination is likely to pose problems according to a relationship between the SAR in the topsoil and the EC of the infiltrating water as described by Rhoades & Loveday (1990). Users can estimate steady-state salinity or solute concentration by multiplying the EC of the irrigation water or solute concentration by a relative concentration fraction, obtained from a lookup table appropriate to the leaching fraction. These estimates are less accurate than the more detailed model, because the latter takes precipitation-dissolution reactions and ion-pair effects into account. The permeability hazard is also assessed as previously described, but the adjusted SAR value is used in place of the SAR supplied by the detailed model. The method of Ayers and Westcot (1985) is similar to that of Rhoades. It is, however, preferred by the South African Water Quality Guidelines for Irrigation (Department of Water Affairs and Forestry, 1993) above that described by Rhoades & Loveday (1990) for low-frequency irrigation purposes, because it has gained greater international acceptance and produces slightly more conservative irrigation water salinity values.

If saline water is used for irrigation, additional water should be applied in excess of crop water use to prevent accumulation of toxic salinity levels in the soil. Requirements for effective leaching to occur are soil physical properties that will allow adequate water infiltration and movement through the soil profile enabling excess salt removal (Oster, 1994). Infiltration rate and hydraulic conductivity (HC) are the main processes determining water movement through the soil. Water infiltration into the soil is more sensitive than HC to soil ESP and the electrolyte concentration in the applied water. High salt concentrations in the soil solution and toxic salt levels do not affect the physical properties of the soil (Shainberg & Letey, 1984). Low salinity water, however, dissolves and leaches most of the soluble minerals, including calcium from the surface soil. The weakened soil structure causes the soil to disperse, small particles clog soil pores and the surface seals, reducing the rate at which water infiltrates the soil surface. Very low salinity water (less than 0.2 dS m^{-1}) almost always results in water infiltration problems, regardless of the SAR (Ayers & Westcot, 1985). Low HC and resultant dry or waterlogged soil conditions can be detrimental to crop production. A 50% decrease in soil HC relative to normal HC could be regarded as critical and will result in poor soil permeability (Shainberg & Letey,

1984). The "threshold concentration" concept of Quirck & Schofield (1955) was therefore redefined by Shainberg & Letey (1984) as the combination of salt concentration and ESP required to cause a 50% change in HC. The HC of soils having an ESP below 10 (SAR ≈ 8.4) is not affected by water of salinity above 0.5 dS m^{-1} (Shainberg *et al.*, 1981). Significant changes (>50%) in soil HC only occur when the sodicity of the soil exceeds an ESP of 15 to 20 (SAR of *c*. 12 to 16) (Shainberg & Letey, 1984). The primary mechanism causing the lower HC at moderate to high soil sodicity (ESP > 10) and water salinity (EC > 0.5 dS m^{-1}) seems to be clay swelling which depends on clay percentage and clay type.

The threshold concentration for water of low salinity to cause a significant decrease in soil HC depends on soil ESP and clay type. If the salt concentration of the percolating water is below the flocculation value of the clay, the main mechanism causing HC reduction is clay dispersion, movement and lodgment in the conductivity pores. The flocculation values of montmorillonite clay are below 5 mmol dm^{-3} at an ESP range of up to 15 (Oster *et al.*, 1980). Water of low salinity for montmorillonite soils is defined as water with EC<0.5 dS m^{-1} (*c.* 5 mmol dm^{-3}) (Shainberg & Letey, 1984). Illitic clays may be more dispersive and need a higher threshold concentration.

The effect of high or low salinity and sodicity of irrigation water on soil permeability is important to determine if the use of the specific irrigation water is sustainable. The aim of this study was to assess the effect of saline irrigation of apricot trees on changes in salinity and sodicity of the soil profile over time. The effect on soil permeability was predicted from norms derived from the literature.

3.2 MATERIALS AND METHODS

The irrigation trial was conducted at Stellenbosch, in the Western Province of the Republic of South Africa in 24 drainage lysimeters (dimensions 1.38 m x 3.0 m and 1.2 m deep). In June 1989, two apricot (*Prunus armeniaca)* cultivar Palsteyn trees on Marianna rootstock were planted per lysimeter (area per tree 1.38 m x 1.5 m and 0.9 m deep) and border trees were established alongside the outer sides of lysimeters. A layer of bitum material separated the soil from the drainage system, which was imbedded in gravel at the bottom of the lysimeters. The soil for the lysimeters originated from A and B horizons of a soil classified as a red Oakleaf (soil family 2220, Rooihoogte) sandy loam soil (Soil Classification Working Group, 1991). The mean cation exchange capacity was estimated by means of an isotopic exchange method (Le Roux, Undated) as 3.2 (Standard deviation(SD) ±0.3) cmol(-) kg^{-1} soil.

Trees received the same irrigation and fertilization after planting and stem circumference of trees was uniform in June 1993. The experiment started in December 1993 with 5-year-old trees. Trees were pruned during winter and summer where necessary. Trees were hand-thinned in the spring and fruit harvested at optimum maturity. Trees were fertilized and lime applied according to ARC-Infruitec guidelines based on growth performance of control treatment trees, leaf and soil analysis (Fruit and Fruit Technology Research Institute, 1983). Lysimeters were weeded by hand and pesticides applied as needed.

The experiment was a randomized complete blocks design with six treatments randomly allocated within each of the four block replicates. Irrigation treatment water qualities were selected to include a range that covers all the degrees of salinity as defined by the FAO guidelines for interpretation of water quality for irrigation (Ayers & Westcot, 1985). Salinity treatments included a control (municipal water) and irrigation water of target salinity levels of 0.7, 1.0, 2.0, 3.0 and 4.0 dS m^{-1} obtained by mixing different volumes of a stock solution containing 1 M NaCl and 1M $CaCl_2$ with control treatment water. For simplicity reasons the control treatment will be referred to as 0 dS m^{-1} in the text. The EC of the irrigation water (EC_{iw}) of the different treatments was determined at all irrigation events with a Hannah HI 8820 Bench Conductivity meter (Hannah Instruments, Italy) and full chemical analyses done at selected dates.

3.2.1 IRRIGATION

The irrigation system was changed in June 1993 from four 2.3 dm^3 h^{-1} pressure compensating drip emitters (Katiff, Israel) spaced 500 mm apart in a circle around each tree, to four drip lines spaced 200 mm apart, with eight drip emitters each spaced 300 mm apart to simulate a fully wetted surface. A 200 mm strip of dry surface was allowed on the outside of the irrigated area to prevent excessive leaching alongside lysimeter walls. All four replicates were irrigated from one container.

Saline water was applied in summer (September until March). During the winter irrigation was supplied whenever the soil reached a soil matric potential of approximately -0.04 MPa to prevent desiccation. A constant leaching fraction of 0.10 was imposed on all treatments. (Leaching fraction refers to the portion of irrigation water that should pass through the root zone to control salts at a specific level). An automated rain shelter was used to prevent winter leaching of salts by rainfall in order to enhance the effect of salinity on the soil and the perennial trees. Inadequate leaching was compensated for by adjusting the irrigation scheduling methods as the experiment progressed. Soil water management applicable to each season is therefore described separately.

Seasons 1993/94 and 1994/95:

The first saline irrigation was imposed during December 1993. Irrigation scheduling was initially based on crop evapotranspiration by using crop factors (Green, 1985) and Class-A pan evaporation. All treatments were irrigated according to the calculated evapotranspiration of the non-stressed control treatment.

Two neutron probe tubes were installed per lysimeter 500 mm from each tree and 150 mm from the nearest drip emitter. Soils were sampled at all positions where neutron water meter access tubes were installed at 0 mm to 150 mm, 150 mm to 300 mm, 300 mm to 600 mm and 600 mm to 900 mm depths. For each plot samples were pooled per depth. Soil water content at -0.01 MPa and -0.1 MPa and particle size characteristics of the soil were determined in the laboratory on disturbed samples according to the method of De Kock *et al*. (1977) and De Kock, undated, respectively. Percentage stone of dried soil samples was calculated as: Stone Mass% = [(Total soil sample mass – mass of soil particles <2 mm)/Total soil sample mass].

The average profile volumetric soil water content (%v/v, ±standard deviation) at -0.01 MPa and -0.1 MPa was 23.6±0.9 and 12.0±0.1, respectively, for all lysimeters. The mean percentage and standard deviation of clay, silt, fine sand, medium sand, coarse sand and stone content, respectively, was 16.9±1.4, 7.5±1.0, 37.8±1.4, 26.1±0.9, 11.7±0.9 and 4.3±0.7. A multiple regression equation utilizing clay, silt, medium and coarse sand content (Unpublished, Karsten) was used to generate a soil water retention curve to estimate the soil water content of the refill point as $y=39.5037x^{-0.21642}$ ($R^2=0.96$) in which x represents the soil matric potential in kPa and y is the profile volumetric soil water content. The volumetric soil water content was empirically corrected for mass percentage stone content according to Knight (1992) as $\theta_{v\ Mass\%\ Stone\ corrected} = \theta_{v\ (-1500\ kPa)} \times 0.9907 - 0.004 \times Mass\%\ Stone - 0.0000584 \times Mass\%\ Stone^2$.

Soil water content was monitored *in situ* at selected times at 200, 300, 600 and 900 mm depths by means of a neutron water meter (CPN 503DR Hydroprobe® Moisture gauge, Boart Longyear Company, California, USA) to determine if irrigation scheduling was accurate. Calibration curves to convert neutron water meter counts to volumetric soil water content (θ_v) for different soils were predicted from soil clay and silt content according to the method of Karsten, Deist and De Waal (1975). Separate calibration curves were obtained for depths shallower than 300 mm (Karsten & Van der Vyver, 1979). A bulk density of 1.5 Mg m^{-3} was used for all plots. Volumetric soil water content (m m^{-1}) was converted to soil water content (SWC) in millimeters as $SWC_{0\text{-}600\ mm} = (0.2 \times (\theta_{v\ 200mm} + \theta_{v\ 300\ mm} + \theta_{v\ 600\ mm})) \times 1000$ for 600 mm deep soils, and as $SWC_{0\text{-}900\ mm} = (0.2 \times \theta_{v\ 200mm}) + (0.2 \times \theta_{v\ 300\ mm}) + (0.3 \times \theta_{v\ 600\ mm}) + (0.2\ m \times \theta_{v\ 900\ mm}) \times 1000$ for

900 mm deep soils, where 0.2 and 0.3 are depth increments in metres and 1000 is for conversion from metres to millimeters.

Field water capacities of plots were determined by measuring the volumetric soil water content (% v/v) by means of a neutron water meter 24 hours after irrigation during winter. This was used as reference value (*c.* 23% v/v) for calculation of the soil water deficit for scheduling of irrigation applications. Effective root depth was taken as 600 mm. Soil was allowed to dry to a soil matric potential of -0.04 MPa that corresponded to a volumetric soil water content of *c.* 17% (66% depletion of readily available water between –0.01 MPa to –0.1 MPa or 36.6 mm). An irrigation system efficiency of 100% was assumed for the custom-made full surface drip irrigation system.

The neutron probe measurements at selected times, however, showed increasing water deficit in plots after irrigation and practically no leaching water could be collected. Various steps were taken sequentially to eliminate the problem. The wetted area initially excluded a strip of 200 mm on the perimeter of the lysimeter to prevent preferential flow of irrigation water along the walls of the lysimeter. Seepage of water probably occurred from the irrigated area to the dry strip, which caused underirrigation in the wetted area. The wetted area was therefore changed from 61% to 100% for calculation of irrigation volumes after the second irrigation. Effective root depth was changed from 600 mm to 900 mm (61.7 mm depletion allowed). Irrigation was changed to a definite weekly interval from January 1995 and irrigation volumes per treatment were calculated according to the replicate plot with the highest water deficit.

Seasons 1995/96-1996/97:

A weekly irrigation interval was applied from October until end March. Soil water content was monitored at 200, 300, 600 and 900 mm depths before and after each irrigation in order to calculate the irrigation volumes needed to refill the different treatments to field capacity and to determine if plots dried out progressively.

Season 1997/98 (August - November):

Irrigation scheduling was done in the same manner as the previous two seasons, but soil water content was only monitored before irrigation.

3.2.2 SOIL SALINITY ANALYSES

Soil samples were taken at each of the 24 plots at the beginning, at harvest and end of the 1995/96 and 1996/97 seasons to determine the total salt concentration of the solution by measuring the electrical conductivity of the saturated soil water extract (EC_e) and the soluble cations and anions. Soils were sampled at the following depths: 0 to 150 mm, 150 to 300 mm, 300 to 600 mm and 600 to 900 mm. Soils were dried, sieved and saturated paste extracts

made (Richards, 1954). Soil texture was relatively uniform and during 1995/96 the saturation percentage of a representative sample was determined and a specific volume of water added to a specific weight of soil for the other samples. During 1996/97 the method of Longenecker & Lyerly (1964) was used and a contact time of 18 hours was selected according to work done by Moolman *et al*. (1999). The saturation percentage, pH (paste) and EC_e (dS m^{-1}) were determined. The soluble cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) in the saturated extract were determined using an inductive coupled plasma atomic emission spectrometer (Liberty 200 ICP, Varian Australia Pty Ltd, Australia), and anions (Cl^{-}, HCO_3^{-}, CO_3^{-2}) according to Richards (1954).

Soil solutions were sampled at selected dates approximately 24 h after irrigation at 150, 300, 600 and 900 mm depths using porous cup soil water samplers and an automatic suction system (Du Toit, 1995). Soil solution samples were retrieved directly after collection for determination of the electrical conductivity of the soil solution (EC_{sw}), pH, cation and anion concentrations.

The SAR was calculated as SAR = $Na^{+}/((Ca^{2+} + Mg^{2+})^{½})$ with Na^{+}, Ca^{2+} and Mg^{2+} expressed in mmol dm^{-3}. The Adjusted SAR of irrigation or soil water was calculated as $Na^{+}/(((Ca_x + Mg^{2+})/2)^{½})$ with Na^{+}, Ca^{2+} and Mg^{2+} expressed in mmol(+) dm^{-3} (Suarez, 1981) and Ca_x as $1.34((CO_3^{-2}+HCO_3^{-})/Ca)^{-0.6666}$ x $(EC/100)^{0.1003}$ with carbonate, bicarbonate and calcium expressed in mmol(+) dm^{-3} and EC of the water in dS m^{-1} (Kotzé, 2001).

3.2.3 STATISTICAL ANALYSES

Standard analyses of variance were performed on untransformed data using SAS Version 8.2 (1999). A Shapiro-Wilk test was performed to test for non-normality (Shapiro, 1965). Where there was significant evidence for non-normality due to skewness, outliers with large residuals were identified and removed until the data were normal or symmetrically distributed. Student's t-Least Significant Difference (LSD) were calculated at the 5% significance level to compare treatment means.

3.3 RESULTS

The first irrigation of each season was applied when the soil matrix potential reached approximately -0.04 MPa. Weekly irrigation started as soon as evaporative demand was high enough for a reasonable amount of water to be applied. Due to differences in bud break and weather conditions the starting date of irrigation varied between seasons. It started on 29/08/94, 20/09/95, 27/08/96 and 03/09/97 during the 1994/95, 1995/96, 1996/97 and 1997/98 seasons, respectively.

3.3.1 Seasonal mean electrical conductivity and chemical composition of irrigation water.

The seasonal mean electrical conductivity value showed that the irrigation treatments were successfully induced (Table 3.1). The cation and anion concentrations generally increased with salinity, with the exception of bicarbonate (HCO_3^-), in 1997/98. During 1995/96 the average Ca:Na molar ratio was 0.73 instead of the required ratio of 1 (Table 3.1). This could be attributed to the calcium content of the municipal water which had a low Ca:Na ratio of 0.19 during that season.

The SAR values in the 0 dS m^{-1} treatment remained below or about 1 and that of the 4 dS m^{-1} treatment ranged between 3 and 4 (Table 3.1). The adjusted SAR values of the irrigation water were similar to that of the SAR in the 0 to 1 dS m^{-1} treatments. The adjusted SAR values of the irrigation water were higher than the SAR values in the 2 to 4 dS m^{-1} treatments for all seasons. The adjusted SAR value was on average 31%, 43% and 50% higher than the SAR in the 2, 3 and 4 dS m^{-1} treatments, respectively, for the 1995/96 to 1997/98 seasons. The maximum adjusted SAR value in the irrigation water of these treatments was 5.3.

Local SAR, adjusted SAR and EC values of irrigation water, soil water and saturated soil water extracted from the top 150 mm of soil for the 1995/96 to 1996/97 seasons, were respectively superimposed on the graph from Rhoades & Loveday (1990). The graph established the likelihood of permeability or tilth problems with irrigation resulting from sodicity (Fig. 3.1). The combination of SAR and EC values of irrigation water, soil water and saturated soil water extracted from the top 150 mm of soil respectively of the 0 dS m^{-1} treatment was categorized as being a potential permeability hazard. Permeability problems were unlikely in the higher salinity treatments, including the 0.7 dS m^{-1} treatment. The adjusted SAR of the irrigation water of the 0 dS m^{-1} treatment predicted a decreased sodicity in this treatment, while that of the 0.7 to 4 dS m^{-1} treatments indicated increased potential for development of sodic conditions. The adjusted SAR of the soil water of the 2 to 4 dS m^{-1} treatments indicated increased sodicity. The EC to SAR or adjusted SAR relation was generally the highest for the soil water, followed by the irrigation water and the saturated extract of the top 150 mm of soil.

3.3.2 Soil salinity

Seasonal trends in depth-weighted EC_e and SAR_e.

The salinity of the 0, 0.7 and 1 dS m^{-1} treatments did not differ significantly at different stages within the 1995/96 season (Table 3.2). The first significant differences between the soil salinity of the lower salinity treatments became apparent in January 1997 and by March 1997 the

Table 3.1. Seasonal mean (± standard deviation) electrical conductivity (EC_{iw}) and chemical composition of saline irrigation water treatments for the period August to March of the 1995/96, 1996/97 and 1997/98 season. Irrigation of all treatments was terminated December 1997. The EC_{iw} values for 1995/96 and 1996/97 are means of EC_{iw} of 28, and for 1997/98, of 13 irrigation events. The chemical composition values are means of at least 15, 21 and 4 analyses for the three respective seasons

Season	Target EC	EC_{iw}	Ca^{2+}	Na^{+}	Cl^{-}	HCO_3^{-}	Ca:Na	SAR	Adjusted SAR
	(dS m^{-1})		(mmol dm^{-3})				(Molar)		
1995/96	0	0.07±0.05	0.06±0.03	0.29±0.08	1.33±1.00	0.73±0.28	0.19±0.06	0.95±0.12	0.77±0.17
	0.7	0.60±0.08	1.39±0.22	1.79±0.22	5.96±1.27	0.79±0.28	0.78±0.05	1.49±0.11	1.64±0.20
	1	0.85±0.12	2.07±0.42	2.53±0.38	7.82±1.71	0.80±0.27	0.82±0.06	1.73±0.14	1.98±0.28
	2	1.81±0.24	4.69±0.89	5.50±0.82	16.39±3.72	0.84±0.28	0.85±0.06	2.51±0.21	3.22±0.46
	3	3.00±0.57	7.60±1.56	8.81±1.39	25.64±5.51	0.92±0.28	0.88±0.08	3.14±0.28	4.33±0.56
	4	3.88±0.54	10.28±2.17	11.96±1.98	35.24±8.86	0.98±0.37	0.86±0.09	3.68±0.33	5.34±0.98
1996/97	0	0.05±0.01	0.13±0.34	0.33±0.27	7.59±1.11	0.67±0.18	0.25±0.24	1.00±0.19	0.79±0.17
	0.7	0.69±0.03	1.86±0.28	2.04±0.23	11.60±0.97	0.72±0.22	0.92±0.14	1.50±0.17	1.65±0.22
	1	1.02±0.09	2.86±0.55	2.88±0.26	17.96±1.76	0.81±0.27	1.00±0.21	1.71±0.18	2.07±0.31
	2	2.00±0.18	6.14±1.00	5.95±0.58	28.43±1.73	0.84±0.22	1.03±0.15	2.40±0.20	3.22±0.39
	3	2.99±0.23	9.46±1.84	8.86±0.97	39.44±1.79	0.98±0.47	1.07±0.16	2.90±0.24	4.28±0.66
	4.0	4.07±0.03	13.09±2.46	11.46±2.43	54.72±1.77	0.97±0.26	1.11±0.18	3.26±0.43	5.07±0.73
1997/98	0	0.07±0.01	0.14±0.03	0.25±0.03	3.16±1.55	0.77±0.07	0.55±0.09	0.61±0.02	0.53±0.03
	0.7	0.71±0.04	1.93±0.09	2.20±0.15	9.02±1.54	0.71±0.18	0.88±0.09	1.57±0.12	1.73±0.16
	1	1.00±0.03	2.93±0.04	3.16±0.18	12.23±1.75	0.65±0.22	0.93±0.04	1.83±0.09	2.06±0.20
	2	2.00±0.06	6.49±0.18	6.56±0.16	23.09±0.77	0.75±0.19	0.99±0.05	2.56±0.09	3.33±0.36
	3	3.00±0.07	10.36±0.18	9.66±0.12	32.59±2.24	0.83±0.19	1.07±0.02	2.99±0.04	4.26±0.28
	4[1]	-	-	-	-	-	-	-	-

[1] Irrigation terminated end of season 1996/97.

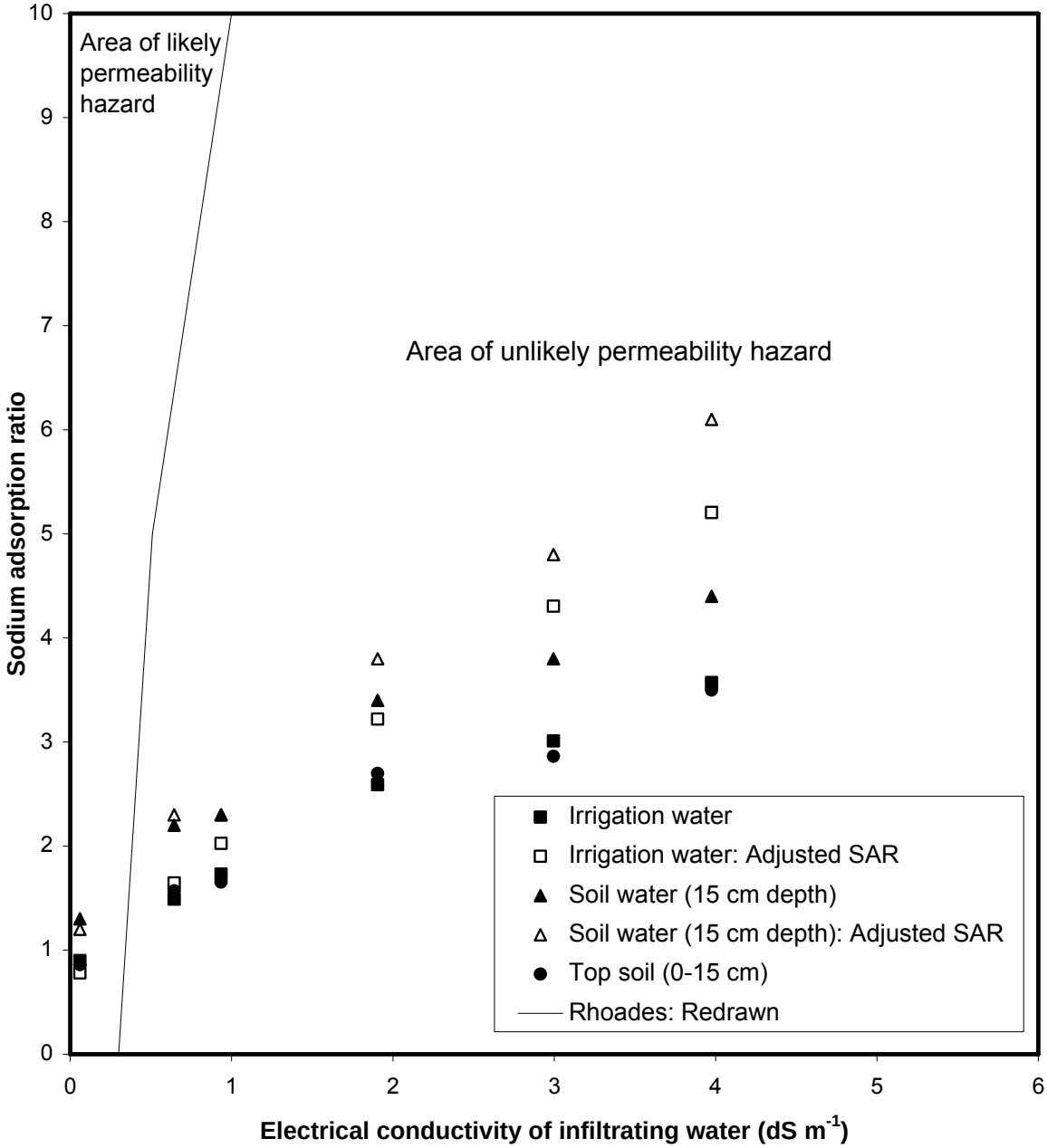


Figure 3.1. The effect of electrical conductivity of the infiltrating water (EC_{iw}) and the sodium adsorption ratio (SAR) of the irrigation water, the top soil (0-150 mm) and soil water (150 mm depth) on the potential soil permeability hazard. Data are the means of the 1995/96 and 1996/97 seasonal means. Seasonal means included EC_{iw} data for 28 irrigation events, SAR data for 23 and 26 irrigation events, adjusted SAR data for 15 and 21 irrigation events, 3 saturated soil water extracts, and 11 and 13 soil water extracts for the 1995/96 and 1996/97 seasons respectively. The adjusted SAR of the irrigation and soil water is also shown. The graph was redrawn from Rhoades & Loveday (1990).

Table 3.2. Depth weighted mean salinity (dS m^{-1}) of the saturated soil extract (EC_e) at the start of the season, at harvest and at the end of the season of different saline irrigation treatments during 1995/96 and 1996/97. Salt content of the irrigation water is expressed in terms of electrical conductivity (EC_{iw}). Values in months designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and means for months and seasons were tested separately (n_h (harmonic mean of observations) or n varied between 2.4 and 4). The experimental standard deviation (SD) and degrees of freedom (df) for each month within each season and for seasonal means are indicated in the table

Season	Month	Salinity treatments (EC_{iw}, dS m^{-1})						LSD	SD	df
		0	0.7	1	2	3	4	(5%)		
1995/96	August	0.38 ^{c}	0.67 ^{c}	0.85 ^{c}	1.38 ^{b}	1.86 ^{b}	2.55 ^{a}	0.485	0.31	14
	December	0.46 ^{d}	0.76 ^{d}	0.83 ^{d}	2.15 ^{c}	2.91 ^{b}	3.55 ^{a}	0.634	0.41	14
	March	0.41 ^{c}	0.46 ^{c}	0.97 ^{c}	2.21^{bc}	2.11^{ab}	3.15 ^{a}	1.412	0.91	14
	Mean	**0.41 ^{c}**	**0.63 ^{c}**	**0.88 ^{c}**	**2.04 ^{b}**	**2.29 ^{b}**	**3.08 ^{a}**	**0.644**	**0.40**	**13**
1996/97	August	0.44 ^{c}	1.16 ^{c}	1.09 ^{c}	1.85^{bc}	3.11^{ab}	4.28 ^{a}	1.564	1.04	15
	January	0.51 ^{c}	0.73^{bc}	1.36^{ab}	1.48 ^{a}	2.29 ^{a}	2.29 ^{a}	0.612	0.39	14
	March	0.38 ^{c}	0.75 ^{c}	0.87 ^{b}	2.04 ^{a}	2.30 ^{a}	2.82 ^{a}	0.831	0.46	11
	Mean	**0.44 ^{d}**	**0.88 ^{d}**	**1.15^{cd}**	**1.79^{bc}**	**2.41^{ab}**	**3.13 ^{a}**	**0.758**	**0.37**	**11**

1 dS m^{-1} treatment had a significantly higher salinity than the 0 and 0.7 dS m^{-1} treatments. All irrigation water quality treatments above 1 dS m^{-1} had at some stage in the season soil salinity conditions (EC_e) exceeding 2 dS m^{-1}.

The SAR of the saturated paste extract (Table 3.3) increased with salt content of different treatments in accordance with the chemical composition of the irrigation water (Table 3.1), but remained below 4. The SAR of the three lowest salinity treatments remained between 0.9 and 2.2 while the two highest salinity treatments ranged between 2.7 and 3.4. The SAR of the two highest salinity treatments did not differ significantly at any stage during the two years over which it was monitored.

Seasonal trends in depth-weighted EC_{sw} and SAR_{sw}.

The trends in depth-weighted EC_{sw} and SAR_{sw} over seasons were displayed in Tables 3.4 and 3.5 respectively. The depth-weighted seasonal average EC_{sw} (Moolman *et al*., 1999) increased with irrigation water salinity (Table 3.4). The minimum and the maximum soil water salinity changed respectively from 0.58 dS m^{-1} and 9.51 dS m^{-1} in 1994/95 to 0.51 dS m^{-1} and 6.95 dS m^{-1} in 1997/98. The soil water salinity in the 0 and 0.7 dS m^{-1} irrigation water salinity treatments remained below 2.1 dS m^{-1} and were significantly lower than those of the three most saline treatments (2, 3 and 4 dS m^{-1}) during all four seasons.

There was a significant increase in the depth-weighted seasonal average SAR_{sw} values of the soil water with increased salinity of the irrigation water during all three seasons (Table 3.5). The SAR of the soil water in the 0 and 0.7 dS m^{-1} treatments were below 1.2 and 2.6 respectively during the 1995/96 to 1997/98 seasons. The SAR_{sw} in the 1 dS m^{-1} treatment showed an increase from 2.8 to 3.3 from 1995/96 to 1996/97 seasons, while it remained at *c*. 4 in the 2 dS m^{-1} treatment. The SAR_{sw} decreased during the same period in the 3 and 4 dS m^{-1} treatments by 0.7 and 1.3 units respectively. The SAR_{sw} values of the three most saline treatments were significantly higher than that of the control and 0.7 dS m^{-1} treatments during all seasons and ranged between 4 and 5.5. The SAR_{sw} was still increasing during the 1997/98 season in all treatments, except in the 0 and 1 dS m^{-1} treatments.

Profile distributions of seasonal average EC_{sw} and SAR_{sw}

The seasonal average EC_{sw} and SAR_{sw} per depth increment were displayed in Figs. 3.2 and 3.3 respectively. Profile distributions of EC_{sw} varied from a mild increase in salinity with depth (0 and 0.7 dS m^{-1} treatments) to a sharp increase with depth (3 dS m^{-1} treatment) during 1994/95 (Fig. 3.2). Salinity profiles in the 0 dS m^{-1} treatment were approximately uniform in depth over the 1995/96 to 1997/98 seasons. The salinity profiles of the 0.7 dS m^{-1} treatment did not

Table 3.3. Depth weighted mean sodium adsorption ratio (SAR) of the saturated soil paste extract at the start of the season, at harvest and at the end of the season of different saline irrigation treatments during 1995/96 and 1996/97 (n=4). Salt content of the irrigation water is expressed in terms of electrical conductivity (EC_{iw}). Values in months designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05), and months were tested separately. The experimental standard deviation (SD) for each month within each season is indicated in the table (degrees of freedom = 15)

Season	Month	Salinity treatments (EC_{iw}, dS m^{-1})						LSD	SD
		0	0.7	1	2	3	4	(5%)	
1995/96	August	1.1^{d}	1.9^{c}	1.9^{c}	2.7^{b}	3.5^{a}	3.4^{a}	0.57	0.4
	December	1.1^{c}	1.6^{b}	1.9^{b}	3.0^{a}	3.1^{a}	3.4^{a}	0.86	0.6
	March	1.7^{d}	2.3^{bcd}	2.1^{cd}	2.7^{abc}	3.1^{a}	2.9^{ab}	0.67	0.5
1996/97	August	1.4^{d}	1.9^{cd}	2.2^{bc}	2.7^{ab}	3.1^{a}	3.1^{a}	0.65	0.4
	January	0.9^{c}	1.7^{b}	2.2^{ab}	2.4^{a}	2.8^{a}	2.7^{a}	0.64	0.4
	March	1.1^{d}	1.8^{c}	2.3^{b}	2.8^{a}	2.7^{ab}	2.7^{a}	0.44	0.3

Table 3.4. Depth weighted seasonal mean soil water salinity of the total soil profile (0-900 mm) for the 1994/95 (nine dates), 1995/96 (twelve dates) 1996/97 (fourteen dates) and 1997/98 (four dates) season (n=4). Salt contents of the irrigation and soil water are expressed in terms of electrical conductivity (EC_{iw} and EC_{sw}, respectively). Irrigation of all treatments was terminated December 1997. Values in seasons designated by the same symbol do not differ significantly (Student's t-LSD (Least Significant Difference), p=0.05) and seasons were tested separately. The experimental standard deviation (SD) and degrees of freedom (df) for each season are indicated in the table

Treatment (EC_{iw}, dS m^{-1})	**Depth weighted seasonal salinity of soil water (EC_{sw}, dS m^{-1})**			
	1994/95	**1995/96**	**1996/97**	**1997/98**
0	0.58 ^{d}	0.48 ^{d}	0.43 ^{d}	0.51 ^{cd}
0.7	1.58 ^{d}	2.06 ^{cd}	1.56 ^{d}	1.90 ^{c}
1	2.60 ^{cd}	2.68 ^{bc}	3.15 ^{c}	3.23 ^{bc}
2	5.29 ^{bc}	4.73 ^{b}	4.57 ^{b}	5.67 ^{ab}
3	7.38 ^{ab}	7.47 ^{a}	6.06 ^{a}	6.95 ^{a}
4	9.51 ^{a}	8.96 ^{a}	5.78 ^{ab}	Terminated end 1996/97
LSD (5%)	2.873	2.191	1.254	2.592
SD	1.91	1.45	0.83	1.68
df	15	15	15	12

Table 3.5. Depth weighted seasonal sodium adsorption ratio of soil water (SAR_{sw}) from the total soil profile (0-900 mm) for the 1995/96 (eleven dates), 1996/97 (thirteen dates) and 1997/98 (four dates) season (n=4). Salt content of the irrigation water is expressed in terms of electrical conductivity (EC_{iw}). Irrigation of all treatments was terminated December 1997. Values in seasons designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and seasons were tested separately. The experimental standard deviation (SD) and degrees of freedom (df) for each season are indicated in the table

Treatment (EC_{iw}, dS m^{-1})	**Depth weighted seasonal sodium adsorption ratio of soil water**		
	1995/96	**1996/97**	**1997/98**
0	1.1 ^{d}	1.0 ^{d}	0.9 ^{d}
0.7	2.3 ^{c}	2.2 ^{c}	2.5 ^{c}
1	2.7 ^{c}	3.3 ^{b}	3.3 ^{bc}
2	4.0 ^{b}	3.9 ^{ab}	4.1 ^{ab}
3	4.8 ^{ab}	4.2 ^{a}	4.4 ^{a}
4	5.5 ^{a}	3.9 ^{ab}	Terminated end 1996/97
LSD (5%)	0.99	0.66	1.02
SD	0.7	0.4	0.7
df	15	15	12

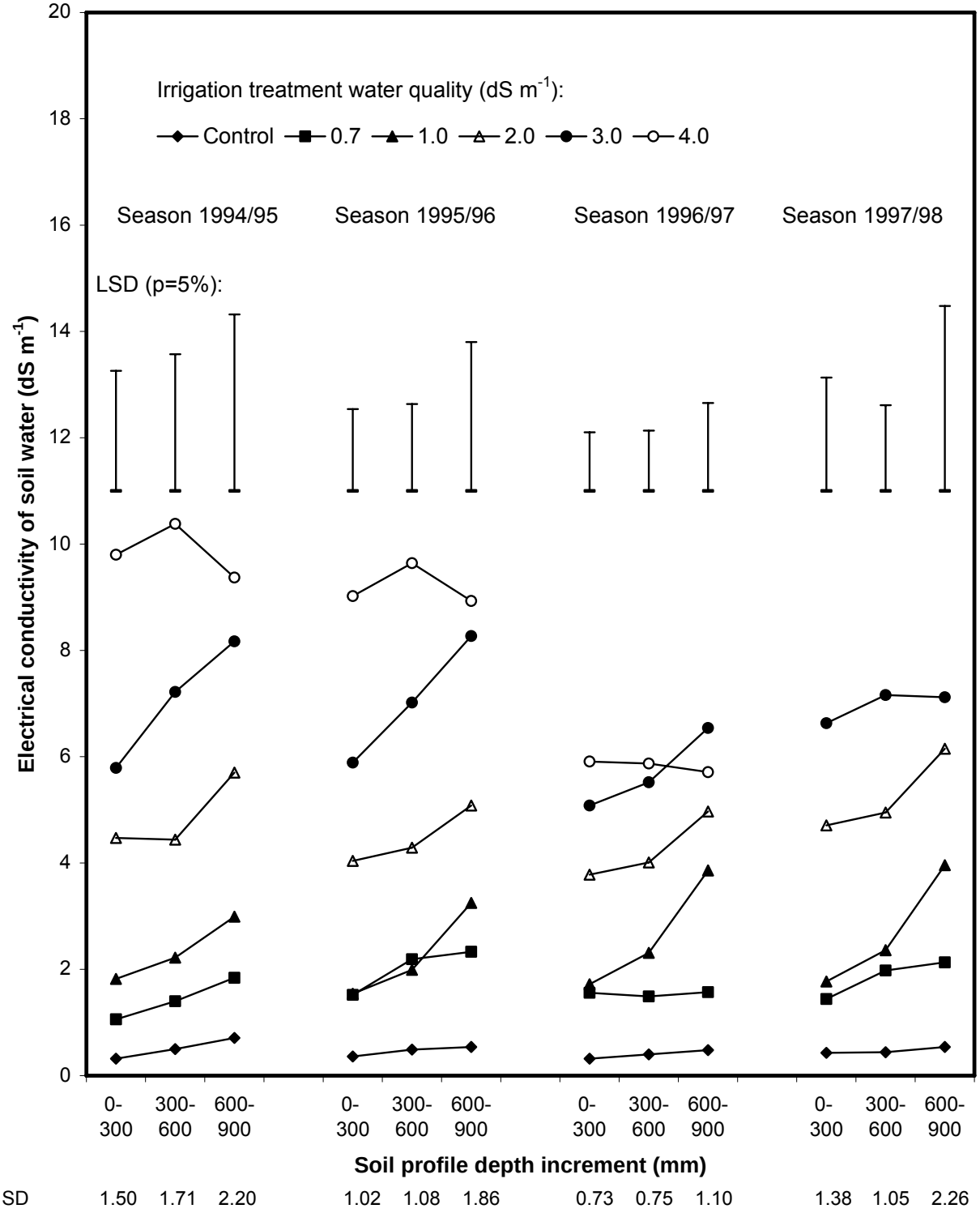


Figure 3.2. Trends of seasonal mean soil water salinity of the top (0-300 mm), middle (300-600 mm) and bottom (600-900 mm) of the soil profile of different saline irrigation treatments during the 1994/95 to 1997/98 seasons (n=4). Seasonal means were derived from data of 9, 12, 14 and 4 soil water extraction dates for the 1994/95, 1995/96, 1996/97 and 1997/98 seasons respectively. The 1997/98 season was terminated shortly after harvest. Salt content of the irrigation and soil water are expressed in terms of electrical conductivity (EC). Significant differences for each depth increment per season were tested separately (Student's t-Least Significant Difference (LSD), p=0.05) and the experimental standard deviation (SD) for each depth within each season is indicated at the bottom of the graph (degrees of freedom = 15 for 1994/95 to 1996/97 and 12 for 1997/98).

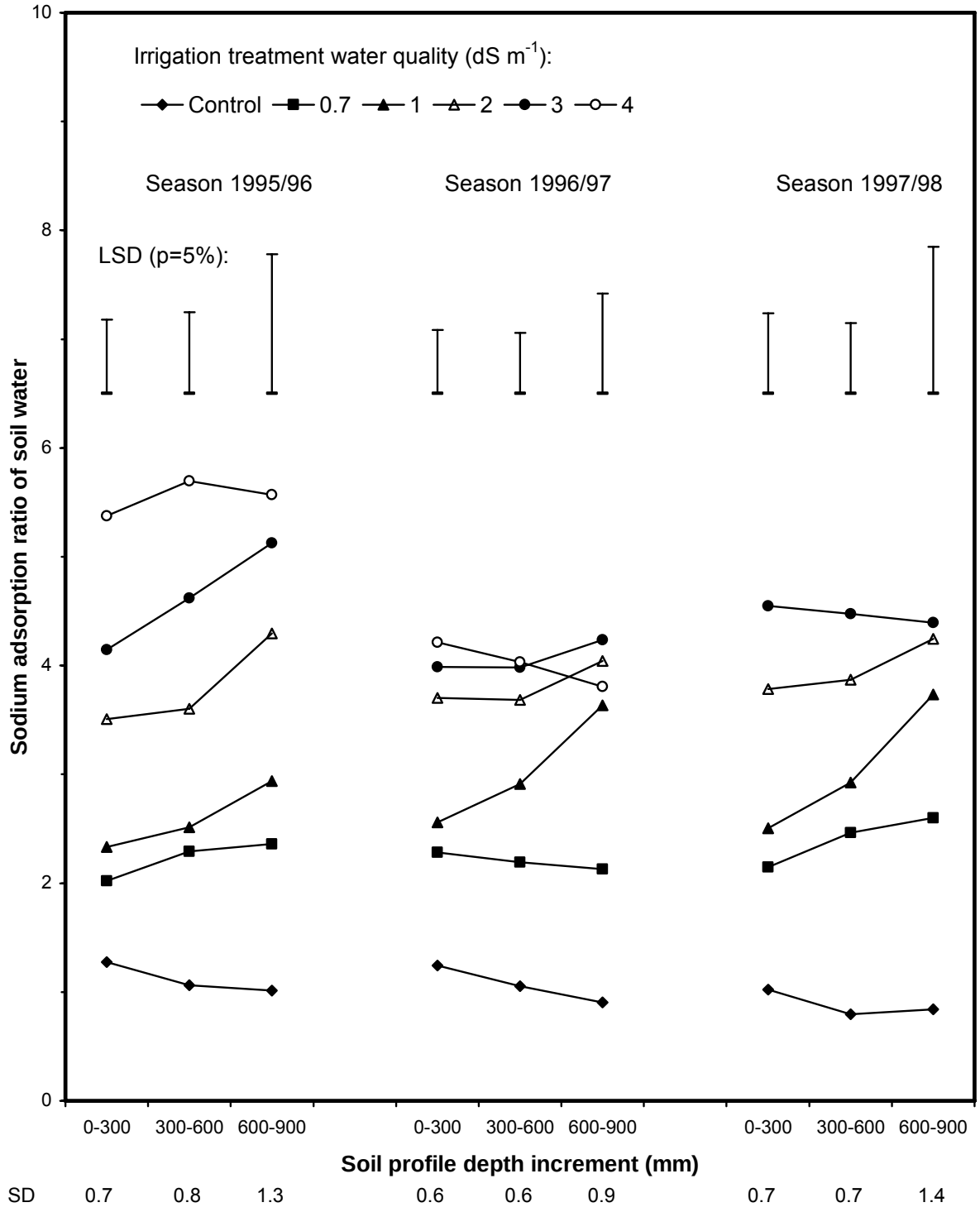


Figure 3.3. Trends of the seasonal average sodium adsorption ratio of the top (0-300 mm), middle (300-600 mm) and bottom (600-900 mm) of the soil profile of different saline irrigation treatments during the 1995/96 to 1997/98 seasons (n=4). Seasonal means were derived from data of eleven, thirteen and four soil water extraction dates for the 1995/96, 1996/97 and 1997/98 seasons respectively. The 1997/98 season was terminated shortly after harvest. Significant differences for each depth increment per season were tested separately (Student's t-Least Significant Difference (LSD), p=0.05)) and the experimental standard deviation (SD) for each depth within each season is indicated at the bottom of the graph (degrees of freedom = 15 for 1995/96 and 1996/97, and 12 for 1997/98).

change much between the 1994/95 and 1997/98 seasons, while that of the 1 dS m^{-1} treatment displayed increasingly steep slopes and higher salinity at the 600 to 900 mm depth as seasons progressed. Salinity in the 2 dS m^{-1} treatment tended to decrease from 1994/95 to 1995/96 and 1996/97 and increased again during 1997/98. The slopes of the profile distributions appeared to be less steep when compared to that of the 1994/95 season. The salinity profile distributions in the 3 dS m^{-1} treatment were very steep during the 1994/95 and 1995/96 seasons. The salinity in the profile decreased during 1996/97 and although salinity levels increased again in 1997/98, it was approximately uniform at the 300-600 mm and 600-900 mm depths. Salinity profile distributions in the 4 dS m^{-1} treatment differed from the general pattern displayed by the other treatments. The maximum EC_{sw} was recorded in the middle of the soil profile during the 1994/95 to 1995/96 seasons. This pattern changed during 1996/97 to an approximately uniform profile with a much lower salinity than in previous seasons.

The SAR profile distribution (Fig. 3.3) followed approximately the same trends over depth as the salinity (Fig. 3.2). The SAR in the 0 dS m^{-1} treatment, however, tended to decrease with depth and over seasons. Profile distributions of SAR in the 0.7 dS m^{-1} treatment varied over seasons, but it increased with depth during the 1997/98 season. There was a definite trend for the SAR to increase with depth in the 1, 2 and 3 dS m^{-1} treatments during the 1995/96 season. The slope of the SAR profile distribution increased in the 1 dS m^{-1} treatment as seasons progressed. The SAR profile distribution in the 2 dS m^{-1} treatment did not change much, but the SAR tended to decrease over time with a smaller gradient between the top and the bottom of the soil profile. The SAR in the soil profile of the 3 dS m^{-1} treatment decreased at all depths from the 1995/96 to the 1996/97 seasons and changed to an approximately uniform profile during the 1997/98 season. The SAR values in the 4 dS m^{-1} treatment increased during 1995/96 from the 0 to 300 mm depth to the 300 to 600 mm depth. Sodicity was uniform between the middle and the bottom of the soil profile. During 1996/97 the SAR values in this treatment decreased by 1.6 units and the sodicity profile distribution had a negative slope.

Seasonal and annual rate of change in EC_{sw} and SAR_{sw}

The seasonal rate of change in salinity and sodicity of the soil profile was estimated by fitting a straight line through the depth-weighted salinity and SAR values, respectively, of the soil water extracts made during each season. The annual rate of change was estimated by fitting the line through the depth-weighted seasonal soil water salinity of the 1994/95 to 1997/98 and SAR values of the 1995/96 to 1997/98 seasons. The seasonal rate of change in salinity (dS m^{-1} $year^{-1}$) of the total soil profile (0 to 900 mm) initially (1994/95) increased with increasing salinity of the irrigation water (Table 3.6). The rate of salinization was significantly higher in the 3 and 4 dS m^{-1} treatments during the 1994/95 season. From the 1995/96 season onwards, however, desalinization of the soil profile took place in the 4 dS m^{-1} treatment. The 2 and 3

Table 3.6. Estimated soil water salinity at the start of each season (intercept) and rate of change in soil water salinity (slope) in the total profile (0-900 mm) of the different saline irrigation water treatments over the 1994/95, 1995/96, 1996/97 and 1997/98 seasons (n=4). Salt content of the irrigation and soil water are expressed in terms of electrical conductivity (EC_{iw} and EC_{sw}, respectively). Values in seasons designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and seasons (intercept and slope) were tested separately. The experimental standard deviation (SD) of the intercept and slope of each season is indicated at the bottom of the table (degrees of freedom (df) = 15 for 1994/95 to 1996/97, df = 12 for 1997/98)

Treatment (EC_{iw}, dS m^{-1})	**Estimated salinity at start of season (intercept) (EC_{sw}, dS m^{-1})**				**Rate of change in soil salinity (Slope) (dS m^{-1} $year^{-1}$)**			
	1994/95	**1995/96**	**1996/97**	**1997/98**	**1994/95**	**1995/96**	**1996/97**	**1997/98**
0	1.22 ^{c}	0.82 ^{d}	0.62 ^{d}	0.55 ^{c}	-1.66 ^{b}	-0.92 ^{a}	-0.54 ^{b}	-0.36 ^{a}
0.7	1.51 ^{c}	1.48 ^{d}	1.68 ^{c}	1.24 ^{bc}	0.19 ^{b}	1.56 ^{a}	-0.36 ^{ab}	4.78 ^{a}
1	2.12 ^{bc}	1.74 ^{d}	2.56 ^{c}	2.72 ^{b}	1.19 ^{b}	2.57 ^{a}	1.90 ^{a}	3.67 ^{a}
2	4.21 ^{ab}	4.81 ^{c}	5.00 ^{b}	4.92 ^{a}	2.53 ^{b}	0.39 ^{a}	-1.27 ^{b}	7.22 ^{a}
3	3.27 ^{abc}	7.14 ^{b}	6.95 ^{a}	4.82 ^{a}	10.14 ^{a}	0.92 ^{a}	-2.74 ^{bc}	15.29 ^{a}
4	5.20 ^{a}	10.68 ^{a}	7.23 ^{a}	-	11.73 ^{a}	-4.54 ^{a}	-4.53 ^{c}	-
LSD (5%)	2.159	2.009	0.938	1.760	4.908	4.545	2.830	10.135
SD	1.43	1.33	0.62	1.14	3.26	3.02	1.88	6.58

dS m^{-1} treatments followed the same trend since 1996/97. The rate of change during 1997/98 only represents the period from bud break until harvest and still followed the pattern initially observed. The annual rate of change in soil water salinity did not differ significantly for the depth-weighted soil water salinity (0 to 900 mm) of the different saline irrigation treatments (Table 3.7). The annual rate of change in soil water salinity of the 4 dS m^{-1} treatment was, however, significantly different from all other treatments at the 0 to 300 mm and 300 to 600 mm depths. The negative rate of change in soil water salinity of the 4 dS m^{-1} treatment agreed with the overall trend of decreasing salinity in this treatment after the first soil water extraction in 1994/95 (Fig. 3.2).

The seasonal rate of change in SAR during 1995/96 was the lowest for the total profile (0-900 mm) in the 0 dS m^{-1} treatment and the highest for the 2 dS m^{-1} treatment (Table 3.8). The seasonal rate of change in SAR did not differ significantly for the 1996/97 season. During 1996/97 the 1 dS m^{-1} treatment maintained the highest rate of change. Significant differences in 1997/98 applied only to the period from bud break till harvest. No trend was evident, but the 3 dS m^{-1} treatment had the highest rate of change (Table 3.8). SAR increased in all treatments except in the control where a negative rate of change was found during the 1995/96 and 1997/98 seasons. The annual rate of change in SAR was significantly lower at all depths for the 4 dS m^{-1} treatment (Table 3.9). The decrease in sodicity was 1.22 SAR units per year for the whole profile (0 to 900 mm). The 1 dS m^{-1} treatment had a significant increase in SAR at the bottom of the soil profile (600 to 900 mm) and had the highest overall positive rate of change in sodicity over the three seasons. This increase in sodicity amounted to 0.46 SAR units per year for the whole profile (0-900 mm).

3.4 DISCUSSION

3.4.1 Seasonal mean electrical conductivity and chemical composition of irrigation water.

Deciduous fruit trees, including apricot, have been described as being sensitive to salinity (Maas & Hoffman, 1977). According to estimations from the calculation procedure of Ayers & Westcot (1985) for conventional irrigation conditions, it can be expected that, provided a ten percent leaching fraction is used, irrigation with water of salinity exceeding 0.76 dS m^{-1} will cause an EC_e of 1.6 dS m^{-1} which could affect apricot growth negatively. The linear average value for the whole root zone calculated by hand according to Rhoades as described by Rhoades & Loveday (1990) rendered a less conservative, but similar value of 0.85 dS m^{-1}. One would therefore expect soil salinity conditions less suitable for apricot production in the treatments receiving irrigation water with salinity of 1 to 4 dS m^{-1}.

Table 3.7. Estimated soil water salinity at the start of the 1994/95 season (intercept) and rate of change in soil water salinity (slope) for the top (0-300 mm), middle (300-600 mm), bottom (600-900 mm) and total (0-900 mm) soil profile of the different saline irrigation water treatments over the 1994/95 to 1997/98 seasons (n=4). Salt content of the irrigation and soil water are expressed in terms of electrical conductivity (EC_{iw} and EC_{sw}, respectively). Values per profile depth designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and profile depths (intercept and slope) were tested separately. The experimental standard deviation (SD) of the intercept and slope of each profile depth is indicated at the bottom of the table (degrees of freedom = 15)

Treatment (EC_{iw}, dS m^{-1})	**Estimated salinity at start of 1994/95 season (intercept) (EC_{sw}, dS m^{-1})**				**Annual rate of change in soil water salinity (slope) (dS m^{-1} $year^{-1}$)**			
	Profile depth (mm)				**Profile depth (mm)**			
	0-300	**300-600**	**600-900**	**0-900**	**0-300**	**300-600**	**600-900**	**0-900**
0	0.39 ^{c}	0.59 ^{d}	0.71 ^{d}	0.60 ^{d}	-0.02 ^{a}	-0.08 ^{a}	-0.09 ^{a}	-0.07 ^{a}
0.7	1.17 ^{c}	1.54 ^{cd}	1.93 ^{dc}	1.68 ^{dc}	0.15 ^{a}	0.09 ^{a}	-0.03 ^{a}	0.03 ^{a}
1	1.77 ^{c}	2.09 ^{cd}	2.61 ^{dc}	2.33 ^{dc}	-0.04 ^{a}	0.07 ^{a}	0.52 ^{a}	0.33 ^{a}
2	4.43 ^{b}	4.41 ^{cb}	5.39 ^{bc}	5.07 ^{bc}	-0.19 ^{a}	-0.06 ^{a}	-0.03 ^{a}	-0.08 ^{a}
3	5.69 ^{b}	7.02 ^{b}	7.74 ^{ab}	7.06 ^{ab}	-0.05 ^{a}	-0.35 ^{a}	-0.26 ^{a}	-0.19 ^{a}
4	10.70 ^{a}	11.38 ^{a}	10.15 ^{a}	10.33 ^{a}	-2.01 ^{b}	-2.25 ^{b}	-1.75 ^{a}	-1.83 ^{a}
LSD	2.493	3.118	4.486	3.737	1.201	1.384	1.987	1.651
SD	1.65	2.07	2.98	2.48	0.80	0.92	1.32	1.10

Table 3.8. Estimated sodium adsorption ratio (SAR) at the start of each season (intercept) and SAR rate of change (slope) of soil water in the total profile (0-900 mm) of the different saline irrigation water treatments over the 1995/96, 1996/97 and 1997/98 seasons (n=4). Salt content of the irrigation water is expressed in terms of electrical conductivity (EC_{iw}). Values in seasons designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p = 0.05) and seasons (intercept and slope) were tested separately. The experimental standard deviation (SD) of the intercept and slope of each season is indicated at the bottom of the table (degrees of freedom = 15 for 1995/96 to 1996/97 and 12 for 1997/98)

Treatment (EC_{iw}, dS m^{-1})	**Estimated SAR at start of season (intercept)**			**Rate of change in soil water SAR (slope) ($year^{-1}$)**		
	1995/96	**1996/97**	**1997/98**	**1995/96**	**1996/97**	**1997/98**
0	1.2 ^{e}	0.8 ^{d}	1.0 ^{d}	-0.34 ^{b}	0.50 ^{a}	-1.31 ^{c}
0.7	1.7 ^{ed}	1.8 ^{c}	2.1 ^{c}	1.88 ^{ab}	0.99 ^{a}	2.78 ^{ab}
1	2.2 ^{d}	2.8 ^{b}	3.2 ^{b}	1.70 ^{ab}	1.55 ^{a}	1.58 ^{abc}
2	3.2 ^{c}	3.6 ^{a}	4.0 ^{a}	3.25 ^{a}	0.99 ^{a}	0.73 ^{bc}
3	4.1 ^{b}	3.8 ^{a}	3.9 ^{ab}	2.24 ^{ab}	1.13 ^{a}	3.77 ^{a}
4	4.9 ^{a}	3.7 ^{a}	-	1.63 ^{ab}	0.72 ^{a}	-
LSD (5%)	0.74	0.56	0.79	2.74	1.82	3.00
SD	0.5	0.4	0.5	1.8	1.2	2.0

Table 3.9. Estimated sodium adsorption ratio (SAR) at the start of the 1995/96 season (intercept) and SAR rate of change (slope) of soil water for the top (0-300 mm), middle (300-600 mm), bottom (600-900 mm) and total (0-900 mm) soil profile of the different saline irrigation water treatments over the 1995/96 to 1997/98 seasons (n=4). Salt content of the irrigation water is expressed in terms of electrical conductivity (EC_{iw}). Values per profile depth designated by the same symbol do not differ significantly (Student's t-Least Significant Difference (LSD), p = 0.05) and profile depths (intercept and slope) were tested separately. The experimental standard deviation (SD) of the intercept and slope of each profile depth is indicated at the bottom of the table (degrees of freedom = 15)

Treatment (EC_{iw}, dS m^{-1})	**Estimated SAR at start of 1995/96 season**				**Annual rate of change in SAR ($year^{-1}$)**			
	Profile depth (mm)				**Profile depth (mm)**			
	0-300	**300-600**	**600-900**	**0-900**	**0-300**	**300-600**	**600-900**	**0-900**
0	1.3 ^{d}	1.1 ^{d}	1.2 ^{d}	1.2 ^{d}	-0.04 ^{a}	-0.07 ^{a}	-0.12 ^{ab}	-0.09 ^{a}
0.7	1.8 ^{cd}	2.0 ^{cd}	1.9 ^{dc}	1.9 ^{d}	0.17 ^{a}	0.13 ^{a}	0.12 ^{ab}	0.14 ^{a}
1	2.1 ^{cd}	2.1 ^{cd}	2.1 ^{dc}	2.1 ^{dc}	0.15 ^{a}	0.32 ^{a}	0.62 ^{a}	0.46 ^{a}
2	3.2 ^{cb}	3.3 ^{cb}	3.9 ^{bc}	3.7 ^{bc}	0.19 ^{a}	0.17 ^{a}	0.04 ^{ab}	0.09 ^{a}
3	3.8 ^{b}	4.7 ^{b}	5.5 ^{ba}	5.0 ^{b}	0.14 ^{a}	-0.18 ^{a}	-0.41 ^{bc}	-0.22 ^{a}
4	6.0 ^{a}	7.0 ^{a}	7.0 ^{a}	6.7 ^{a}	-0.96 ^{b}	-1.33 ^{b}	-1.34 ^{c}	-1.22 ^{b}
LSD (5%)	1.54	1.43	2.24	1.76	0.75	0.65	1.00	0.79
SD	1.0	1.0	1.5	1.2	0.50	0.43	0.66	0.52

The combination of the low salinity water and low SAR values in the 0 dS m^{-1} and the 0.7 dS m^{-1} treatments (Table 3.1) could, according to Ayers & Westcot (1985), have had severe and slight to moderate negative effects, respectively, on the infiltration rate of water into the soil. The less conservative guidelines from Rhoades & Loveday (1990), however, excluded the 0.7 dS m^{-1} treatment from the area of likely permeability hazard (Fig. 3.1). The adjusted SAR values of the irrigation water in the 0 dS m^{-1} treatment predicted conditions favorable to dissolution of solid calcium compounds in the soil and this could further deter development of sodicity. No problems were expected in the higher salinity treatments with regard to water infiltration, because the elevated salt levels counteracted the dispersive effect of sodium (Table 3.1).

3.4.2 Soil salinity

Seasonal trends in depth-weighted EC and SAR of the saturated soil extract and soil water.

After irrigation, water is concentrated in the soil by evapotranspiration and can affect crop yield and soil permeability by means of the salinity and sodicity conditions it creates in the soil. Treatments that received irrigation water of salinity of 1 dS m^{-1} or more had at some stage during the 1995/96 and 1996/97 seasons EC_e values exceeding 1.6 dS m^{-1} (Table 3.2). According to Ayers & Westcot (1985) those levels of soil salinity affect the growth of apricot trees negatively. Although the SAR values in Table 3 were low (Ayers & Westcot, 1985) and permeability problems due to sodicity not foreseen, a problem with regard to the hydraulic conductivity of the soil was expected in the control treatment, where the electrolyte concentration was less than 0.5 dS m^{-1} (Table 3.2, Fig. 3.1). Water of salinity above 0.5 dS m^{-1} do not affect the hydraulic conductivity of soils with an ESP below 10 which is equivalent to a SAR of *c.* 8.4 (Shainberg *et al*., 1981).

The *in situ* extracted soil water gives a better indication of soluble salts than the saturated soil extract (Richards, 1954). In order to establish the threshold soil water salinity at which reduced apricot growth and production is expected if exceeded, the relationship between EC_e and EC_{sw} one day after irrigation for this soil was determined from 1995/96 data as $EC_{sw} = 2.6EC_e$ (R^2 = 0.92) and from 1996/97 data as $EC_{sw} = 2.02EC_e$ (R^2 = 0.73). The mathematical relationship for 1996/97 agreed well with the “rule of thumb” formulae recommended by Maas & Hoffman (1977) for such conversions ($EC_{sw} = 2EC_e$), although the latter applied to a 15 to 20% leaching fraction. The threshold soil water salinity was therefore estimated as 4.2 dS m^{-1} for 1995/96 and as 3.2 dS m^{-1} for 1996/97. Irrigating with water of a 1 dS m^{-1} salinity caused the soil water salinity to approach the appropriate threshold value in 1996/97 and exceed it in the period from bud break until harvest 1997 (Table 3.4). The depth-weighted seasonal EC_{sw} of the 2, 3 and 4 dS m^{-1} treatments exceeded the calculated threshold values at all depths, except for the 0 to

300 mm depth for the 2 dS m^{-1} treatment in 1994/95, from 1994/95 until the treatments were terminated.

Although the low SAR values in the 0 dS m^{-1} treatment were not problematic (Ayers & Westcot, 1985), salinity values of the soil water were too low to prevent clay dispersion and low soil permeability and concurrent drainage problems were still expected (Table 3.5, Fig. 3.1). Dispersed clay residues were observed in drainage water from some of the replicate blocks in this treatment. Salinity levels of all the other treatments (Table 3.4) were adequate to prevent hydraulic conductivity problems at the relatively low SAR levels (Table 3.5, Fig. 3.1). Soil water salinity was only monitored the day after irrigation and it is therefore uncertain what levels the SAR could attain at the high salinity treatments between irrigations due to evapotranspiration. If the SAR became too high, the soil HC could have been reduced significantly. In order to establish if this would happen, hypothetical SAR values were estimated by an equation used by Shainberg & Letey (1984). According to them, the affinity of the soil for the sodium ion increases when the salt concentration is doubled, and the SAR of the concentrated solution is to be multiplied by the factor $\sqrt{2}$ (Shainberg & Letey, 1984). The maximum estimated SAR_{sw} for the 4 dS m^{-1} treatment could therefore approach 8.5. Significant changes in soil hydraulic conductivity (>50%) only occur when the sodicity of the soil exceeds SAR values of 12 to 16 (Shainberg & Letey, 1984). The sodicity hazard was, however, decreased further during 1996/97 when excessive leaching decreased the SAR in the two highest salinity treatments significantly (Table 3.5). The SAR stayed approximately the same in the 2 dS m^{-1} treatment, but continued to increase in the 1 dS m^{-1} treatment from 1995/96 to 1996/97.

Profile distributions of seasonal average EC_{sw} and SAR_{sw}

Salinity profiles for a given soil depend on the amount of irrigation water applied and salt content of the irrigation water as well as the amount of water extracted by plant roots from various depths (Shalevet & Reiniger, 1964). The leaching fraction of 0.1 applied according to the replicate block with the highest water deficit was high enough to control the accumulation of salt in the 0.7 dS m^{-1} treatment (Fig. 3.2). The 1 dS m^{-1} treatment, however, started to accumulate salts in the bottom of the soil profile from 1994/95 and it increased steadily until the 1997/98 season. The high salinity levels in the 1 dS m^{-1} treatment were restricted to the bottom soil layer, while salinity in the top and middle soil layers did not show accumulative patterns over time. The decrease in salinity of the soil water in the 2, 3 and 4 dS m^{-1} treatments during the 1995/96 and 1996/97 seasons was due to foliar damage (data not shown). During this period trees in the 4 dS m^{-1} treatment were in an advanced state of damage and water consumption was minimal. Enhanced leaching due to foliage damage (data not shown) removed the excessive salt loads from the profiles during the 1996/97 season. The maximum

EC_{sw} was recorded in the middle of the soil profile during 1994/95 to 1995/96 seasons in the 4 dS m^{-1} treatment and in the 3 dS m^{-1} treatment during 1997/98. This region most probably coincides with the main root zone. This pattern changed in the 4 dS m^{-1} treatment during 1996/97 to an approximately uniform profile with a much lower salinity than in previous seasons.

Lime was added during fertilization to keep the pH of the soil profile above 5.5 to provide the optimum conditions for uptake of nutritional elements by apricot trees. Exchange of sodium for calcium and leaching of sodium from the soil profile could have caused the decrease in SAR in the 0 dS m^{-1} treatment (Fig. 3.3). The increase in SAR in the 1 dS m^{-1} treatment over the seasons agreed well with the increase in salinity with depth and over time. The decrease in SAR over time in the 2, 3 and 4 dS m^{-1} treatments was attributed to enhanced leaching (data not shown). The excessive accumulation of sodium had already extended to the 300-600 mm depth increment in the profile of the 4 dS m^{-1} treatment during 1995/96 (Fig. 3.3). Excessive leaching in the 3 and 4 dS m^{-1} treatments, however, caused the SAR values of the three most saline treatments, to approach each other during the 1996/97 season (Table 3.5, Fig. 3.3).

It is assumed that water with salinity levels of 1 dS m^{-1} could still be used for irrigation of apricot, provided that it is managed correctly. After four years of irrigation negative effects on trees were still absent and excessive accumulation of salts was mainly restricted to the bottom of the root zone. The excess salts could be removed at selected intervals by an increased leaching fraction or natural leaching by winter rainfall.

Seasonal and annual rate of change in EC_{sw} and SAR_{sw}.

Irrigation water with a higher salinity and sodium content initially caused a higher seasonal rate of change in salinity and sodicity in the soil water (Tables 3.6 and 3.8). Osmotic adaptation of the tree to salt stress can, however, restrict growth and reduce the transpirational surface area while toxic ions can cause foliar damage and leaf fall. These processes reduced water use over time and resulted in desalinization that caused the rate of change in salinity to become negative in the 3 and 4 dS m^{-1} treatments. The high rate of change in SAR_{sw} in the 2 dS m^{-1} treatment during 1995/96 and the 1 dS m^{-1} treatment in the season thereafter, was due to accumulation of salt, mainly at the bottom of the soil profile (Fig. 3.3).

3.5 CONCLUSIONS

The accumulation of salt in the soil profile and the soil permeability problems that were observed in the current study in general agreed with that predicted from irrigation water quality. Salts accumulated in the soil profile at treatments receiving irrigation water of 1 to 4 dS m^{-1} until the profile salinity level exceeded the salinity threshold above which potential growth and

production of apricot trees is decreased. With regard to soil permeability, observations in the current study indicated that the detrimental effects of salinity on soil properties are not restricted to low salinity and high SAR, but that clay dispersion may occur where irrigation water with a SAR of below 1 and EC of less than 0.1 dS m^{-1} is applied to soil. The sodium adsorption ratio in the soil remained relatively low (below 8) and no problems with infiltration and hydraulic conductivity were expected in any of the saline irrigation treatments. Under field conditions, however, rain water, which typically has low salinity, could cause problems with soil permeability, especially where the SAR in the soil exceeds 3. Higher salinity irrigation water treatments caused a higher rate of change in soil salinity and sodicity, but it decreased and became negative as the salts negatively affected tree evapotranspiration and leaching increased.

Excessive accumulation of salts in the 1 dS m^{-1} treatment was mainly restricted to the bottom of the root zone and no negative effects on trees were observed, even though the profile salinity eventually exceeded the salinity threshold after four years of irrigation. Irrigation water of such quality can therefore still be used, provided the excess salts are removed at selected intervals by an increased leaching fraction or natural leaching by winter rainfall.

3.6 REFERENCES

Ayers, R.S. & Westcot., D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: FAO.

De Kock, I.S., Undated. Bepaling van tekstuur van grond met behulp van ‘n hidrometer. NIVV Prosedures en Tegnieke, No. 56. Fruit and Fruit Technology Research Institute, Stellenbosch, South Africa.

De Kock, I.S., Louw,M.B.S. & Gelderblom, H.J., 1977. Bepaling van grondvogspanning met behulp van drukplaat ekstraheerders. NIVV Prosedures en Tegnieke, No. 67. Navorsingsinstituut vir Vrugte en Vrugtetegnologie, Stellenbosch, Suid-Afrika.

Department of Water Affairs and Forestry, 1993. South African Water Quality Guidelines, Vol 4: Agricultural use. Pretoria: Department of Water Affairs and Forestry.

Du Plessis, H.M. & Van Veelen, M., 1991. Water quality: salinisation and eutrophication time series and trends in South Africa. *S.Afr.J.Sci*., 87: 11-16

Du Toit, S.F., 1995. Tyd- en ruimtelike veranderinge in die grondchemiese samestelling van 'n wingerd wat met soutryke water besproei word. (*Afrikaans*). M.Sc. Tesis, Universiteit van Stellenbosch, Stellenbosch, Suid-Afrika.

Fruit and Fruit Technology Research Institute, 1983. Anorganic fertilization of deciduous fruit. *Inf. Bull*. 512. Stellenbosch: Dept. of Agriculture.

Green, G.C. (ed.), 1985. Beraamde Besproeiingsbehoeftes van gewasse in Suid-Afrika. Deel 1. Pretoria: Departement van Landbou en Watervoorsiening.

Karsten. J.H.M., Deist,J. & De Waal, H.O., 1975. A method of predicting the calibration curve for a neutron moisture meter. *Agrochemophysica* 7, 49-54.

Karsten, J.H.M. & Van der Vyver, C.J., 1979. The use of a neutron moisture meter near the soil surface. *Agrochemophysica* 11, 45-49.

Knight,F.H., 1992. Grondwaterbeweging. *Proc. of the IRRIGATION SYMPOSIUM,* Langenhoven Student Centre, Stellenbosch, South Africa. 3.1-3.9.

Kotzé, W.A.G., 2001. Voeding van bladwisselende vrugtebome, bessies, neute en ander gematigde klimaat gewasse in Suid-Afrika. LNR Infruitec-Nietvoorbij, Stellenbosch.

Le Roux, J.M., Undated. Bepaling van die katioonuitruilkapasiteit van gronde met behulp van isotopiese uitruiling. NIVV Prosedures en Tegnieke, No. 6. Navorsingsinstituut vir Vrugte en Vrugtetegnologie, Stellenbosch, Suid-Africa.

Longenecker, D.E. & Lyerly, P.J., 1964. Making soil pastes for salinity analysis: A reproducable capillary procedure. *Soil Sci.,* 97: 268-275

Maas, E.V. & Hoffman, G.J., 1977. Crop salt tolerance-current assessment. *J. Irrig. Drain Div. ASCE*, 103: 115-134.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J., Meiri, A. & Moolman, C.G., 1999. The use of saline water for irrigation of grapevines and the development of crop salt tolerance indices. WRC Report No. 303/1/98. Pretoria: Water Research Commission.

Oster, J.D., 1994. Irrigation with poor quality water. *Agric. Water Man.*, 25: 271-297.

Oster, J.D., Shainberg, I. & Wood, J.D., 1980. Flocculation value and gel structure of Na/Ca montmorillonite and illite suspension. *Soil Sci. Soc. Am. J.,* 44: 955-59.

Quirk, J.P. & Schofield, R.K., 1955. The effect of electrolyte concentration on soil permeability. *J. Soil Sci.,* 6: 163-178.

Rhoades, J.D., 1972. Quality of water for irrigation. *Soil Sci*., 113: 277-284.

Rhoades, J.D. & Loveday, J., 1990. Salinity in irrigated agriculture. *Agronomy,* 30: 1089-1142.

Richards, L.A., (ed.), 1954. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No. 60. Washington, DC: USDA.

SAS, 1999. SAS Institute Inc., SAS/STAT® User's Guide, Version 8. Cary, NC: SAS Institute Inc.

Shainberg, I. & Letey, J., 1984. Response of soils to sodic and saline conditions. *Hilgardia,* 52: 1-57.

Shainberg, I., Rhoades, J.D. & Prather, R.H., 1981. Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of a sodic soil. *Soil. Sci. Soc. Am. J.,* 45: 273-77.

Shalhevet, J. & Reiniger, P., 1964. The development of salinity profiles following irrigation of field crops with saline water. *In*: H.Frenkel and A.Meiri (eds.). Soil Salinity. New York: Van Nostrand Reinhold, p. 166-175.

Shapiro, S.S. & Wilk, M.B., 1965. An Analysis of Variance Test for Normality (complete samples). *Biometrika,* 52: 591-611.

Soil Classification Working Group, 1991. Soil classification: A taxonomic system for South Africa. Department of Agricultural Development, Pretoria.

Suarez, D.L., 1981. Relationship between pHc and SAR and an alternative method of estimating SAR of soil or drainage water. *Soil Sci. Soc. Am. J*., 45: 469-475.

Suarez, D.L., 1982. Graphical calculation of ion concentration in CaCO3 and/or gypsum solutions. *J. Environ. Qual*., 11: 302-308.

CHAPTER 4

The effect of saline irrigation water on evapotranspiration of Palsteyn apricot

4.1 INTRODUCTION

The Breede River Valley in the Western Cape, South Africa, is an important area for the growing of vines and fruit, including apricot, under irrigation. The increasing salinity in the Breede River over time gave rise to concern about sustainability of using the water for the irrigation of these high-value salt-sensitive crops (Moolman *et al*., 1999). The problem of salinisation could, in part, be caused by the fact that the Breede River not only provides irrigation water, but that it also serves as a drain for saline irrigation return-flows (Wolf-Piggott, 1995). The knowledge of the effect of salinity on tree water use could assist in improving irrigation scheduling and efficiency and could significantly reduce drainage and the associated irrigation return flow. This could reduce the rate of salinisation of the Breede River.

Evapotranspiration losses from orchards without cover crops are caused by the combination of direct evaporation from the soil surface and transpiration losses from the trees (Fereres & Goldhamer, 1990). The effect of salinity and toxicity on evapotranspiration is mainly manifested by its effect on tree growth. Growth depression is initially controlled mostly by the osmotic effects of the total salt concentration of the soil solution, but as soon as toxic levels of specific ions are accumulated by the plant, the effect becomes additive (Bernstein, 1980; Munns, 2002). Reduced plant growth impacts transpiration by reducing ground cover (Allen *et al*., 1998). Total water uptake of grapefruit was reduced as salt concentration in the soil increased. However, salt accumulation in the soil depended on the quantity and salt concentration of the irrigation water, rainfall and the amount of leaching (Bielorai, Shalevet & Levy, 1978). Salinity also reduced evapotranspiration of peaches as a result of lower stomatal conductance and reduced canopy size and density (Boland, Mitchell & Jerie, 1993).

The effect of irrigation with water with different salinity levels on salinity indexes of the soil and variations in soil water with depth and over time was discussed in Chapter 3. Salts accumulated in the soil profile of saline irrigation water treatments which received irrigation water of salinity $\geq$ 1.0 dS m^{-1} until the salinity level exceeded the threshold above which potential growth and production of apricot trees is decreased. Higher salinity irrigation water treatments caused a higher rate of change in soil salinity. More salts were removed from the soil as time progressed. It is hypothesized that leaching was caused by lower evapotranspiration due to foliar damage and reduced leaf area of trees. The sodium adsorption ratio (SAR) in the soil

remained relatively low (below 8) and no problems with infiltration and hydraulic conductivity were expected in any of the saline irrigation treatments, provided the soil water was not concentrated more than 2-fold between irrigations. The soil salinity of the lowest salinity treatment was, however, normally less than the necessary salt concentration (0.5 dS m^{-1}) needed to prevent clay dispersion at low SAR values. Dispersed clay in leached water indicated that problems with water infiltration into the soil, as well as hydraulic conductivity in the soil occurred.

The aim of this investigation was to determine the effect of irrigation with water of varying salinity on the evapotranspiration of apricot. The resulting salt leaching, which could contribute to water source salinisation was estimated from the ratio of the salt in the irrigation water to that in the drainage water, as well as according to a salt balance that considers the total amount of salt added by the irrigation water to the soil during the season, as well as the salt content of the soil at the beginning and the end of an irrigation season.

4.2 MATERIALS AND METHODS

The irrigation trial at Stellenbosch (Western Province, Republic of South Africa) started in December 1994 with 5-year-old Palsteyn apricot trees on Marianna rootstock in 24 drainage lysimeters. Two trees were planted per lysimeter (area per tree 1.38 m x 1.5 m) and border trees were established alongside the outer sides of lysimeters. Trees were pruned during winter and summer pruning was performed when necessary. Trees were hand-thinned in the spring and fruit harvested at optimum maturity. Trees were fertilized according to guidelines based on growth performance of control treatment trees, as well as leaf and soil analysis (Fruit and Fruit Technology Research Institute, 1983). Lysimeters were weeded by hand and pesticides applied as needed.

The experimental design consisted of four replicates of six treatments. Salinity treatments included a municipal water treatment which is referred to as the "0 dS m^{-1}" treatment in the text, and irrigation waters of target salinity levels of 0.7, 1, 2, 3 and 4 dS m^{-1}. Different salinity levels were achieved by mixing different volumes of a stock solution containing 1 M NaCl and 1 M $CaCl_2$ with municipal water.

4.2.1 Irrigation and soil water extraction

A full description of the irrigation system and detailed irrigation procedures for each season was included in Chapter 3. Soil water content values were measured both before and 24 hours after irrigation by means of a neutron water meter (CPN 503DR Hydroprobe® Moisture gauge, Boart Longyear Company, California, USA). A weekly irrigation interval was applied and the required

irrigation volumes per treatment were calculated relative to the "full point" determined field capacity according to the replicate plot with the highest water deficit. All four treatment replicates were irrigated from one container and irrigation volumes recorded after each irrigation event. Full chemical analysis of irrigation water was done at selected intervals and salinity monitored by measuring the electrical conductivity of the water (EC_{iw}) by means of a HI 8820 Bench Conductivity meter (Hannah, Italy). The soluble cations (Ca^{+2}, Mg^{+2}, Na^{+}) in the water were determined using an inductive coupled plasma atomic emission spectrometer (Liberty 200 ICP, Varian Australia Pty Ltd, Australia) and anions (Cl^{-} , HCO_3^{-}, CO_3^{-2}) as described by Richards (1954). The SAR was calculated as SAR = $Na^{+}/((Ca^{2+} + Mg^{2+})^{½})$ with Na^{+}, Ca^{2+} and Mg^{2+} expressed in mmol dm^{-3}. Soil water was extracted at selected dates 24 h after irrigation throughout the season at 150, 300, 600 and 900 mm depths to determine the total salinity, measured as electrical conductivity. Soil water salinity (EC_{sw}) was integrated over depth of the root zone according to Moolman *et al*. (1999) and averaged for each month.

4.2.2 Plant measurements

Transpiration rate measurements were performed fortnightly during the 1995/96 season (10 days in total) one day prior to irrigation. During the 1996/97 season measurements were performed one day after irrigation and restricted to the beginning of the season (October), before harvest (November/December) and after harvest (February). An LCA2 or LCA3 photosynthesis system (ADC, Herts, England) was used to determine the transpiration of three leaves per tree from the middle of extension shoots between 10h00 to 12h00. During 1995/96 the LCA2 was used and inlet air dried by means of silica gel. During the 1996/97 season ambient air was used by the LCA3 and the incoming humidity recorded.

Leaf water potential was determined on the same three leaves per tree as used for transpiration rate measurements with an Arimad pressure chamber following the method of Scholander *et al*. (1965). Directly afterwards the leaves were snap frozen in liquid nitrogen. Leaves were later defrosted and osmotic potential of the expressed cell sap determined with a Wescor Model 5 500 Vapour pressure osmometer (Wescor Inc., Logan, Utah, USA).

*V*egetative growth was evaluated by measuring the leaf area index by means of the LAI2000 plant canopy analyser (Li-Cor, Lincoln, Nebraska, USA) before summer pruning in 1995/96 (January), monthly during the 1996/97 season from November until April (excluding December) and during 1997/98 from October until December. Leaf area duration was calculated according to Chiariello, Mooney & Williams (1989) by means of integration of leaf area index over days of season for the 1996/97 season.

Leaves were sampled during the 1995/96 season during December, January and April, during the 1996/97 season monthly, and during 1997/98 monthly from mid-October until end of November in order to monitor chloride content and average area per leaf. Leaf areas were determined by means of the Li-Cor C3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA). Leaves were washed with a diluted detergent solution, rinsed once with tap water and three times with deionised water to remove dirt from the outside surfaces and dried to a constant dry weight in a forced-draft oven at 65°C. Leaves were milled in a stainless steel mill (Wiley) and passed through a 40-mesh screen prior to re-drying. Samples of 1 g were weighed directly after cooling and dry incinerated in a microwave oven at 480°C for 45 minutes and chloride concentrations were determined by titration (Anon, 1973).

4.2.3 Evapotranspiration

Data of the 1994/95 season were not used for evaluation of evapotranspiration due to problems with irrigation scheduling and the possibility of significant matric potential induced water stress. In order to compare the 1995/96 and 1996/97 seasons, average evapotranspiration per tree per day was derived according to the universal soil water balance equation from the weekly measured soil water content before irrigation (24 weeks measured) and irrigation data from October until March, and was used to reconstruct monthly values by multiplying by days per month.

Evapotranspiration was calculated as $ET = SWC_b - SWC_e + P + I - R - D$, in which ET, SWC_b, SWC_e, P, I, R and D respectively, represent the evapotranspiration over the period, soil water content at the beginning of the period, soil water content at the end of the period, precipitation, irrigation, runoff and drainage; all in units of mm. Irrigation volumes applied to the wetted area were expressed as mm based on the lysimeter area. Precipitation and runoff were assumed to be negligible. Drainage was considered to be instantaneous and estimated from the soil water deficit of the soil profile of the previous week to the "full point" determined field capacity and irrigation applied ($Drainage_{week\ n}$ = Soil water $deficit_{week\ n-1}$ + $Irrigation_{week\ n}$). It was assumed that no drainage occurred if the calculation resulted in negative numbers.

The evapotranspiration response of Palsteyn apricot to salinity was estimated by means of piecewise linear response functions (Maas & Hoffman, 1977; Van Genuchten, 1983) from data for October to March for the 1995/96 and 1996/97 seasons. Empirical relations based on ET are usually valid for a single crop at a specific location (Ragab, 1996). The evapotranspiration was thus expressed as a ratio of that of the control to make the data more generalized and transferable to other sites. The relative evapotranspiration (RET) response to irrigation water or soil salinity can be calculated as $RET = 100 - s(x - c_t)$ in which x is the irrigation water salinity (EC_{iw}) or depth-weighted average root-zone soil salinity (EC_e) during the period concerned, c_t =

the threshold, the maximum EC_{iw} or EC_e without evapotranspiration reduction as compared to evapotranspiration under non-saline conditions; and s = the slope, the percentage evapotranspiration decrease per unit salinity increase (Van Genuchten, 1983). The depth-weighted average root-zone soil salinity (EC_e) for the soil was estimated from the depth-weighted average root-zone soil water salinity (EC_{sw}) one day after irrigation from 1995/96 data as $EC_e = 0.3751EC_{sw}$ ($R^2 = 0.73$, $p<0.001$, $n=12$) and from 1996/97 data as $EC_e = 0.4567EC_{sw}$ ($R^2 = 0.92$, $p<0.001$, $n=12$). Parameters for the response functions were estimated by means of a non-linear least squares statistical procedure (SAS, 1999).

4.2.4 Leaching

A constant leaching fraction of 0.1 was imposed on all treatments. Leached water was collected in glass aspirators and sampled at selected dates within 24 hours after irrigation throughout the 1995 (12 weeks sampled) and 1996 (14 weeks sampled) seasons to determine the total salinity, measured as electrical conductivity. Leaching fractions (LF) were estimated as $LF = EC_{iw}/EC_{dw}$ in which EC_{iw} and EC_{dw} is electrical conductivity of the irrigation water and drainage water, respectively (Hoffman & Durnford, 1999).

The amount of salt leached for seasons 1995/96 and 1996/97 was estimated from a salt balance according to Du Toit (1995) as LS = {(A + B) – C} in which LS, A, B and C respectively, designates the amount of salt leached, the mass of salt per plot at the start of the season (*c.* 31 August), the mass of salt per plot applied through irrigation and the mass of salt per plot at the end of the season (31 March). The amount of chloride present in treatment plots at the start and end of a season was obtained from cation analysis of the saturated soil extract solution. The area used for calculation of the irrigation requirement was 3.0 x 1.38 m^2. Chemical analysis of irrigation water was used to estimate the total amount of chloride added. This was achieved by multiplying the volume weighted seasonal average of chloride in the irrigation solution by the total volume irrigated for the season. This was compared with the amount of chloride leached estimated from the salt balance.

4.2.5 Statistical analyses

Standard analyses of variance were performed on untransformed data using SAS Version 8.2 (1999). A Shapiro-Wilk test was performed to test for non-normality (Shapiro, 1965). Where there was significant evidence for non-normality due to skewness, outliers with large residuals were identified and removed until the data were normal or symmetrically distributed. Student's t-Least Significant Difference (LSD) was calculated at the 5% significance level to compare treatment means. A forward stepwise regression procedure (SAS Version 8.2, 1999) was

performed to select a model to predict transpiration rate. Partial correlation was calculated to give an indication of the relative contribution of each independent variable to the model.

4.3 RESULTS

4.3.1 Irrigation water quality

Seasonal mean electrical conductivity indicated that target salinities of the different treatments were successfully induced for each of the three seasons concerned (Table 4.1). The calcium, sodium, and chloride concentrations as well as SAR increased with increasing salinity. Chloride levels in the water supply were excessively high in all the treatments during the 1996/97 season.

4.3.2 Plant response

Linear regression analysis revealed significant relationships between transpiration rate one day before irrigation and irrigation water salinity at the beginning of the season, before harvest and after harvest of the 1995/96 season. Transpiration rate decreased as irrigation water salinity increased and the slope of the relationships decreased, becoming more negative as the season progressed (Fig 4.1A). Transpiration rate was restricted to a narrow range for the 1996/97 season and data points were limited. A significant relationship between transpiration rate one day after irrigation and irrigation water salinity was found only after harvest (Fig. 4.1B).

The transpiration rate of Palsteyn apricot leaves measured one day before irrigation during the 1995/96 season was much higher compared to that measured one day after irrigation during the 1996/97 season in all treatments (Fig. 4.1A & B). The highest transpiration rate was found in the 0.7 dS m^{-1} treatment during the 1995/96 season. Analysis of variance indicated that the transpiration rate one day before irrigation during 1995/96 was significantly lower in both the 3 and 4 dS m^{-1} treatments at the beginning of the season compared to that in the 0.7 dS m^{-1} treatment with a least significant difference (LSD) of 1.67 mmol m^{-2} s^{-1}. Before harvest the transpiration rate in the 3 dS m^{-1} treatment was significantly lower compared to that in the 0.7 dS m^{-1} treatment while that in the 4 dS m^{-1} treatment was significantly lower compared to that of the 0, 0.7 and 1 dS m^{-1} treatments (LSD = 2.34). After harvest the 4 dSm^{-1} treatment was significantly lower compared to all other treatments (LSD = 2.10). During 1996/97, the transpiration rate one day after irrigation was only significantly lower in the 3 dS m^{-1} treatment compared to that of the control and 1 dS m^{-1} treatment before harvest (LSD = 1.14).

Table 4.1. Seasonal mean (± standard deviation) electrical conductivity (EC_{iw}), calcium, sodium and chloride content and sodium adsorption ratio (SAR) of saline irrigation water treatments for the period August until March of the 1995/96, 1996/97 and 1997/98 seasons. Irrigation of all treatments was terminated December 1997. The EC_{iw} values for 1995/96 and 1996/97 are means of EC_{iw} of 28, and for 1997/98, of 13 irrigation events. The chemical composition values are means of at least 15, 21 and 4 analyses for the three respective seasons

Season	Target EC	EC_{iw}	Ca^{2+}	Na^{+}	Cl^{-}	SAR
	(dS m^{-1})		(mmol dm^{-3})			
1995/96	0	0.07±0.05	0.06±0.03	0.29±0.08	1.33±1.00	0.95±0.12
	0.7	0.60±0.08	1.39±0.22	1.79±0.22	5.96±1.27	1.49±0.11
	1	0.85±0.12	2.07±0.42	2.53±0.38	7.82±1.71	1.73±0.14
	2	1.81±0.24	4.69±0.89	5.50±0.82	16.39±3.72	2.51±0.21
	3	3.00±0.57	7.60±1.56	8.81±1.39	25.64±5.51	3.14±0.28
	4	3.88±0.54	10.28±2.17	11.96±1.98	35.24±8.86	3.68±0.33
1996/97	0	0.05±0.01	0.13±0.34	0.33±0.27	7.59±1.11	1.00±0.19
	0.7	0.69±0.03	1.86±0.28	2.04±0.23	11.60±0.97	1.50±0.17
	1	1.02±0.09	2.86±0.55	2.88±0.26	17.96±1.76	1.71±0.18
	2	2.00±0.18	6.14±1.00	5.95±0.58	28.43±1.73	2.40±0.20
	3	2.99±0.23	9.46±1.84	8.86±0.97	39.44±1.79	2.90±0.24
	4.0	4.07±0.03	13.09±2.46	11.46±2.43	54.72±1.77	3.26±0.43
1997/98	0	0.07±0.01	0.14±0.03	0.25±0.03	3.16±1.55	0.61±0.02
	0.7	0.71±0.04	1.93±0.09	2.20±0.15	9.02±1.54	1.57±0.12
	1	1.00±0.03	2.93±0.04	3.16±0.18	12.23±1.75	1.83±0.09
	2	2.00±0.06	6.49±0.18	6.56±0.16	23.09±0.77	2.56±0.09
	3	3.00±0.07	10.36±0.18	9.66±0.12	32.59±2.24	2.99±0.04
	4[1]	-	-	-	-	-

[1] Irrigation terminated end of season 1996/97.

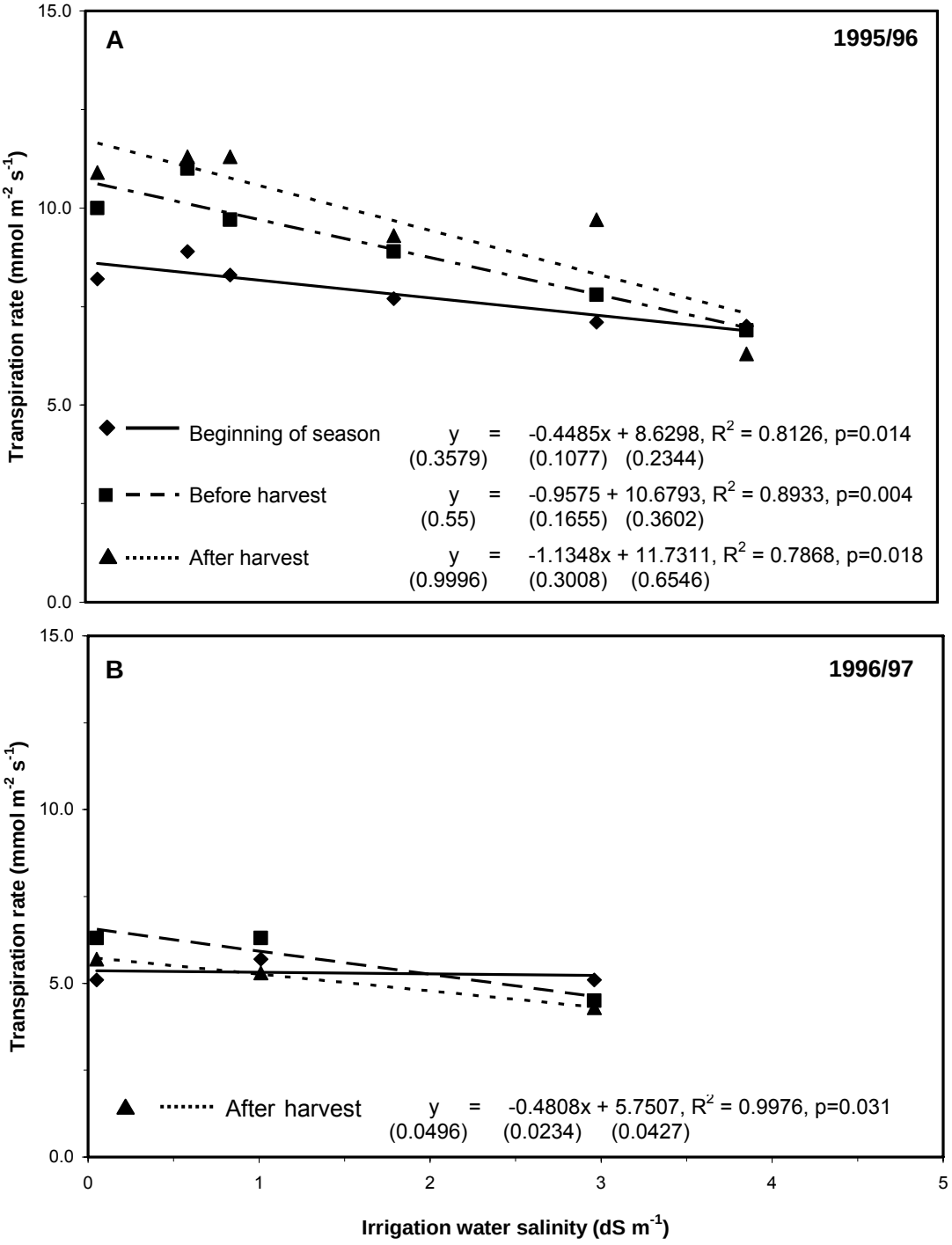


Figure 4.1. The effect of irrigation water salinity on the transpiration rate of Palsteyn apricot leaves at the beginning, before and after harvest of the 1995/96 (n=6) and 1996/97 (n=3) seasons. Measurements during 1995/96 were performed one day before irrigation and during 1996/97 one day after irrigation. Mathematical functions are displayed on graphs only for linear regression relationships that are statistically significant at a 95% confidence level and the standard errors of the estimate and coefficients are indicated below each equation in brackets. Data are the means of 4 replicate blocks, where replicate block values are the means of 3 leaves from 1 tree for 1995/96 and of 3 leaves from 2 trees each for 1996/97.

The transpiration rate of Palsteyn apricot leaves decreased with decreasing pre-dawn leaf water potential during the 1995/96 season (Fig. 4.2A). The linear regression relationship between transpiration rate and pre-dawn leaf water potential measured one day before irrigation was significant for the beginning of the season ($p = 0.047$), before harvest ($p = 0.028$) and after harvest ($p < 0.006$) during the 1995/96 season with the best coefficient of determination found after harvest (Fig. 4.2A). The intercept and slope of the statistical function at the beginning of the season was respectively significantly lower and higher (less negative) compared to that before and after harvest with no significant differences between that for the latter two periods. During 1996/97 data points were limited and the transpiration rate was restricted to a narrow range. A significant relationship between transpiration rate and pre-dawn leaf water potential measured one day after irrigation was found only before harvest during this season (Fig. 4.2B).

Linear regression relationships of transpiration rate of Palsteyn apricot leaves with pre-dawn leaf osmotic potential during the 1995/96 season indicated that transpiration rate decreased with decreasing pre-dawn leaf osmotic potential at the beginning of the season ($p = 0.006$), before harvest ($p = 0.096$) and after harvest ($p < 0.001$) (Fig. 4.2C). No significant differences were found between intercepts and slopes of these lines. No significant relationships were found between transpiration rate and pre-dawn leaf osmotic potential during the 1996/97 season at a 95% statistical confidence level (Fig. 4.2D). The relationship between transpiration rate and pre-dawn leaf osmotic potential before harvest for both seasons were, however, significant at a 90% statistical confidence level (Fig. 4.2C & D).

Pre-dawn leaf water and leaf osmotic potential are correlated and a forward stepwise selection linear regression procedure (SAS, 1999) was used to determine the relative contributions of leaf water and leaf osmotic potential to the variation in transpiration rate at the beginning of the season, before harvest and after harvest of the 1995/96 season. Only variables significant at the 0.15 level were entered in the model. Pre-dawn leaf osmotic potential correlated the best with transpiration rate of the two X-variables considered at the beginning of the season and after harvest, while both pre-dawn leaf water and osmotic potential were significantly related to transpiration rate before harvest, with leaf water potential being the most important variable (Table 4.2).

A strong non-linear regression relationship was found between irrigation water salinity and leaf chloride content of Palsteyn apricot trees by the end (April) of both the 1995/96 and 1996/97 seasons (Fig. 4.3). The leaf chloride content increased exponentially as the irrigation water salinity increased. Leaf area duration and area per leaf, respectively, decreased linearly with increasing soil water salinity during the 1996/97 season (Fig. 4.4 & 4.5).

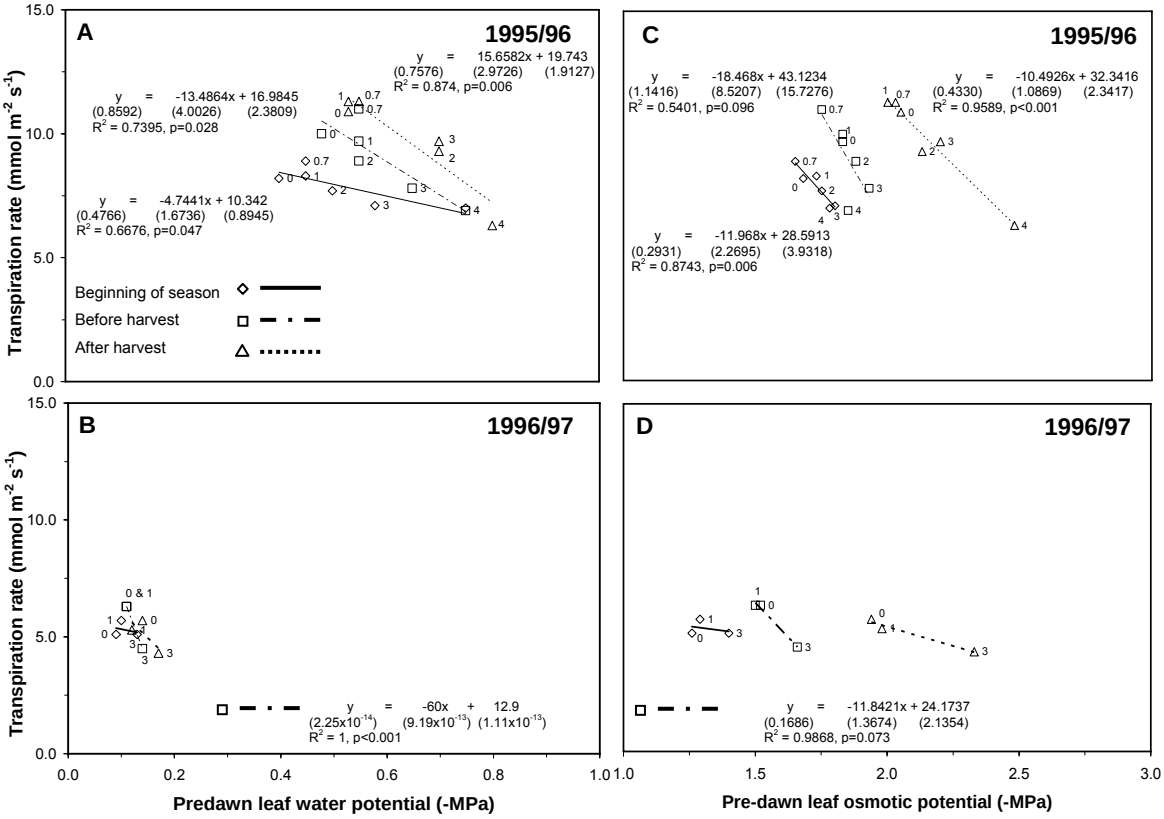


Figure 4.2. The relationship between transpiration rate and pre-dawn leaf water potential (A,B) as well as transpiration rate and pre-dawn leaf osmotic potential (C,D) of Palsteyn apricot leaves at the beginning of the season, before harvest and after harvest one day before irrigation during the 1995/96 (A, C; n=6), and one day after irrigation during the 1996/97 (B, D; n=3) season. Data are the means of 4 replicate blocks, where replicate block values are the means of 3 leaves from 1 tree for 1995/96 and of 3 leaves from 2 trees each for 1996/97. Data labels indicate treatment irrigation water salinity (dS m^{-1}). Mathematical functions are displayed on graphs only for linear regression relationships that are statistically significant at a 90% confidence level and the standard errors of the estimate and coefficients are indicated below each equation in brackets.

Table 4.2. A summary of the correlation and partial correlation of pre-dawn leaf water potential (LWP_{pd}) and leaf osmotic potential (LOP_{pd}) with transpiration rate of leaves as determined by a forward stepwise selection linear regression procedure (n=6). Leaf water relations and gas exchange were measured one day before irrigation at the beginning of the season, before harvest and after harvest during the 1995/96 season for treatments receiving municipal water or water with target salinity of 0.7, 1, 2, 3 and 4 dS m^{-1}. Data are means of 4 replicate blocks in which the relevant variables were measured on 3 leaves per tree

Summary of forward stepwise selection results					
Period of measurement	**X-Variable**	**Number of model variables**	**Partial R^2**	**Model R^2**	**Pr>F**
	Transpiration rate				
Beginning of season	LOP_{pd}	1	0.8743	0.8743	0.0062
Before harvest	LWP_{pd}	1	0.7395	0.7395	0.0281
	LOP_{pd}	2	0.2033	0.9428	0.0469
After harvest	LOP_{pd}	1	0.9588	0.9588	0.0006

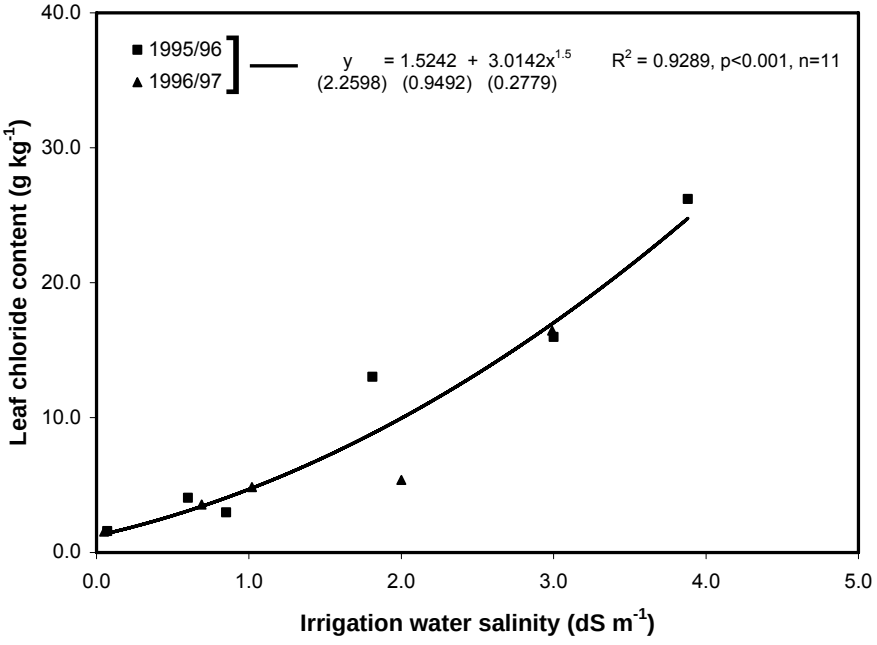


Figure 4.3. The relationship between seasonal mean irrigation water salinity and leaf chloride content of Palsteyn apricot on Marianna rootstock in April during the 1995/96 (n=6) and 1996/97 (n=5) seasons. Data are the means of 4 replicate blocks (10 leaves sampled from the middle of one year old extension shoots per block). The standard errors of the estimate and coefficients of the mathematical function are displayed below the equation in brackets.

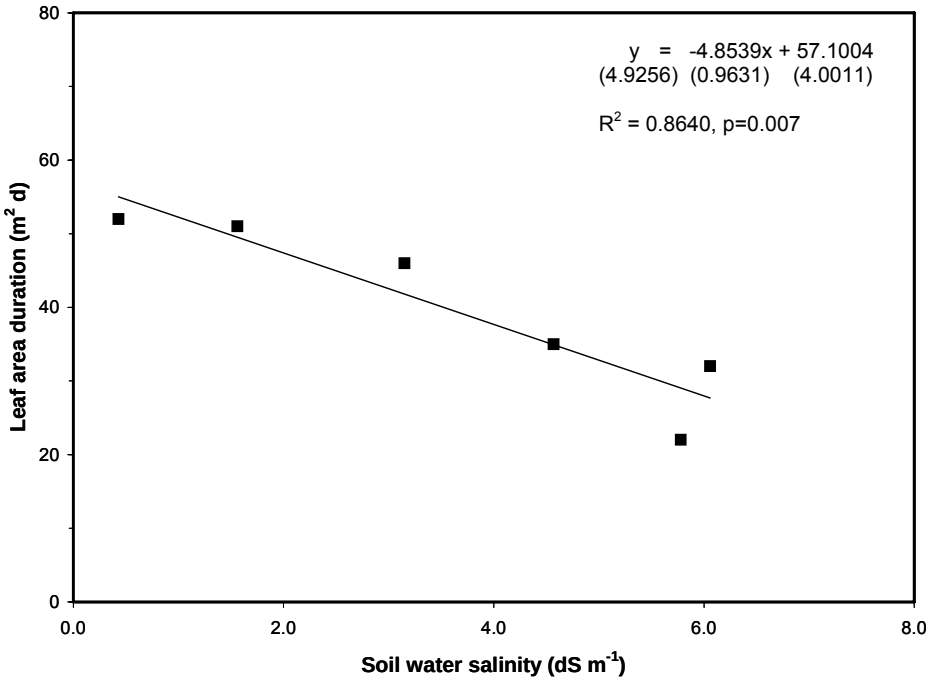


Figure 4.4. The effect of depth-weighted seasonal mean soil water salinity (0-900 mm) on leaf area duration of Palsteyn apricot trees on Marianna rootstock during the 1996/97 season (n=6). Data are the means of 4 block replicates and leaf area duration was determined for 2 trees per block. The standard errors of the estimate and coefficients of the mathematical function are displayed below the equation in brackets.

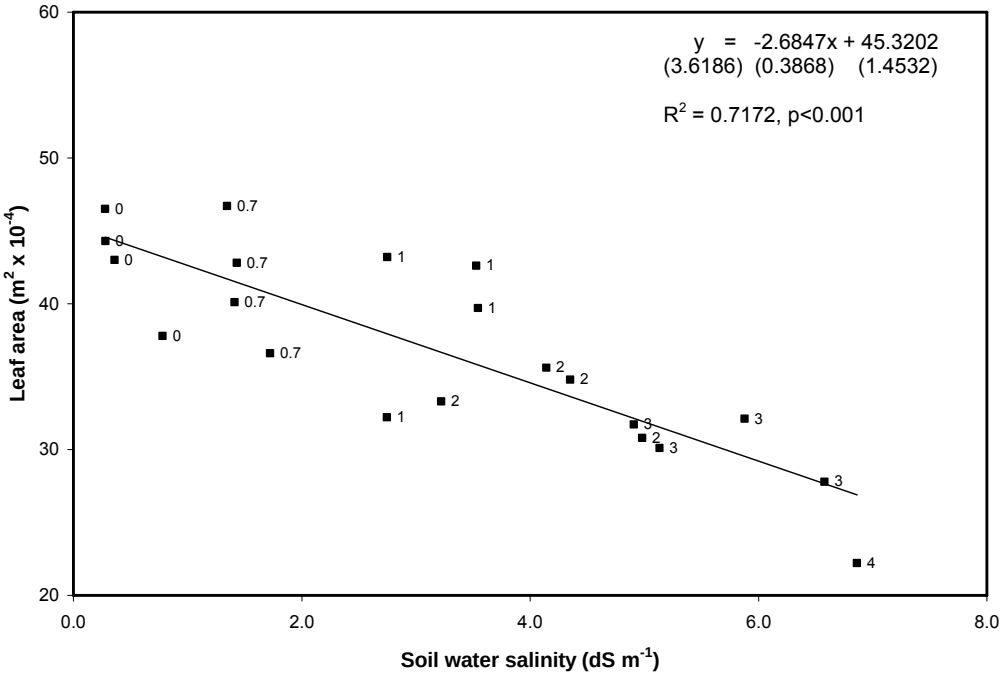


Figure 4.5. The effect of depth-weighted seasonal mean soil water salinity (0-900 mm) on area per leaf of Palsteyn apricot sampled for selected periods during the 1996/97 season. The standard errors of the estimate and coefficients of the mathematical function are displayed below the equation in brackets. Data are the means of 4 replicate blocks (10 leaves sampled from the middle of one year old extension shoots per block). Data labels indicate treatment irrigation water salinity (dS m^{-1}).

4.3.3 Irrigation quantities and evapotranspiration

Volumes of irrigation water applied tended to decrease as salinity increased (Table 4.3). The lower volume of irrigation water applied in the 0.7 dS m^{-1} in comparison with the 1 dS m^{-1} treatment during 1994/95 was due to lower evapotranspiration of one tree that was affected by bacterial canker (*Pseudomonas syringae*). This tree and drippers were removed from the experimental plot at the end of the 1994/95 season and irrigation volumes adjusted. Irrigation amounts tended to increase from 1994/95 to 1996/97 for the 0, 0.7 and 1 dS m^{-1} treatments. In contrast, the irrigation amounts used for the 2 and 3 dS m^{-1} salinity treatments increased from season 1994/95 to 1995/96, but declined from 1996/97. However, if volumes are compared relative to the 0 dS m^{-1} treatment, both treatments already used less irrigation water in 1995/96. The negative effect of salinity on the gross irrigation amount applied was already apparent for the 4 dS m^{-1} treatment in 1994/95 and decreased to 34% of that of the control treatment in 1996/97, after which this treatment was terminated.

Evapotranspiration during the 1995/96 and 1996/97 seasons in general increased from October to January after which it decreased until March (Fig. 4.6A & B). Evapotranspiration was significantly higher during 1995/96 compared to that during 1996/97, except for February during which it was similar (data not shown). Evapotranspiration in the 0 dS m^{-1} treatment was unexpectedly lower than that in the 0.7 and 1 dS m^{-1} treatments during both seasons (Fig. 4.6A & B). Evapotranspiration was the highest in the 0.7 and 1 dS m^{-1} treatments, while evapotranspiration decreased in the higher salinity treatments. The exception was evapotranspiration for February and March of 1995/96, which was similar for all treatments except for the 4 dS m^{-1} treatment. The declining trend in evapotranspiration at high salinity seemed to be enhanced during the 1996/97 season. Evapotranspiration was only significantly reduced in the 4 dS m^{-1} treatment during the 1995/96 season while evapotranspiration in the 3 and 4 dS m^{-1} salinity treatments was significantly lower relative to the 0, 0.7 and 1 dS m^{-1} treatments in the 1996/97 season.

In order to facilitate comparison of the regression relationships of evapotranspiration with other variables between both the 1995/96 and 1996/97 seasons independent of the seasonal evapotranspirational demand differences, evapotranspiration of all treatments was expressed relative to the evapotranspiration of the 0 dS m^{-1} treatment. Linear regression relationships between leaf area index and evapotranspiration between four to six weeks after harvest indicated that relative evapotranspiration decreased with decreasing leaf area index during both the 1995/96 (R^2 = 0.82, p = 0.013, n=6) and 1996/97 (R^2 = 0.86, p = 0.007, n=6) seasons as the target irrigation water salinity increased within a season (data not shown). The linear regression relationships for separate seasons did not differ

Table 4.3. Gross irrigation volumes and relative volume (expressed as percentage of the volume applied in the 0 dS m^{-1} treatment) of irrigation water applied per treatment for the period August until March for the 1994/95, 1995/96, 1996/97 and 1997/98 seasons. Irrigation of all treatments was terminated December 1997

Season	**Saline irrigation treatment (dS m^{-1})**					
	0	0.7	1	2	3	4[1]
	Gross irrigation volume applied (m^3)					
1994/95	25.1	24.0	25.4	24.4	21.8	17.6
1995/96	36.5	31.0	32.8	28.3	26.9	15.3
1996/97	37.3	35.3	33.9	27.2	22.1	12.7
1997/98	17.3	16.0	15.7	10.4	6.8	[1]-
Season	**Percentage of irrigation water applied**					
1994/95	100	96	101	97	87	70
1995/96	100	85	90	78	74	42
1996/97	100	95	91	73	59	34
1997/98	100	92	91	60	39	[1]-

[1] Irrigation terminated end of 1996/97season.

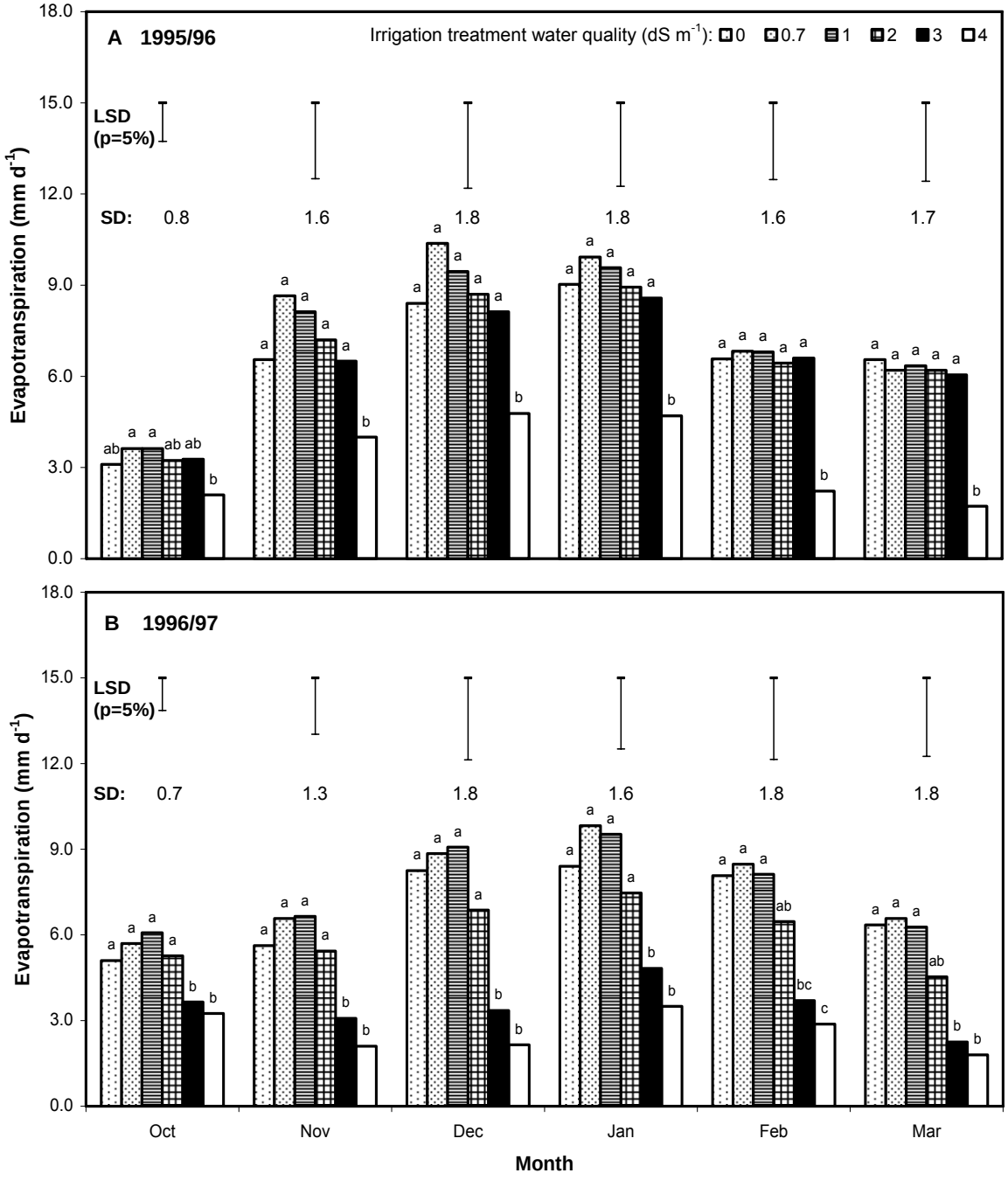


Figure 4.6. Evapotranspiration of the different salinity treatments for October to March during the 1995/96 and 1996/97 seasons, calculated from a soil water balance during drying cycles of the total soil area allotted per tree (1.38 m x 1.5 m). Columns within the same month capped by the same letter do not differ significantly according to Student's t-LSD calculated at a 5% significance level (the harmonic mean for replicates was 3.79) and the experimental standard deviation (SD) of each month within each season is indicated on the graphs (degrees of freedom = 14).

significantly and data for both seasons were combined in a single linear regression relationship (R^2 = 0.83, $p < 0.001$; n=12, data not shown).

Cumulative evapotranspiration for October to March of the 1995/96 and 1996/97 seasons was only significantly reduced in the 4 dS m^{-1} treatment during the 1995/96 season while evapotranspiration in the 3 and 4 dS m^{-1} salinity treatments was significantly lower relative to the 0, 0.7 and 1 dS m^{-1} treatments in the 1996/97 season (Fig. 4.7A & B). The estimation of a reliable threshold and slope for the response function of cumulative evapotranspiration with soil salinity for 1995/96 by means of the non-linear least squares statistical procedure was deterred by the distribution of evapotranspiration values, as five of the six values were of the same magnitude and only that of the 4 dS m^{-1} was significantly lower (Fig. 4.7A). The linear regression between cumulative evapotranspiration of the 1996/97 season and the mean soil salinity of the 1996/97 season rendered a lower coefficient of determination (R^2 = 0.40, p = 0.001, n = 23) than the linear regression between cumulative evapotranspiration of the 1996/97 season and the mean soil salinity of the 1995/96 and 1996/97 seasons (R^2 = 0.56, $p < 0.001$, n = 23). The response function of evapotranspiration of 1996/97 with the mean soil salinity during 1995/96 and 1996/97 resulted in a salinity threshold value of 1.72 and a slope of *c*. 54% evapotranspiration decrease per unit salinity increase (Fig. 4.8).

4.3.4 Leaching

The electrical conductivity of the drainage water (EC_{dw}) increased asymptotically as the irrigation water salinity (EC_{iw}) increased for the 1995/96 and 1996/97 seasons (Fig. 4.9). The salt content of the drainage water during 1995/96 was significantly higher than that for 1996/97 and the EC_{dw} increased at a higher rate as irrigation water salinity increased during 1995/96 compared to that for 1996/97. The mean leaching fraction for 1995/96 was 0.27, which was significantly lower than the leaching fraction of 0.35 for the 1996/97 season. The leaching fraction for all saline irrigation water treatments exceeded the intended leaching fraction of 0.1 and increased as irrigation water salinity increased during both seasons (Fig. 4.10).

The amount of chloride leached as estimated by means of a salt balance also increased as irrigation water salinity increased and compared well with the amount of chloride added by irrigation (Fig. 4.11). The mathematical relationships between chloride leached and the amount of chloride added by irrigation for the 1995/96 and 1996/97 seasons were similar, but the slopes differed significantly. The amount of salt lost more or less equaled the amount of salt added to the soil profile during the season for both 1995/96 and 1996/97, with the rate of salt loss significantly higher for 1995/96 compared to that for 1996/97.

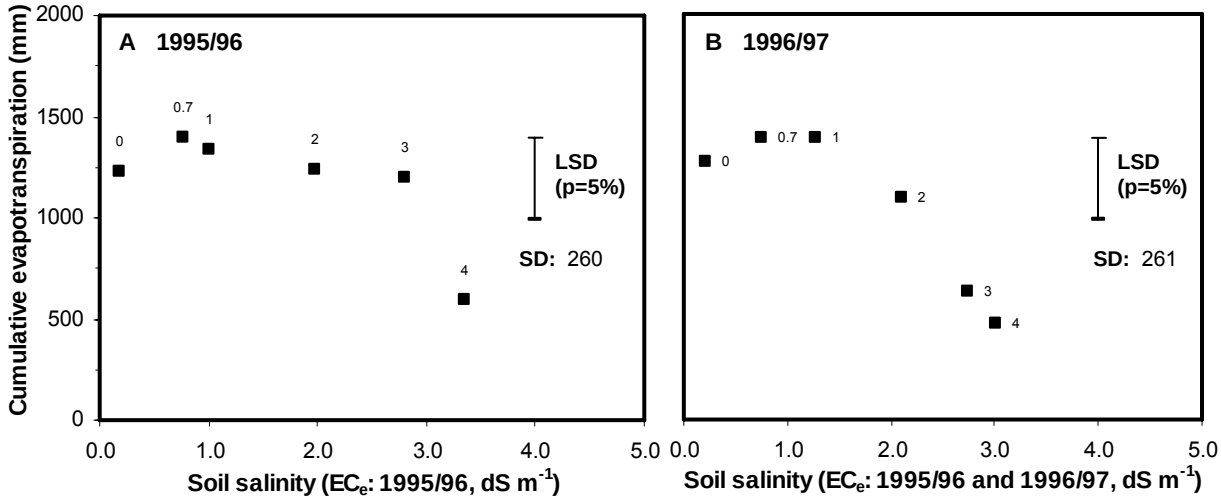


Figure 4.7. The effect of depth-weighted seasonal mean soil salinity (EC_e) of different saline irrigation treatments on cumulative evapotranspiration of Palsteyn apricot trees from October to March during the 1995/96 (A) and 1996/97 (B) seasons. Data labels indicate treatment irrigation water salinity (dS m^{-1}). Data are the means of replicate blocks (harmonic mean of replicate blocks = 3.79). Significant differences for cumulative evapotranspiration of different seasons were tested separately and the Stutent's t-LSD (Least Significant Difference, p=0.05) and experimental standard deviation (SD) of each season is indicated on the graphs (degrees of freedom = 14).

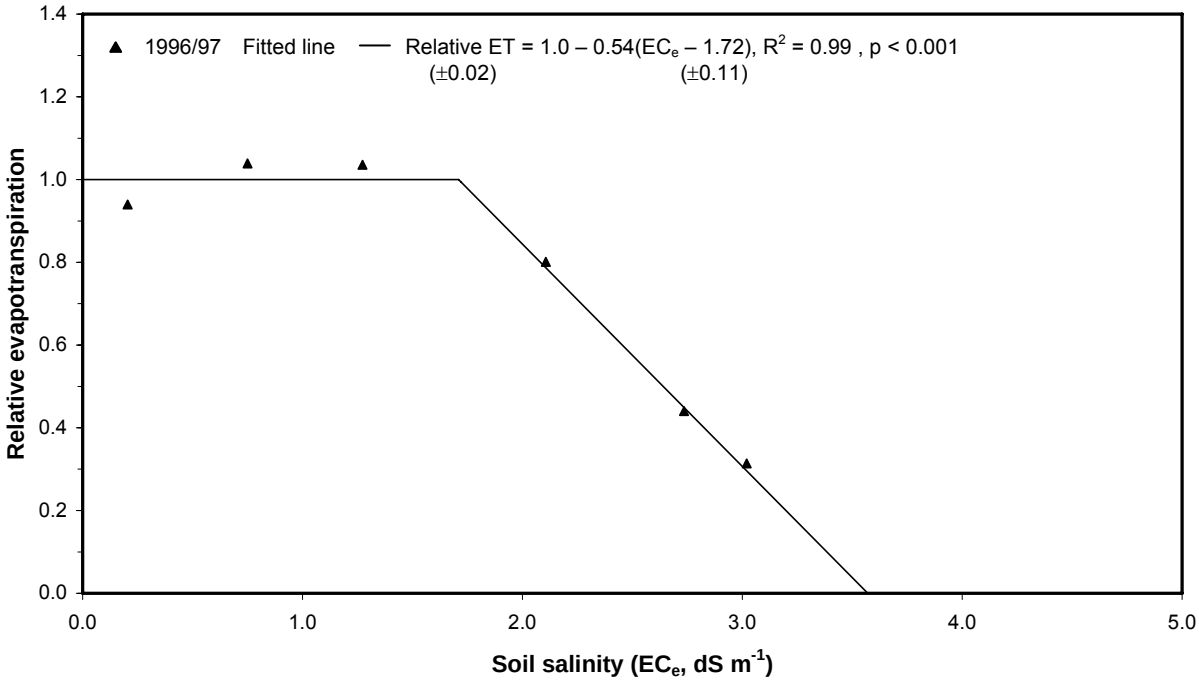


Figure 4.8. The effect of mean depth-weighted seasonal soil salinity at field capacity (EC_e) for the 1995/96 and 1996/97 seasons on relative evapotranspiration of Palsteyn apricot for October to March of the 1996/97 season (harmonic mean of treatment replicates = 3.79). Cumulative evapotranspiration of all treatments were expressed relative to that of trees in the lowest soil water salinity (the 0 dS m^{-1} irrigation water treatment). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets and equals zero if not indicated.

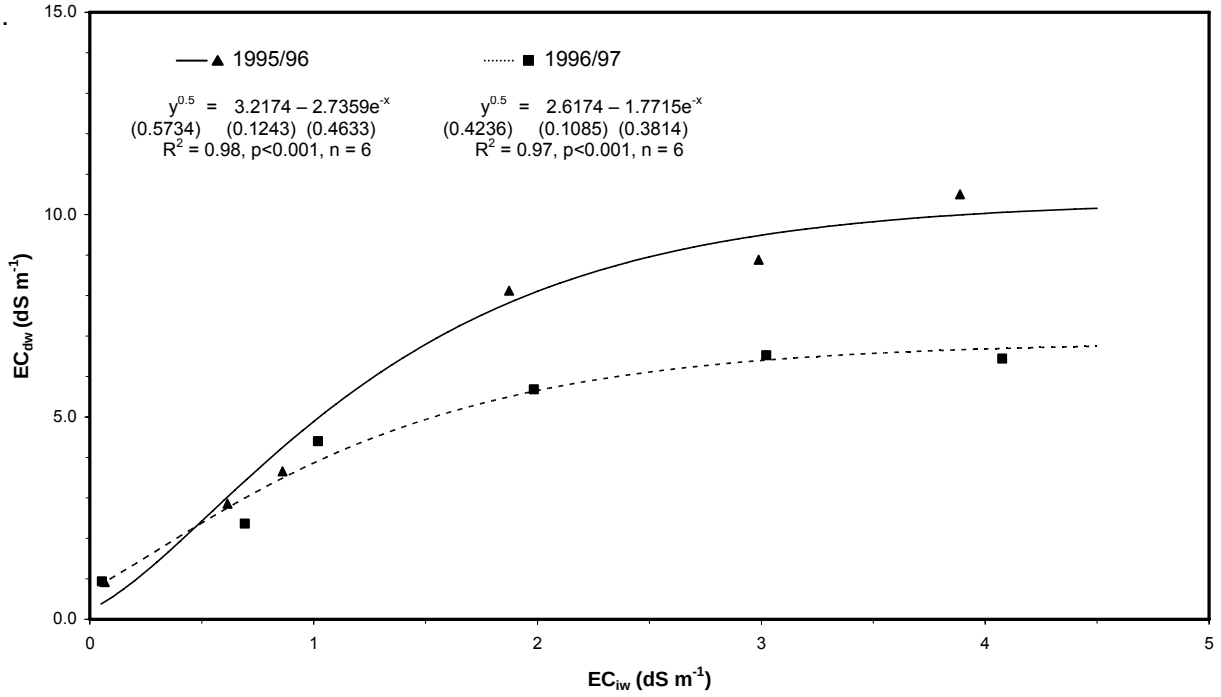


Figure 4.9. The effect of irrigation water salinity (EC_{iw}) on drainage water quality (EC_{dw}) during the 1995/96 and 1996/97 seasons. The salt content of the irrigation and drainage water is indicated in terms of electrical conductivity (EC). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets. Data are the means of replicate blocks (harmonic mean = 3.43).

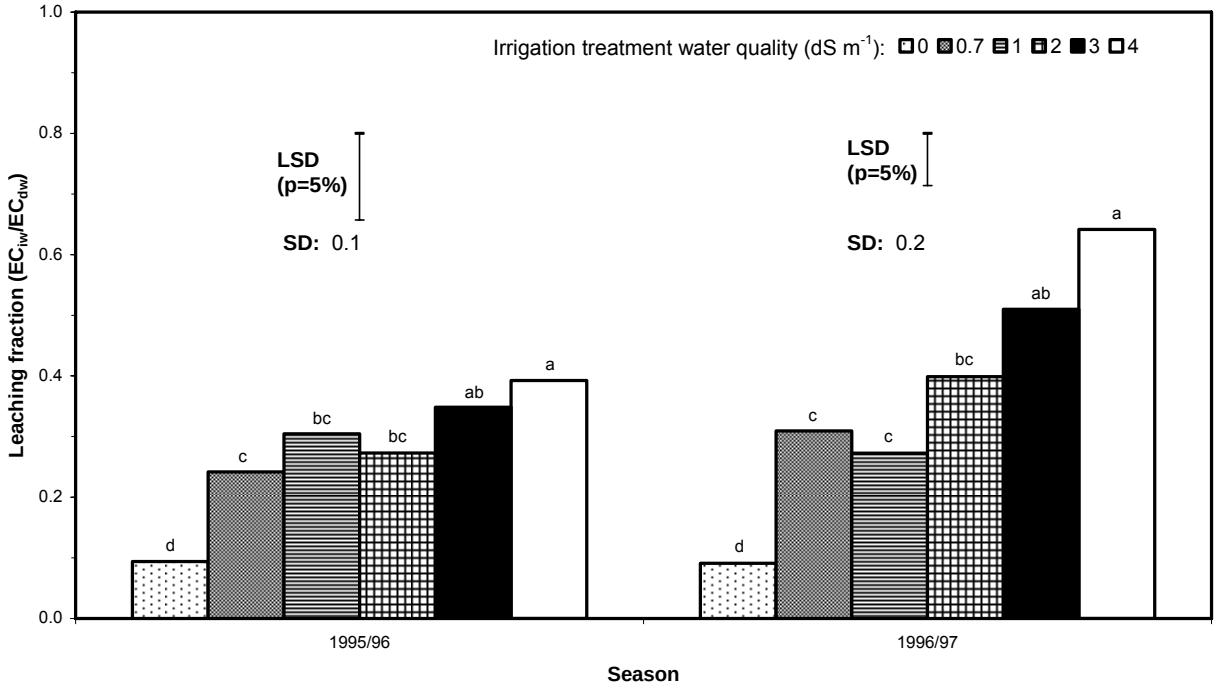


Figure 4.10. The effect of saline irrigation water treatments on the leaching fraction for the 1995/96 and 1996/97 seasons. The leaching fraction was estimated as the ratio of the electrical conductivity of the irrigation water (EC_{iw}) to the electrical conductivity of the drainage water (EC_{dw}). Columns within the same season capped by the same letter do not differ significantly according to Student's t-Least Significant Difference (LSD) calculated at a 5% significance level (the harmonic mean for replicates was 3.43) and the experimental standard deviation (SD) of each season is indicated on the graphs (degrees of freedom = 13).

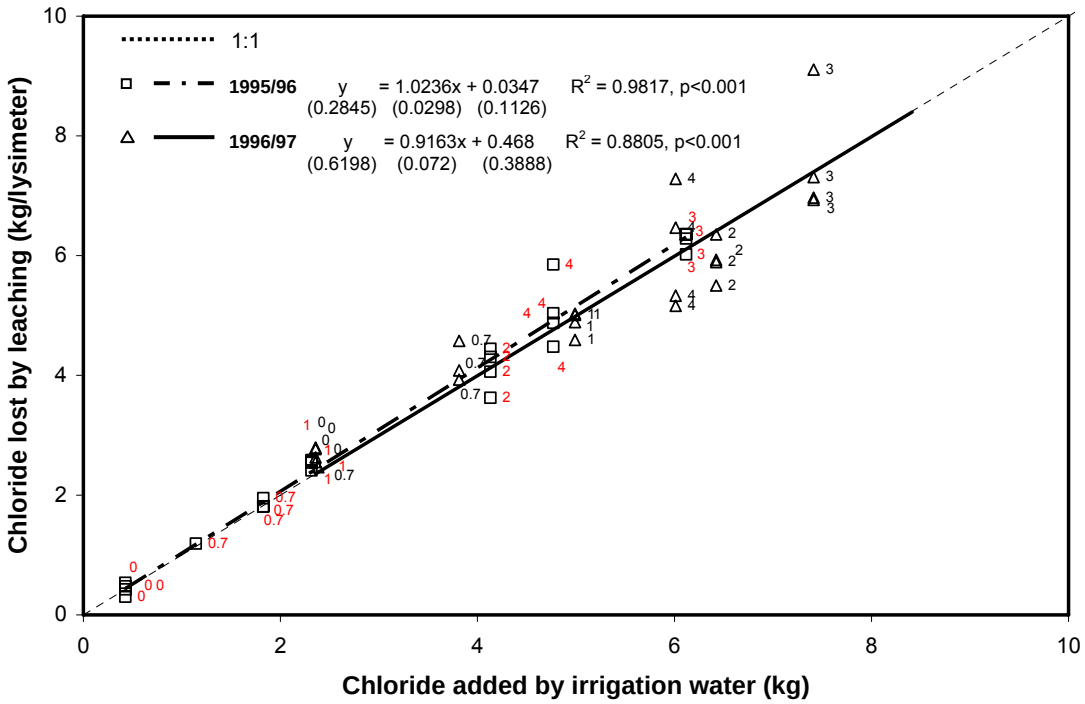


Figure 4.11. Comparison of the amount of chloride added by irrigation water and leached from the soil profile (0-900 mm) per lysimeter (3 m x 1.38 m) from August to March during the 1995/96 and 1996/97 seasons (n=24). Data labels indicate the treatment irrigation water salinity (dS m^{-1}) and data are replicate block values. The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.

4.4 DISCUSSION

Transpiration and by implication also evapotranspiration, is determined by evaporative demand, by factors that influence water supply and by plant factors such as leaf area, leaf structure and exposure, stomatal behaviour and the effectiveness of water absorption by the root system (Kramer, 1983). It follows that irrigation water quality, through its indirect effect on the abovementioned soil- and plant-related factors, is an important factor determining evapotranspiration.

4.4.1 Irrigation water quality.

Important criteria of irrigation water quality are salinity, specific ion concentrations and sodicity (Shainberg & Letey, 1984). Salinity refers to total salt concentration and is most commonly measured and reported as electrical conductivity (EC). It was previously found (Chapter 3) that the use of irrigation water with salinity levels equal to and exceeding 1 dS m^{-1} with a leaching fraction of 0.1 applied, caused soil salinity levels that could affect apricot growth negatively. Although salt toxicity does not affect the physical properties of the soil (Shainberg & Letey, 1984), it can affect tree evapotranspiration and resultant leaching. Sodium concentrations in irrigation water (Table 4.1) from high salinity treatments (≥ 2 dS m^{-1}) could pose moderate to severe toxicity problems for apricot trees (Ayers & Westcot, 1985). Woody crops are especially sensitive to sodium toxicity and concentrations as low as 5 mmol dm^{-3} in the soil water can cause toxicity injury of stone fruit trees (Rhoades & Loveday, 1990). Palsteyn apricot on Marianna rootstock, however, restricted accumulation of sodium in leaves by retention in woody tree parts (Chapter 5) and sodium is therefore not considered to have contributed to foliar damage that could reduce transpiration. Sodium could, however, indirectly have reduced growth by utilization of metabolites to provide energy for sodium exclusion or recycling processes in the plant (Jacoby, 1994).

Irrigation water containing chloride concentrations of <4 mmol dm^{-3}; 4 to 10 mmol dm^{-3} and >10 mmol dm^{-3} are designated as “no restriction on use”, “slight to moderate restriction on use” and “severe restriction on use” respectively (Ayers & Westcot, 1985). High chloride levels in the irrigation water indicated a slight to moderate restriction on use of water, even in the 0 dS m^{-1} treatment during the 1996/97 season (Table 4.1). Chloride levels in the municipal water probably contributed to the excessively high chloride levels in all the treatments during the 1996/97 season. Fortunately some rootstocks restrict chloride accumulation. The maximum chloride permissible in irrigation water to prevent leaf injury for Marianna rootstock was estimated as 12 mmol dm^{-3}. This value was recalculated from data adapted from Maas (1984) by Ayers & Westcot (1985) using the intended leaching fraction of 0.1 and assuming $Cl_e = 2.1 \times Cl_{iw}$. The symbols Cl_e and Cl_{iw} refer to the chloride concentration in the saturated soil water

extract and irrigation water respectively. These values represent the maximum concentrations in the irrigation water, while Table 4.1 displays averages. Based on the seasonal averages for chloride concentration, one would expect toxicity problems with irrigation water with electrical conductivity greater than 1 dS m^{-1}.

Problems with water infiltration into the soil as well as hydraulic conductivity in the soil were noticed in the 0 dS m^{-1} treatment. This could cause either temporary water deficit or temporary waterlogged conditions. In both cases transpiration, and therefore also evapotranspiration, would be reduced.

4.4.2 Plant physiological and vegetative growth response

Transpirational losses from trees are largely determined by the leaf transpiration rate and the effective transpiring leaf area. According to the irrigation water quality assesment discussed in the section above, it was expected that irrigation treatments with salinity equal to or in excess of 1 dS m^{-1} would affect water relations of trees such that growth and also stomatal conductance, are reduced. Leaf transpiration rate measured one day before irrigation did decrease linearly as irrigation water salinity increased during the 1995/96 season (Fig. 4.1A) and after harvest during the 1996/97 season (Fig. 4.1B). The transpiration rate was, however, according to analysis of variance only significantly reduced by irrigation water salinity in the 3 and 4 dS m^{-1} treatments during the 1995/96 season and in the 3 dS m^{-1} treatment during the 1996/97 season. The transpiration response was thus not as sensitive to salinity as expected, seeing that the transpiration rates of the 1 and 2 dS m^{-1} treatments was not significantly affected by salinity. Although transpiration rates in the 0 dS m^{-1} treatment appeared to be repressed compared to that in the 0.7 dS m^{-1} treatment and at times the 1 dS m^{-1} treatment during the 1995/96 and 1996/97 seasons (Fig. 4.1A & B), no significant differences in gas exchange or leaf water relations were found between these treatments (data not shown). Problems with water infiltration into the soil as well as hydraulic conductivity in the soil in the 0 dS m^{-1} treatment therefore had no significant effect on the transpiration rate of Palsteyn apricot trees.

The transpiration rate during the 1996/97 season was considerably lower compared to that for the 1995/96 season (Fig. 4.1A & B). The differences in transpiration rates between the two seasons could partially be due to the use of dry and ambient inlet air respectively for gas exchange measurements during the 1995/96 and 1996/97 seasons. The maximum temperature on the days that gas exchange was measured at the beginning or before and after harvest during the 1995/96 season was furthermore respectively 2.7°C and 6.1°C warmer than during the 1996/97 season and could have enhanced the transpiration rate during the 1995/96 season. According to Schulze *et al*. (1974, 1975), stomatal response in apricot are mainly controlled by air humidity and temperature and can overrule or modify plant internal stomatal

control mechanisms. Meteorological data obtained for the experimental plot from the Agricultural Research Council Institute for Soil, Climate and Water were, however, incomplete and effects of vapor pressure deficit on tree water loss could not be assessed. In addition, Alarcón *et al*. (2000), from diurnal courses of leaf conductance and transpiration of three-year-old Búlida apricot trees growing in pots, concluded that transpirational loss of water do not solely depend on stomatal factors. The diffusion pathway for transpiration is complex and includes diffusion of vapor from the site of vaporization inside the leaf, through the leaf stomata, through the leaf boundary layer and finally through the canopy boundary layer (Sinclair, 1990). According to Kramer (1983) a change in one of the environmental or plant factors affecting transpiration does not necessarily produce a proportional change in the rate of transpiration since several factors interact to determine the rate.

Reduced soil water availability is the most perceptible indirect effect of salinity on plant performance, because as salinity increases, soil water potential decreases (Orcutt & Nilsen, 2000). Pre-dawn leaf water potential measured one day before irrigation during the 1995/96 season indicated that trees in the 2, 3 and 4 dS m^{-1} treatments experienced a water deficit compared to the 0 dS m^{-1} treatment (Chapter 6). The pre-dawn leaf water potential measured before irrigation reflected the contributing effects of soil matric potential as well as soil osmotic potential to soil water potential resulting from a weekly irrigation frequency. Transpiration rate decreased with lower pre-dawn leaf water potential during the 1995/96 season (Fig. 4.2A). Pre-dawn leaf water potential measured one day after irrigation before harvest during the 1996/97 season indicated salinity induced water stress in the 3 dS m^{-1} treatment (Chapter 6), and transpiration decreased linearly with lower pre-dawn leaf water potential during this period (Fig. 4.2B). High osmotic pressure in the soil water where saline irrigation exceeded 1 dS m^{-1} lowered the total soil water potential, which probably restricted root water uptake, reduced stomatal conductivity and thus lowered transpiration (Fig. 4.2A & B). Transpiration rate was however only significantly reduced in the 3 and 4 dS m^{-1} saline irrigation water treatments during the 1995/96 season. It was thus concluded that transpiration rate was reduced with decreasing pre-dawn leaf water potential, the latter resulting from soil water deficit at least partially induced by the osmotic effects of saline irrigation.

The lack of more significant differences in transpiration rate of apricot between the saline irrigation water treatments could be due to the dominant effect of vapour pressure deficit on regulation of stomatal conductance. According to Schulze *et al*. (1974), humidity and temperature are the main factors controlling the daily course of *Prunus armeniaca* diffusion resistance. The stomatal regulation system in apricot can furthermore adjust to long term stress by increasing the sensitivity of stomata to changes in air humidity towards the end of a dry season in non-irrigated trees, while such a change remain absent in irrigated trees (Schulze

et al., 1975). A larger decrease in the transpiration rate per unit decrease in pre-dawn leaf water potential was observed later in the season compared to that at the beginning for comparable leaf water potentials (Fig. 4.2A & B). This phenomenon in saline irrigated Palsteyn apricot could possibly be explained by an adjustment of the stomatal regulation system as the osmotic effect of salt in the soil solution produces, according to Munns (2002), plant responses identical to those of water stress caused by drought.

The decrease in pre-dawn osmotic potential of Palsteyn apricot leaves was previously ascribed to accumulation of ions in the apoplast/ symplasm/ vacuole or of organic osmolytes in the cytoplasm/ vacuole or any combination thereof (Chapter 6). Transpiration rate reduced with decreasing pre-dawn leaf osmotic potential during the 1995/96 season (Fig. 4.2C). Stepwise linear regression indicated that leaf water potential effects accounted for *c*. 74% of the variation in transpiration, while *c*. 21% was due to pre-dawn leaf osmotic potential effects during the period before harvest (Table 4.2).

Chloride most likely contributed to the lower osmotic potential in leaves (Chapter 6) as the chloride content of leaves increased with increasing irrigation water salinity (Fig. 4.3). A decrease in stomatal conductance of grapevine with increasing leaf chloride concentration was found by Downton (1977). However, Munns (2002), based on work of Rawson, Long and Munns (1988) on barley leaves, cautioned that strong correlations between increases in leaf ion concentrations and reductions in stomatal conductance do not necessarily indicate unambiguous evidence for causal relationships as correlations can disappear when considering different leaves or different salinities. It is possible that bulk leaf chloride concentrations can cause confusion regarding the cause of stomatal response as mechanisms of salt tolerance such as salt compartmentation can differ between plants. Accumulation of chloride in the apoplast could, for instance, cause a water deficit effect rather than an ion specific effect (Bingham, Fenn & Oertli, 1968).

Transpiration of the whole tree can, apart from the effect of salinity on the transpiration rate and stomatal conductance, be determined by the effect of salinity on the effective transpiring leaf area. Soil water osmotic potential induced water deficit can reduce growth due to the high energy requirement to synthesize organic solutes if it is used for osmotic adjustment to enable continued water uptake (Yeo, 1983). Ion toxicity can also reduce the effective leaf area of trees indirectly by redirecting metabolites destined for growth to salt exclusion, intracellular compartmentation or recycling processes to the root system (Jacoby, 1994; Munns, 2002) and directly through foliar damage and premature leaf fall (Bingham, Fenn & Oertli, 1968; Hoffman *et al*., 1989; Munns, 2002). Leaf area duration of Palsteyn apricot trees decreased with increasing irrigation water salinity during the 1996/97 season (Fig. 4.4) due to lower area per

unit leaf, chloride-related foliar damage and advanced leaf fall (Chapter 6). The magnitude of foliar damage generally increased with salinity of irrigation water and with each subsequent season.

Transpiration losses can also be influenced by wilting, rolling and changes in leaf orientation that reduce the amount of solar radiation received by leaves (Kramer, 1983). Leaf curling in response to excess salinity was previously documented for apricot (Bernstein, 1980) and was observed for Palsteyn apricot trees in the 3 and 4 dS m^{-1} treatments during the 1996/97 season and in the 2 and 3 dS m^{-1} treatments during the 1996/97 season (Chapter 6) and could thus have contributed to lower transpiration losses.

4.4.3 Evapotranspiration

The decrease in the volume of irrigation water applied as salinity increased (Table 4.3) was to be expected as irrigation was applied according to the water consumption of each treatment and it is known that salinity effects decrease water consumption (Boland, Mitchell & Jerie, 1993). Evapotranspiration losses during both seasons were abnormally high considered normal evapotranspiration rates for orchards (Fig. 4.6A & B). This could be explained by the area used to calculate the evapotranspiration rate being less than the area actually covered by the tree canopy. If the same evapotranspiration loss is expressed on the area for a high density orchard (1.5 m x 4.5 m) the values get much more realistic for deciduous fruit trees and the maximum is in the order of *c.* 3 mm d^{-1}. The higher evapotranspiration losses for 1995/96 could be due to higher leaf area indexes compared to that for the 1996/97 season (data not shown) and daily maximum temperature was on average 1.4°C higher during October to March for the 1995/96 season compared to that for the 1996/97 season. The daily maximum temperature for the 1996/97 season compared well with the long term average.

Although evaporation also contributes to evapotranspiration, results in general agreed with that found regarding the effect of salinity on leaf transpiration rate, but with less significant differences (refer to discussion in the section above). Evapotranspiration in the 0 dS m^{-1} treatment was also repressed compared to, but not significantly lower than that in the 0.7 and 1 dS m^{-1} treatments (Fig.4.6A &B). The apparantly lower evapotranspiration of this treatment could be attributed to problems with infiltration and hydraulic conductivity caused by the very low salinity water (Table 4.1). Evapotranspiration relative to that of the 0 dS m^{-1} treatment was the highest in the 0.7 and 1 dS m^{-1} treatments, while evapotranspiration decreased in the higher salinity treatments except for February and March during the 1995/96 season (Fig. 4.6A & B). The declining trend in evapotranspiration at high salinity seemed to be enhanced as seasons progressed, and evapotranspiration was significantly reduced in the 4 dS m^{-1} treatment during the 1995/96 season compared to all other treatments and in the 3 and 4 dS m^{-1} salinity

treatments relative to the 0, 0.7 and 1 dS m^{-1} treatments in the 1996/97 season. During the 1995/96 season significant differences was found in transpiration rate in the 3 dS m^{-1} treatment but not for evapotranspiration. The lack of significant difference in evapotranspiration in this treatment could be due to higher evaporation losses from beneath more sparse canopies (data not shown) that offset the lower transpiration rates. The lack in response of evapotranspiration to irrigation water salinity during February and March 1995/96 may be ascribed to the effect of severe summer pruning that reduced the evapotranspirating area for all treatments (data not shown).

The decreasing evapotranspiration in the 2, 3 and 4 dS m^{-1} salinity treatments (Fig. 4.6A &B) can be explained by the fact that the soil water salinity level exceeded the salinity threshold for reduction of growth in apricot at all measured soil depths after the 1994/95 season (data not shown). Furthermore toxic ion effects aggravated the effect of salinity on canopy volume and evapotranspiration decreased with lower leaf area index as irrigation water salinity increased (data not shown). Although irrigation with 1 dS m^{-1} salinity water also caused the depth weighted profile soil water salinity to exceed the threshold after the 1996/97 season, there was a total absence of negative effects of salinity on trees. This phenomenon could be explained by the fact that the soil water salinity in the top 600 mm did not exceed the 3.2 dS m^{-1} threshold (Chapter 3). Water extraction by roots generally tended to increase in the topsoil layer (0-300 mm) and decrease at the bottom of the soil profile (600 mm – 900 mm) as salinity increased. Water extraction monitored in the 1 dS m^{-1} treatment during a week in mid-summer (1995/96 and 1996/97 seasons) showed that 44%, 34% and 22% of the total was extracted from the top, middle and bottom soil layers, respectively. These results agrees with general water uptake patterns in irrigated soils, where most of the water uptake occurs in less saline soil depths until sufficient water is removed to lower the total water potential at that depth to a point where conditions elsewhere in the profile are more conducive for water uptake (Rhoades, 1999). It also confirms the conclusion of Rhoades (1999) that the level of salinity that can be tolerated by the crop do not solely depend on the salt tolerance of the crop, but also on the distribution of salinity in the soil profile, on the amount and frequency of irrigation and on the hydraulic properties of the soil.

The implication of the abovementioned results with regard to the management of saline irrigation of apricot trees is that, if the upper soil layers can be maintained at soil water salinity levels less than the 3.2 dS m^{-1} threshold, normal growth and full yield potential can still be attained, provided that the irrigation interval prevent matric potential induced water stress. The irrigation interval should in such cases rather be based on the soil water content of the upper soil layers. These assumptions apply only to salinity induced water extraction problems and

exclude consideration of toxic ion effects as no toxicity symptoms were observed on trees during the four-year irrigation period.

A lack in response of cumulative evapotranspiration to soil salinity of the 1995/96 season (Fig. 4.7A) may partially be due to severe summer pruning that changed the evapotranspirating area of the saline irrigation treatments, as summer pruning weight during 1995/96 was 2 to 3-fold that removed during 1996/97 (data not shown). Evapotranspiration of all treatments except for the 4 dS m^{-1} treatment was similar during February and March 1995/96 despite a trend earlier in the season for evapotranspiration to decrease with increasing salinity (Fig.4.6A). Minimal summer pruning during 1996/97 apparantly did not affect the evapotranspiration of saline irrigation water treatments during February and March 1996/97 (Fig. 4.6B) and a clear response of cumulative evapotranspiration for the 1996/97 season to increasing mean soil salinity of the 1995/96 and 1996/97 seasons was obtained (Fig. 4.7B).

Perennial deciduous woody plants accumulate salt in roots and trunks and the effect of salinity does increase in successive years (Bernstein, 1980). The mean depth-weighted soil salinity of the 1995/96 and 1996/97 seasons combined related better to the evapotranspiration for the 1996/97 season than the depth-weighted soil salinity of the 1996/97 season alone and was therefore used for the evapotranspiration to salinity response function. The poorer regression relationship between evapotranspiration and soil salinity for 1996/97 can be explained by decreased evapotranspiration at lower soil salinity at the 4 dS m^{-1} treatment while the trend for the other treatments was for evapotranspiration to decrease with increasing soil salinity (data not shown). The soil salinity at the 4 dS m^{-1} treatment decreased progressively from December of the 1995/96 season (data not shown) and was during the 1996/97 season significantly decreased (Chapter 3) due to excessive leaching that occurred during both seasons at this treatment (Figs. 4.9 & 4.10).

The response of relative cumulative evapotranspiration of 1996/97 to the mean depth-weighted soil salinity of the 1995/96 and 1996/97 seasons resulted in a salinity threshold of 1.72 dS m^{-1} and the slope a 54% decrease in relative evapotranspiration per unit increase in soil water salinity (Fig. 4.8). The soil salinity threshold of relative evapotranspiration for Palsteyn apricot for the 1996/97 season did not differ significantly from the 1.6 dS m^{-1} threshold for vegetative growth of apricot according to Ayers and Westcot (1985). Linear regression between yield and cumulative evapotranspiration of the 1996/97 season indicated a highly significant relationship (R^2=0.83, $p< 0.001$, n=23; data not shown) and the soil salinity threshold of relative evapotranspiration for Palsteyn apricot was practically the same as the soil salinity threshold of 1.7 dS m^{-1} for the relative yield salinity response function for 1996/97 after yield was adjusted for soil water depletion differences (Chapter 6).

4.4.4 Salt leaching.

The salt content of leached water can be estimated as the ratio of the salt content of the irrigation water to the leaching fraction under steady state conditions (Hoffman & Durnford, 1999). This calculation indicates an expected tenfold increase in irrigation water salinity for leached water if a leaching fraction of 0.1 is applied. The salt content of the leached water at the saline irrigation treatments, however, was much less (Fig. 4.9) and the lower salinity was ascribed to excessive leaching at all saline treatments during both the 1995/96 and 1996/97 seasons (Fig. 4.10). The higher leaching fractions resulted from the application of irrigation to all treatment replicates according to the water deficit of the replicate plot with the highest water deficit and variability in tree response to salinity within replicate plots (data not shown).

According to the salt balance for 1995/96, more chloride was leached from the soil profile than was added by irrigation during the season (Fig. 4.11). Chloride that previously accumulated in the soil profile as a result of inadequate leaching during the 1994/95 season (Chapter 3) could have been removed by the higher leaching fractions that realised during the 1995/96 season (Fig. 4.10) and as such contributed to the higher loss of chloride from the soil profile (Fig. 4.11). Enhanced leaching occurred especially in the 2, 3 and 4 dS m^{-1} treatments and the depth-weighted soil water salinity in these treatments during the 1996/97 season decreased from the 1995/96 to the 1996/97 season (Chapter 3). The salt balance for 1996/97, however, indicated that approximately equivalent amounts of chloride was added to and lost from the soil profiles (Fig. 4.11). The salt content of the soil did, therefore, not change significantly during the 1996/97 season and indicated steady state conditions in the soil profile (Rhoades & Loveday, 1990).

Three reasons for the enhanced leaching in the high salinity treatments are possible: 1) High osmotic pressure in soil water lowered the total water potential which restricted root water uptake, reduced stomatal conductivity and decreased transpiration; 2) Osmotic stress, sodium and/or chloride toxicity reduced the canopy volume (smaller leaf size and premature leaf fall due to salt toxicity) and therefore evapotranspiration and 3) Irrigation applications were calculated relative to the measured soil water deficit of the replicate block with the highest water deficit per treatment and more replicate trees per treatment in the more saline treatments reached an advanced state of damage with reduced evapotranspiration that caused over-irrigation. The results from the salt balance could still be relevant to that what happens in practice if producers utilizing saline irrigation water irrigate according to water requirements of trees least affected by salinity in order to ensure soil matric potential related water stress is minimized.

4.5 CONCLUSIONS

Evapotranspiration of Palsteyn apricot was decreased by saline irrigation water through reduced leaf area duration and lower transpiration that was related to water deficit and ion toxicity effects. Evapotranspiration calculations for irrigation scheduling purposes of apricot under non-saline conditions can still be applied when saline irrigation water is used. A prerequisite, however, is that the soil salinity in the upper soil layers remains below the 1.72 dS m^{-1} threshold value, that the irrigation interval prevent matric potential induced water stress and that specific ion toxicity symptoms remain absent. Whenever matric potential induced water stress occur and/or salinity exceeds these levels, osmotic effects will significantly influence canopy size and density, and overestimation of water consumption will cause increased leaching. This research did not take the effect of rainfall into account which may allow the use of irrigation water of salinity in excess of 1 dS m^{-1} or a reduced leaching fraction in the orchard.

4.6 REFERENCES

Alarcón, J.J., Domingo, R., Green, S.R., Sánchez-Blanco, M.J., Rodrígues, P. & Torrecillas, A., 2000. Sap flow as an indicator of transpiration and the water status of young apricot trees. *Plant Soil*, 227: 77-85.

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M., 1985. Crop evapotranspiration. FAO Irrigation and Drainage Paper No. 56. Rome: FAO.

Anon., 1973. The determination of chloride in plants and feedingstuffs. *In*: Ministry of Agriculture, Fisheries and Food (ed.). The analysis of agricultural materials: A manual of the analytical methods used by the agricultural development and advisory service. Tech. Bull. No. 27. London: Ministry of Agriculture, Fisheries and Food.

Ayers, R.S. & Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: FAO.

Bernstein, L., 1980. Salt tolerance of fruit crops. *USDA Agric. Inf. Bull*. 292: 1-8.

Bielorai, H., Shalevet, J. & Levy, Y., 1978. Grapefruit Response to Variable Salinity in Irrigation Water and Soil. *Irrig. Sci.*, 1: 61-70.

Bingham, F.T., Fenn, L.B., & Oertli, J.J., 1968. A sandculture study of Chloride Toxicity to Mature Avocado Trees. *Soil. Sci. Soc. Amer. Proc.,* 32: 249-252.

Boland, A.M., Mitchell, P.D. & Jerie, P.H., 1993. Effect of saline water combined with restricted irrigation on peach tree growth and water use. *Aust. J. Agric. Res.,* 44: 799-816.

Chiariello, N.R., Mooney, H.A. & Williams, K., 1989. Growth, carbon allocation and cost of plant tissues. *In*: R.W. Pearcy, J. Ehleringer, H.A. Mooney & P.W. Rundel (eds.). Plant Physiological Ecology: Field methods and instrumentation. New York: Chapman and Hall, p. 327-365.

Downton, W.J.S., 1977. Photosynthesis in salt-stressed grape vines. *Aus. J. Plant Physiol.,* 4: 183-192.

Du Toit, S.F., 1995. Tyd- en ruimtelike veranderinge in die grondchemiese samestelling van 'n wingerd wat met soutryke water besproei word. (*Afrikaans*). M.Sc. Tesis, Universiteit van Stellenbosch, Stellenbosch, Suid-Afrika.

Fereres, E. & Goldhamer, D.A., 1990. Deciduous Fruit and Nut Trees. *Agronomy,* 30: 987-1017.

Fruit and Fruit Technology Research Institute, 1983. Anorganic fertilization of deciduous fruit. *Inf. Bull*. 512. Stellenbosch: Dept. of Agriculture.

Hoffman, G.J., Catlin, P.B., Mead, R.M., Johnson, R.S., Francois, L.E. & Goldhamer, D., 1989. Yield and foliar injury responses of mature plum trees to salinity. *Irrig. Sci.*, 10: 215-229.

Hoffman, G.J. & Durnford, D.S., 1999. Drainage Design for Salinity Control. *Agronomy,* 38: 579-614.

Jacoby, B., 1994. Mechanisms involved in Salt Tolerance by Plants. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 97-123.

Kramer, P.J., 1983. Water relations of plants. Florida: Academic Press.

Maas, E.V., 1984. Crop tolerance. *Calif. Agric*., 38(10): 20-21.

Maas, E.V. & Hoffman, G.J., 1977. Crop salt tolerance-current assessment. *J. Irrig. Drain Div. ASCE,* 103: 115-134.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J., Meiri, A. & Moolman, C.G., 1999. The use of saline water for irrigation of grapevines and the development of crop salt tolerance indices. WRC Report No. 303/1/98. Pretoria: Water Research Commission.

Munns, R., 2002. Comparative physiology of salt and water stress. *Plant Cell Environ.,* 25: 239-250.

Orcutt, D.M. & Nilsen, E.T., 2000. Physiology of plants under stress. New York: John Wiley & Sons, Inc.

Ragab, R., 1996. Constraints and applicability of irrigation scheduling under limited water resources, variable rainfall and saline conditions. *In*: Irrigation scheduling: from theory to practice: Proceedings of the ICID/FAO Workshop on Irrigation Scheduling, Rome, Italy, September 1995. Rome: FAO: ICID, p. 149-165.

Rawson, H.M., Long, M.J. & Munns, R., 1988. Growth and development in NaCl-treated plants. I. Leaf Na+ and Cl- concentrations do not determine gas exchange of leaf blades in barley. *Aust. J. Plant Physiol*., 15: 519-527.

Richards, L.A. (ed.), 1954. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No. 60. Washington, DC: USDA.

Rhoades, J.D. & Loveday, J., 1990. Salinity in irrigated agriculture. *Agronomy,* 30: 1089-1142.

Rhoades, J.D., 1999. Use of saline drainage water for irrigation. *Agronomy,* 38: 615-657.

SAS, 1999. SAS Institute Inc., SAS/STAT® User's Guide, Version 8. Cary, NC: SAS Institute Inc.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemmingsen, E.A., 1965. Sap pressure in vascular plants. S*cience*, 148: 339-46.

Schulze, E.D., Lange, O.L., Evenari, M., Kappen, L. & Buschbom, U., 1974. The role of air humidity and leaf temperature in controlling stomatal resistance of *Prunus armeniaca* L. under desert conditions. I. A simulation of the daily course of stomatal resistance. *Oecologia (Berl.)*, 17: 159-170.

Schulze, E.D., Lange, O.L., Kappen, L., Evenari, M. & Buschbom, U., 1975. The role of air humidity and leaf temperature in controlling stomatal resistance of *Prunus armeniaca* L. under desert conditions. II. The significance of leaf water status and internal carbon dioxide concentration. *Oecologia (Berl.)*, 18: 219-233.

Shainberg, I. & Letey, J., 1984. Response of soils to sodic and saline conditions. *Hilgardia,* 52: 1-57.

Shapiro, S.S. & Wilk, M.B., 1965. An Analysis of Variance Test for Normality (complete samples). *Biometrika,* 52: 591-611.

Sinclair, T.R., 1990. Theoretical Considerations in the Description of Evaporation and Transpiration. *Agronomy,* 30: 343-361.

Van Genuchten, M.Th., 1983. Analyzing crop salt tolerance data: Model description and user's manual. Research report No.120, U.S. Salinity Laboratory. California: USDA/ARS.

Wolff-Piggott, B., 1995. Demonstrating the potential of GIS technology in hydrosalinity modelling through interfacing the DISA model and a GIS. WRC Report No. 588/1/95. Pretoria: Water Research Commission.

Yeo, A.R., 1983. Salinity resistance: Physiologies and prices. *Physiol. Plant.,* 58: 214-222.

CHAPTER 5

The effect of saline irrigation water on the sodium, calcium and chloride concentration in vegetative and reproductive organs of Palsteyn apricot trees

5.1 INTRODUCTION

Palsteyn apricots are produced in South Africa for the fresh market for local consumption and export purposes (Victor, 1995). Some of the main apricot producing areas in the Western Cape Province receive irrigation water that is becoming more saline (Murray, Biesenbach & Badenhorst Inc, 1989; Moolman *et al.*, 1999). Under saline conditions, sodium and/or chloride concentrations often exceed those of most macro- and micro-nutrients, and can cause osmotic and/or specific-ion injury as well as nutritional disorders (Grattan & Grieve, 1999). Among the first crops to suffer yield reductions when irrigation water becomes saline are the deciduous fruit trees (Hoffman *et al.*, 1989) and profit margins for farmers are such that decreased yields cannot be tolerated.

Most fruit crops are sensitive to chloride and sodium salts (Bernstein, 1980; Hoffman *et al.*, 1989). Woody crops are especially sensitive to sodium toxicity and concentrations as low as 5 mmol dm^{-3} in the soil water caused toxicity injury to stone fruit trees (Rhoades & Loveday, 1990). Sodium concentrations of < 3 mmol dm^{-3}; 3 to 9 mmol dm^{-3} and > 9 mmol dm^{-3} in irrigation water are expected to have no, slight to moderate and severe degrees of restriction on use, respectively, according to the Food and Agricultural Organisation of the United Nations guidelines (Ayers & Westcot, 1985). In the Western Cape Province sodium levels of 6.5 mmol dm^{-3} are not regarded as detrimental for stone fruit for under-tree irrigation without foliage wetting (Kotzé, 1998).

Stone fruit trees normally restrict accumulation of sodium in leaves, but continued growth on saline substrate results in high leaf concentrations of both sodium and chloride. Sodium causes leaf tip burn in the concentration range of 1.8 to 2.3 g kg^{-1} (0.18 to 0.23 %) of leaf dry weight in plum (Ehlig & Bernstein, 1959). There appears to be no restriction to sodium accumulation in other plant parts like the roots, wood and bark (Bernstein, Brown & Hayward, 1956; Ziska *et al.*, 1991). The proportion of sodium accumulated in leaves of sodium excluder species may, according to Storey & Walker (1999), change dramatically upon saturation of the sodium readsorptive process or above a “threshold” salinity.

In the case of chloride, concentrations of <4 mmol dm^{-3}, 4 to 10 mmol dm^{-3} and >10 mmol dm^{-3} in irrigation water are expected to have no, slight to moderate and severe degrees of restriction on use, respectively (Ayers & Westcot, 1985). Chloride levels of 5.6 mmol dm^{-3} in irrigation water are not regarded as detrimental for stone fruit for under-tree irrigation without foliage wetting in the Western Cape (Kotzé, 1998). Chloride causes marginal leaf chlorosis when the concentration exceeds 10 g kg^{-1} (1%) of dry weight in apricot leaves and approximately 6 g kg^{-1} (0.6%) of leaf dry weight in plum (Bernstein *et al*., 1956).

Scion, as well as rootstock influences the level of chloride accumulation. Marianna rootstock restricted chloride and sodium accumulation in plum and prune relative to Lovell rootstock (Bernstein *et al*., 1956). The maximum chloride concentration permissible in irrigation water to prevent leaf injury for Marianna rootstock was estimated as 12 mmol dm^{-3}. Irrigation with such water would result in soil water concentrations of approximately 50 mmol chloride dm^{-3}. This value was recalculated from data adapted from Maas (1984) by Ayers & Westcot (1985) using the leaching fraction of 0.1 and assuming $Cl_e = 2.1 \times Cl_{iw}$ and $Cl_{sw} = 4.2 \times Cl_{iw}$. The abbreviations Cl_e, Cl_{iw} and Cl_{sw} refer to the chloride concentration in the saturated soil water extract, irrigation water and soil water, respectively.

Perennial deciduous woody plants accumulate salt in roots and trunks and the effect of salinity increases in successive years (Bernstein, 1980). Irrigation with lower salinity water would in the long-term produce responses similar to those observed with higher salinities over shorter periods (Catlin *et al.,* 1993). Chloride in leaves of plum trees at lower salinity treatments of 1 and 2 dS m^{-1} (Catlin *et al.,* 1993) and that of vines of the cultivar Colombar/R99 (Van Zyl, 1997) reached maximum levels during the fourth year of saline irrigation. These levels were in proportion to the concentration of salt in the irrigation water. Accumulation of salts from the irrigation water was apparently balanced by losses of salts through leaf abscission, cropping and pruning. Conversion from saline to non-saline irrigation water showed potential for revival of plum trees (Catlin *et al.,* 1993). Chloride reserves previously accumulated in plum trees during saline irrigation were reduced after non-saline irrigation, apparently by removal of fruit, prunings and leaves, while sodium after initial reduction, remained at approximately the same concentrations in perennial tree parts. These authors proposed that the difference in behaviour between sodium and chloride might be caused by slower release of sodium from storage pools within the tree.

Evaluation of long-term responses (at least three years) of deciduous fruit trees to saline irrigation is imperative to establish the true effect of salinity on tree vigour, productivity and survival. This information is needed for producers who are forced to use moderately saline irrigation water, to make informed decisions with regard to crop and cultivar selection. The

cumulative toxic effects of sodium and chloride can cause fruit trees to die in the long term with severe economic implications for the producer. Approximately 50% of the salinity in the Breede River in the area where apricots are produced is attributed to sodium and chloride (Murray, Biesenbach & Badenhorst Inc, 1989). The viability of irrigation of the apricot cultivar Palsteyn on Marianna rootstock with saline irrigation water was assessed by evaluating the accumulation and distribution of sodium, calcium and chloride in trees at the end of a four year irrigation period.

5.2 METHODOLOGY

The irrigation trial was conducted at Stellenbosch, in the Western Province of the Republic of South Africa in 24 drainage lysimeters. This area is a winter rainfall region, which necessitates irrigation of deciduous fruit trees during the warm dry summer. Five-year-old Palsteyn apricot trees on Marianna rootstock (2 trees per lysimeter; area per tree 1.4 m x 1.5 m and 1.2 m deep) were used in this experiment. Trees were pruned during winter and summer pruning was performed when necessary. Trees were hand-thinned in the spring and fruit harvested at optimum maturity. Trees were fertilised according to guidelines based on growth performance of control treatment trees, leaf and soil analysis (Research Institute for Fruit and Fruit Technology, 1983). Lysimeters were weeded by hand and pesticides applied as needed.

The experimental design consisted of six treatments replicated four times. Salinity treatments included municipal water, referred to as the "0 dS m^{-1} treatment", and irrigation water of target salinity levels (EC_{iw}) of 0.7, 1, 2, 3 and 4 dS m^{-1}. Different salinity levels were achieved by mixing different volumes of a stock solution of 1:1 M NaCl:$CaCl_2$ with municipal treatment water and the salt concentrations of the solutions corresponding to the EC_{iw} were 0; 2.2; 3.3; 7.1; 10.8 and 14.6 mM. Irrigation water of the different treatments was sampled at all irrigation events and the electrical conductivity determined with a HI 8820 Bench Conductivity meter (Hannah, Italy). Full chemical analyses were done at selected intervals only. Soil water was extracted at selected dates 24 h after irrigation throughout the season at 150, 300, 600 and 900 mm depths to determine the total salinity, measured as electrical conductivity, pH and cation and anion concentrations. Salinity values were integrated over time and over depth of the root zone according to Moolman *et al*. (1999) for each season, excluding the period when trees were dormant.

The irrigation system consisted of four drip lines with eight 2.3 dm^3 h^{-1} pressure compensating drip emitters (Katiff, Israel) each, to supply a nearly fully wetted surface. Saline irrigation treatments were induced during the period September until March each season. Irrigation

during the winter period occurred whenever the soil reached a soil matric potential of approximately -0.04 MPa to prevent desiccation. A constant leaching fraction (0.10) was imposed on all treatments. An automated rain shelter prevented winter rain from leaching salts.

Trees were sampled destructively shortly after harvest (December) of the 1997/98 season. Since the majority of trees at the 4 dS m^{-1} treatment died at the end of the 1996/97 season, only trees of the five remaining treatments were used. All leaves were stripped from the trees and trees were divided into the following parts: trunk, scaffold branches, lateral branches, long shoots, spurs, new growth and dead wood. The total masses of all the different tree parts were determined and two representative sub-samples of each tree part taken and weighed. The first sample was used for estimation of total dry mass and the second for chemical analyses. All tree parts were rinsed once with tap water and three times with deionised water to remove dirt from the outside surfaces. This was done before subdivision into smaller parts to prevent any possibility of leaching of mineral elements from the samples. The trunk and scaffold branches were subdivided into wood and bark. Roots, both fibrous and woody, were sampled 300 mm from the tree trunk for a 400 mm x 400 mm soil surface section for 0 to 150 mm, 150 to 300 mm, 300 to 600 mm and 600 to 900 mm depths. Roots with diameter less than 5mm were washed in distilled water to remove soil and blotted dry. All tree parts were dried to a constant dry mass in a forced-draft oven at 65°C.

Tree parts were ground in a stainless steel mill and passed through a 40-mesh screen. Ground samples were dried overnight in a forced-draft oven at 60°C and left to cool to room temperature. Samples of 1 g were weighed out directly after cooling and dry incinerated in a microwave oven at 480°C for 45 minutes. The resultant ash was wetted with deionised water and dissolved in 5 ml 5 M HCl, quantitatively transferred into a 50 ml volumetric flask and made to volume with deionised water. Sample solutions were filtered through Whatman no.2 filter paper before determination of K, Ca, Mg, P, Na, Mn, Fe, Cu, Zn and B concentrations by means of the inductive coupled plasma atomic emission spectrometer (Liberty 200 ICP AES, Varian, Australia). Nitrogen concentrations were determined with a LECO N-analyser (FP428 Determinator, ®LECO Corporation, United States of America) and chloride concentrations in all plant material determined by titration (Anon, 1973). Mineral content for roots were integrated over the 900 mm depth of the root zone according to Moolman *et al*. (1999) to obtain a single value per mineral per tree.

Fruit were sampled at harvest during the 1994/95 to 1997/98 seasons. Fruit were washed in a 1% HCl solution, rinsed once with tap water and twice with deionised water. Two small wedges, approximately an eighth of each fruit, were sampled from opposite sides of the fruit. The fruit cores were removed and the remainder of the wedges sliced into small pieces. Composite

samples of approximately 10 g, taken from 8 to 10 fruit, were dried in a forced-draft oven at 100°C, cooled and 1 g of dried sample material prepared for incineration. Fruit samples were incinerated in a microwave oven at 480°C for 45 minutes. Samples were allowed to cool, wetted with deionised water and acidified with 3 ml 5 M HCl. The acid was vaporized from samples in a sandbath until dry. Samples were then incinerated for a second time in a microwave at 480°C for 45 minutes and 3 ml 5 M HCl added before being quantitatively transferred into a 50 ml volumetric flask and made to volume with deionised water. Sample solutions were filtered through Whatman No.2 filter paper and solutions analyzed as described above for other tree parts.

5.3 RESULTS

5.3.1 Irrigation and soil water concentration

The specific ion concentrations in the irrigation water of the different saline irrigation treatments remained below 10 mmol dm^{-3} for sodium as well as for calcium, and reached 32 mmol dm^{-3} for chloride for the period 1995/96 to 1997/98 (Table 5.1). Increasing saline irrigation increased the amount of sodium, calcium and chloride in the soil water extract, with chloride being approximately 3 times more concentrated than the associated cations (Table 5.1). Linear regressions of sodium, calcium and chloride ions, respectively, of irrigation water and soil water extracts made during 1995/96 to 1997/98, rendered correspondingly coefficients of determination of 0.96, 0.97 and 0.94. The sodium, calcium and chloride in the irrigation water were concentrated 2.35 (Standard error (SE) 0.28); 2.36 (SE 0.24) and 2.53 (SE 0.36) times in the soil water extract, respectively. The ratios of $Na^{+}/(Na^{+}+Ca^{2+})$ of the irrigation water used in this study was 0.5 for the saline irrigation treatments and 0.7 for the control and that of the soil water varied from 0.4 to 0.5.

5.3.2 Tree mineral analysis

Sodium

Higher concentrations of sodium in the soil water did not necessarily cause higher sodium concentrations in the plant, especially in the leaves (Fig. 5.1). There was, however, a significant increase in sodium in the roots in all saline irrigation treatments and in above-ground parts of the tree in the 3 dS m^{-1} saline irrigation treatment (Fig. 5.2) when sodium levels reached approximately 5 mmol dm^{-3} and 21 mmol dm^{-3} in the soil water (Fig. 5.1) respectively. The sodium concentration in Palsteyn apricot tended to increase with increasing salinity in all tree

Table 5.1. The specific ion concentrations of sodium, calcium and chloride in the irrigation water and soil water extract of the different saline irrigation treatments for the period August to March from 1995/96 to 1997/98. All four treatment replicates were irrigated from one container and seasons were considered as random replications for irrigation water ion content statistical analysis. Seasonal means included 28, 28 and 4 irrigation and 10, 13 and 4 soil water extraction events during 1995/96, 1996/97 and 1997/98 respectively. Values for ion concentrations followed by the same letter do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and different ions were tested separately (harmonic mean of replicate blocks is 2.77 for irrigation water and 3.75 for the soil water extract). The LSD and experimental standard deviation (SD) is indicated at the bottom of the table (degrees of freedom = 11)

Treatments (dS m^{-1})	**Specific ion concentrations (mmol dm^{-3})**					
	Irrigation water			**Soil water extract**		
	Sodium	**Calcium**	**Chloride**	**Sodium**	**Calcium**	**Chloride**
0	0.3^{d}	0.1^{d}	4.0^{c}	1.2^{c}	1.6^{b}	3.8^{c}
0.7	2.0^{c}	1.7^{cd}	8.9^{c}	5.2^{bc}	5.1^{b}	16.8^{bc}
1	2.9^{c}	2.6^{c}	12.7^{bc}	10.3^{b}	9.4^{b}	37.4^{b}
2	6.0^{b}	5.8^{b}	22.6^{ab}	18.0^{a}	17.5^{a}	63.2^{a}
3	9.1^{a}	9.1^{a}	32.6^{a}	21.4^{a}	22.2^{a}	73.9^{a}
LSD	0.86	1.85	11.64	4.6	4.9	14.3
SD	0.5	1.0	6.2	7.35	7.88	22.99

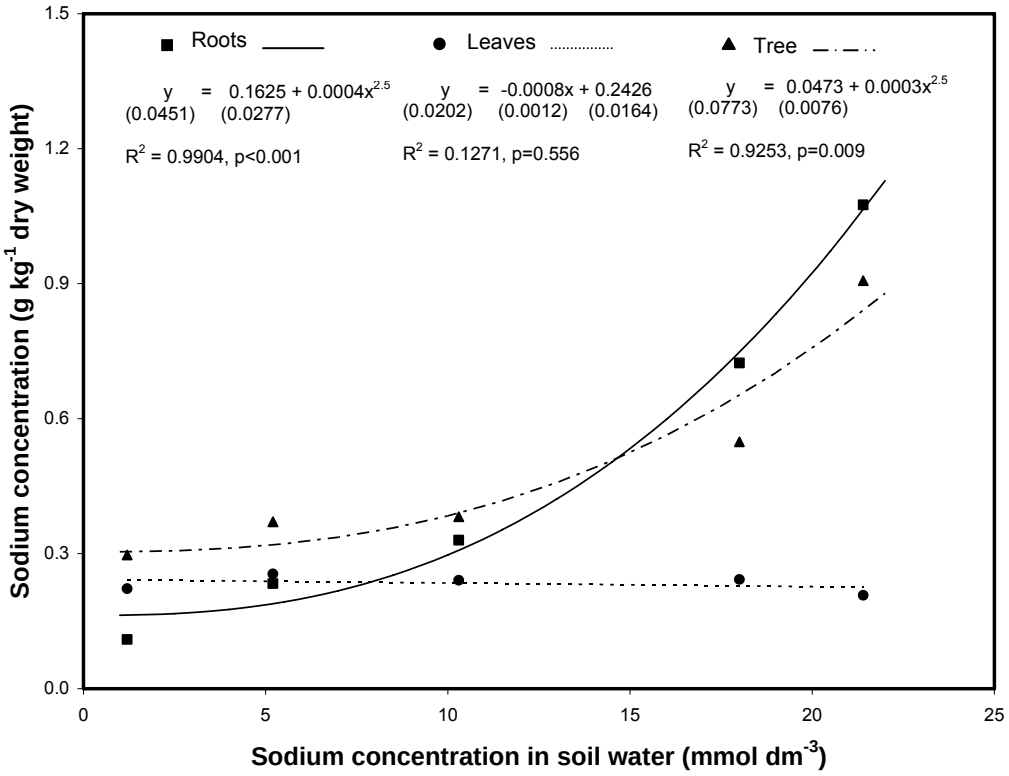
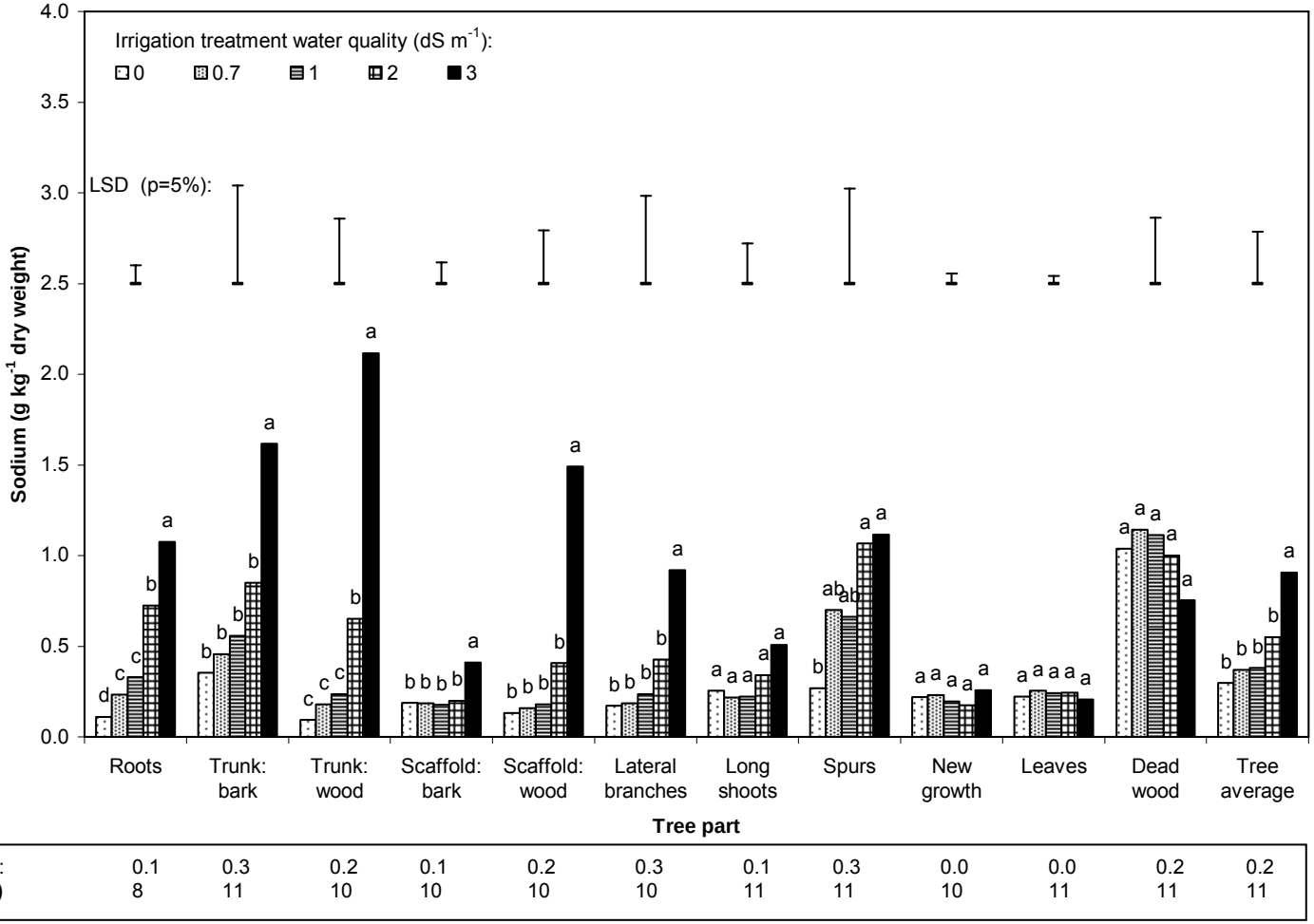


Figure 5.1. The effect of sodium in the soil water on concentration of sodium in the roots, leaves and above-ground tree parts of Palsteyn apricot on Marianna rootstock after four seasons of irrigation with water with varying salinity concentrations (n=5). Data are the harmonic means of replicate blocks (3.16 to 3.75). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.



SD:	0.1	0.3	0.2	0.1	0.2	0.3	0.1	0.3	0.0	0.0	0.2	0.2
(df)	8	11	10	10	10	10	11	11	10	11	11	11

Figure 5.2. The cumulative effect of four seasons of saline irrigation on the concentration of sodium in tree parts of Palsteyn apricot on Marianna rootstock. New growth refers to new shoot growth for the 1997/98 season. Columns within the same tree part capped by the same letter do not differ significantly according to Student's t-LSD calculated at a 5% significance level (the harmonic mean for replicates ranged between 3.16 and 3.75). The experimental standard deviation (SD) for each analysis of variance and degrees of freedom (df) is indicated at the bottom of the graph.

parts except new growth, leaves and dead wood (Fig. 5.2). Sodium in trees at the 2 dS m^{-1} treatment reached significantly higher concentrations in the roots and wood of the trunk. In comparison with all other treatments, the 3 dS m^{-1} treatment had significantly higher concentrations of sodium in the roots, wood and bark of the trunk, wood and bark of the scaffold, lateral branches and the average of all aboveground parts of the tree. Sodium concentrations decreased in the different tree parts of the most saline treatment as follows: trunk wood > bark of the trunk > scaffold wood > spurs > roots > lateral branches > dead wood > long shoots > scaffold bark > new growth > leaves (Fig. 5.2). The sodium concentration in spurs increased in all salinity treatments, with the 2 and 3 dS m^{-1} treatments significantly different only from the control.

The total amount of sodium in the wood of the trunk, wood of the scaffold and lateral branches in trees receiving the 3 dS m^{-1} treatment was significantly higher than in all other treatments. These tree parts retained 14%, 42% and 24% of the total sodium per tree while comprising 7%, 28% and 27% of the total aboveground dry weight per tree, respectively. The total amount of sodium retained in aboveground parts of trees at the end of the experiment in the most saline treatment was 6.3 g sodium $tree^{-1}$ compared with the 1.8 g $tree^{-1}$ of the control trees.

Calcium

The calcium content of the roots, aboveground parts of the tree and leaves increased as the calcium concentration in the soil water increased, with higher concentrations in leaves compared to the roots and aboveground average for the tree (Fig. 5.3). The calcium concentration was the highest in the bark and the lowest in the wood of the trunk and scaffold (Fig. 5.4). The concentration in the leaves, new growth, long shoots and roots was significantly higher in the 2 and 3 dS m^{-1} treatments in comparison with all of the less saline treatments. The calcium concentration in all saline treatments was significantly higher in the bark of the scaffold in comparison with the 0 dS m^{-1} treatment and increased in the wood of the scaffold with increasing salinity.

The highest absolute amount of calcium in trees receiving the 3 dS m^{-1} treatment was approximately 23% of the total calcium accumulated per tree in the bark of the scaffold, leaves and lateral branches each which comprised 8%, 12% and 27% respectively of the total aboveground dry weight per tree. Trees in the most saline treatment accumulated 130 g calcium $tree^{-1}$ at the end of the experiment in comparison with the 113 g calcium $tree^{-1}$ in the 0 dS m^{-1} treatment.

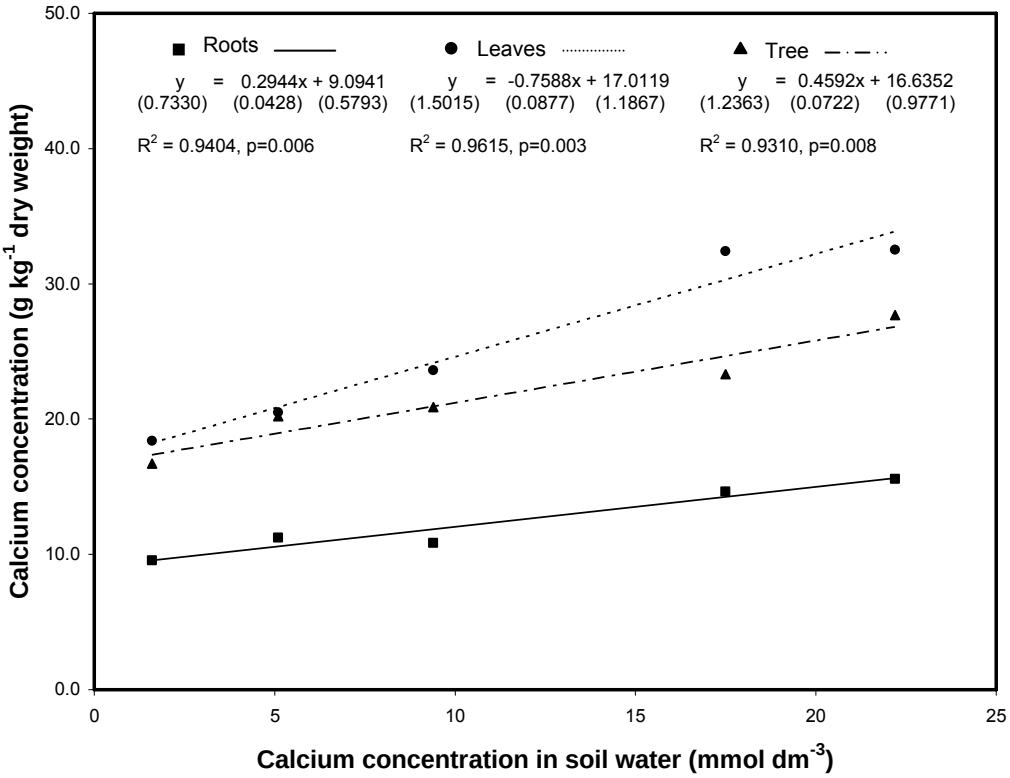
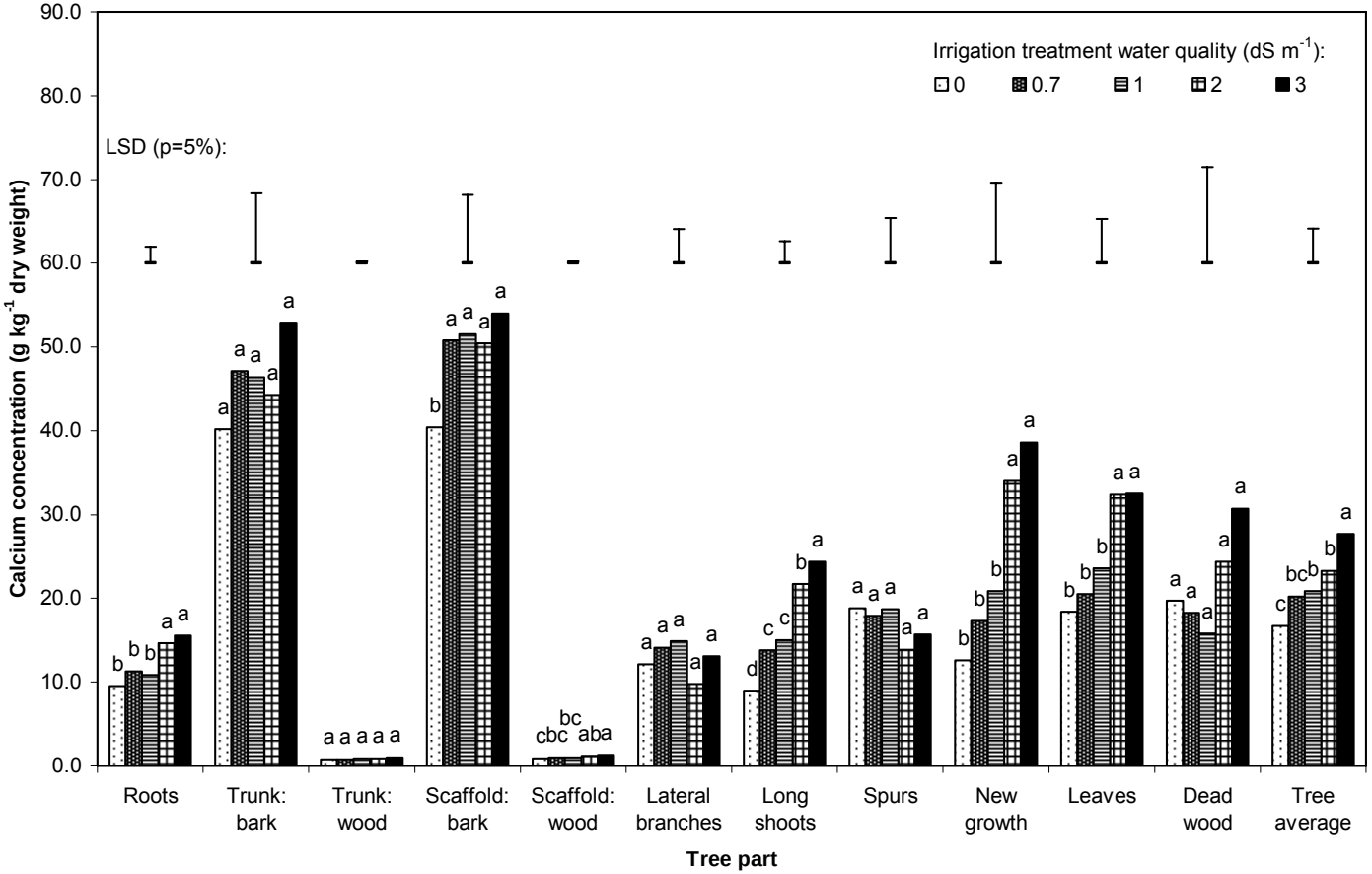


Figure 5.3. The effect of calcium in the soil water on concentration of calcium in the roots, leaves and above-ground tree parts of Palsteyn apricot on Marianna rootstock after four seasons of irrigation with water with varying salinity concentrations (n=5). Data are the harmonic mean of replicate blocks (3.53 to 3.75). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.



SD:	1.2	5.2	0.1	4.9	0.1	2.5	1.6	3.4	5.9	3.3	7.1	2.6
(df)	10	11	10	10	10	11	11	11	11	11	11	11

Figure 5.4. The cumulative effect of four seasons of saline irrigation on the concentration of calcium in tree parts of Palsteyn apricot on Marianna rootstock. New growth refers to new shoot growth for the 1997/98 season. Columns within the same tree part capped by the same letter do not differ significantly according to Student's t-LSD calculated at a 5% significance level (the harmonic mean for replicates ranged between 3.53 and 3.75). The experimental standard deviation (SD) for each analysis of variance and degrees of freedom (df) is indicated at the bottom of the graph.

Chloride

Chloride concentration increased exponentially in the roots, leaves and all aboveground parts of the tree as the chloride concentration in the soil water increased (Fig. 5.5). The average concentration of chloride per tree increased from 0.4 g kg^{-1} dry weight in the 0 dS m^{-1} treatment, to 4.9 g kg^{-1} dry weight in the most saline (3 dS m^{-1}) treatment (Fig. 5.6). There was a 7-fold increase in concentration of chloride levels in leaves of Palsteyn apricot on Marianna rootstock between the 1 to the 2 dS m^{-1} treatments. The highest chloride concentration was observed in the leaves of the 2 and 3 dS m^{-1} treatments and amounted to 13 and 20 g kg^{-1} dry weight, respectively (Fig. 5.6). Leaf analyses included a sample of all the leaves on the tree.

The chloride concentrations in almost all tree parts were significantly higher in the 2 and 3 dS m^{-1} treatments in comparison with the 0, 0.7 and 1 dS m^{-1} treatments (Fig. 5.6). It was only concentrations in the bark of the trunk and bark and wood of the scaffold that deviated from this pattern. Chloride concentrations in the wood of the scaffold did not differ significantly between treatments. The concentration of chloride in the different tree parts in the most saline treatment decreased as follows: leaves > new growth > bark of trunk > dead wood > long shoots > spurs > roots > lateral branches > bark of scaffold > wood of scaffold > wood of trunk.

The absolute amount of chloride was significantly higher in trees in the 1, 2 and 3 dS m^{-1} treatments in comparison with the 0 dS m^{-1} treatment, and increased with increasing salinity. Trees in the most saline treatment contained 29 g chloride $tree^{-1}$ in comparison with the 3.2 g $tree^{-1}$ of the 0 dS m^{-1} treatment trees at the end of the experiment. The majority of chloride in the most saline treatment was confined to the leaves (56%), lateral branches (12%) and wood of the scaffold (9%). These parts comprised respectively 12%, 27% and 28% of the total aboveground dry weight per tree.

5.3.3 Ion composition of fruit

Potassium, calcium and magnesium composed 91%, 6% and 3% respectively of the total cation content (TCC=$[K^+]$ + $[Ca^{2+}]$ + $[Mg^{2+}]$ + $[Na^+]$) of the fruit. Levels of sodium were as low as 0.7% of the TCC in the fruit and were on average the highest during the first season of saline irrigation (Fig. 5.7A). Significant differences between treatments were only found during 1997/98 and could not be related to saline irrigation treatments. Calcium increased significantly in the fruit of the 4 dS m^{-1} treatment during the 1995/96 season and in the fruit of the 2 and 3 dS m^{-1} treatments during the 1996/97 season (Fig. 5.7B). At harvest 1997/98 the calcium content

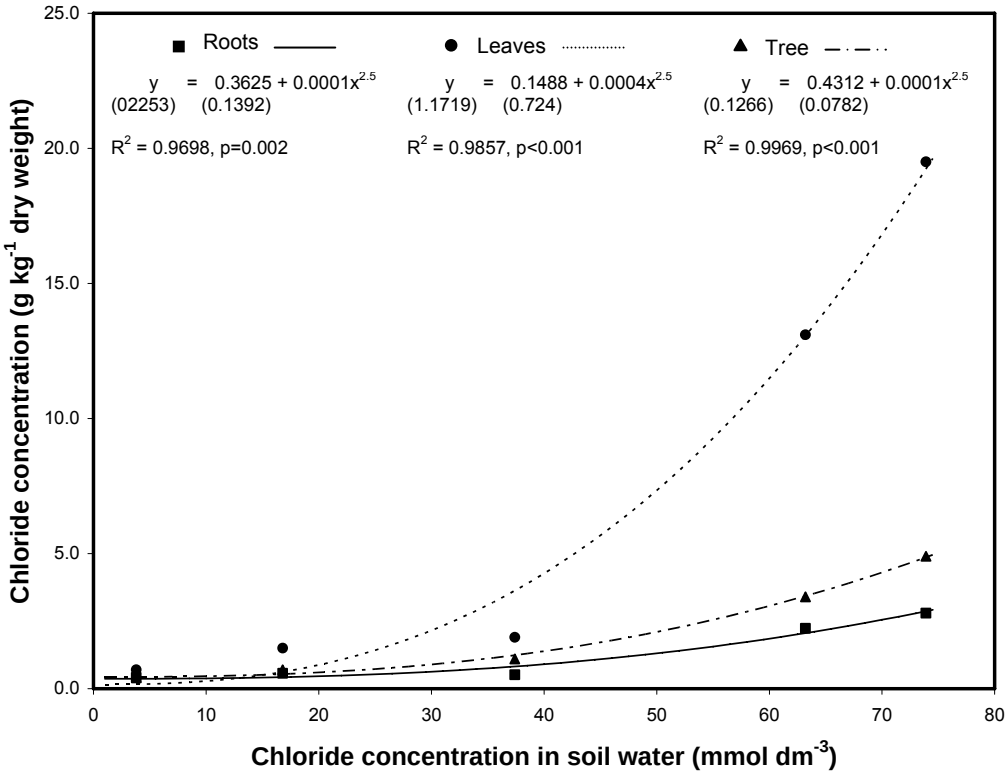
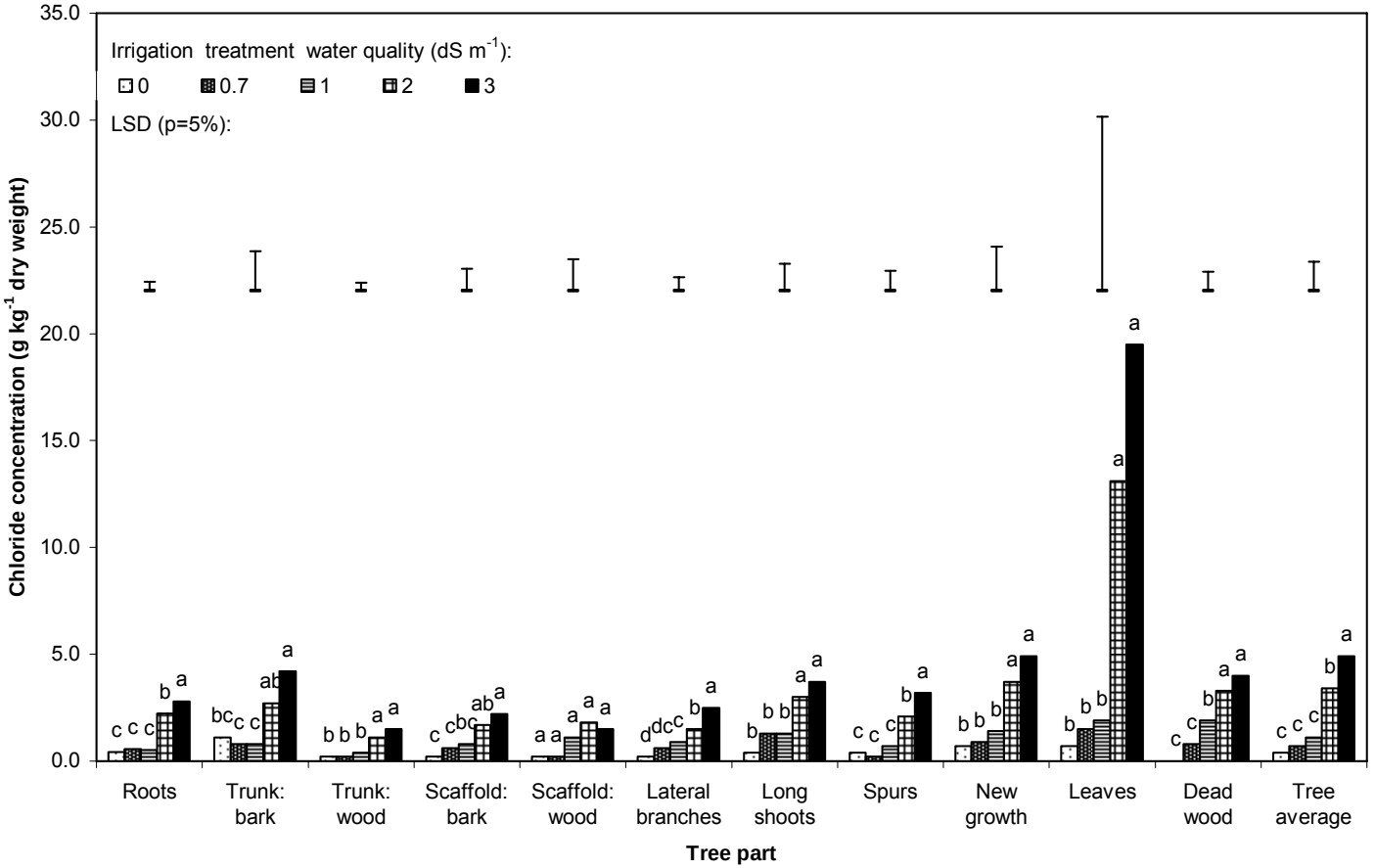


Figure 5.5. The effect of chloride in the soil water on concentration of chloride in the roots, leaves and above-ground tree parts of Palsteyn apricot on Marianna rootstock after four seasons of irrigation with water with varying salinity concentrations (n=5). Data are the means of replicate blocks (harmonic means of 3.33 to 3.75). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.



	Roots	Trunk: bark	Trunk: wood	Scaffold: bark	Scaffold: wood	Lateral branches	Long shoots	Spurs	New growth	Leaves	Dead wood	Tree average
SD:	0.3	1.2	0.2	0.7	0.9	0.4	0.8	0.6	1.3	5.1	0.6	0.9
(df)	9	11	10	11	10	10	11	11	11	11	11	11

Figure 5.6. The cumulative effect of four seasons of saline irrigation on the concentration of chloride in tree parts of Palsteyn apricot on Marianna rootstock. New growth refers to new shoot growth for the 1997/98 season. Columns within the same tree part capped by the same letter do not differ significantly according to Student's t-LSD calculated at a 5% significance level (the harmonic mean for replicates ranged between 3.33 and 3.75). The experimental standard deviation (SD) for each analysis of variance and degrees of freedom is indicated at the bottom of the graph.

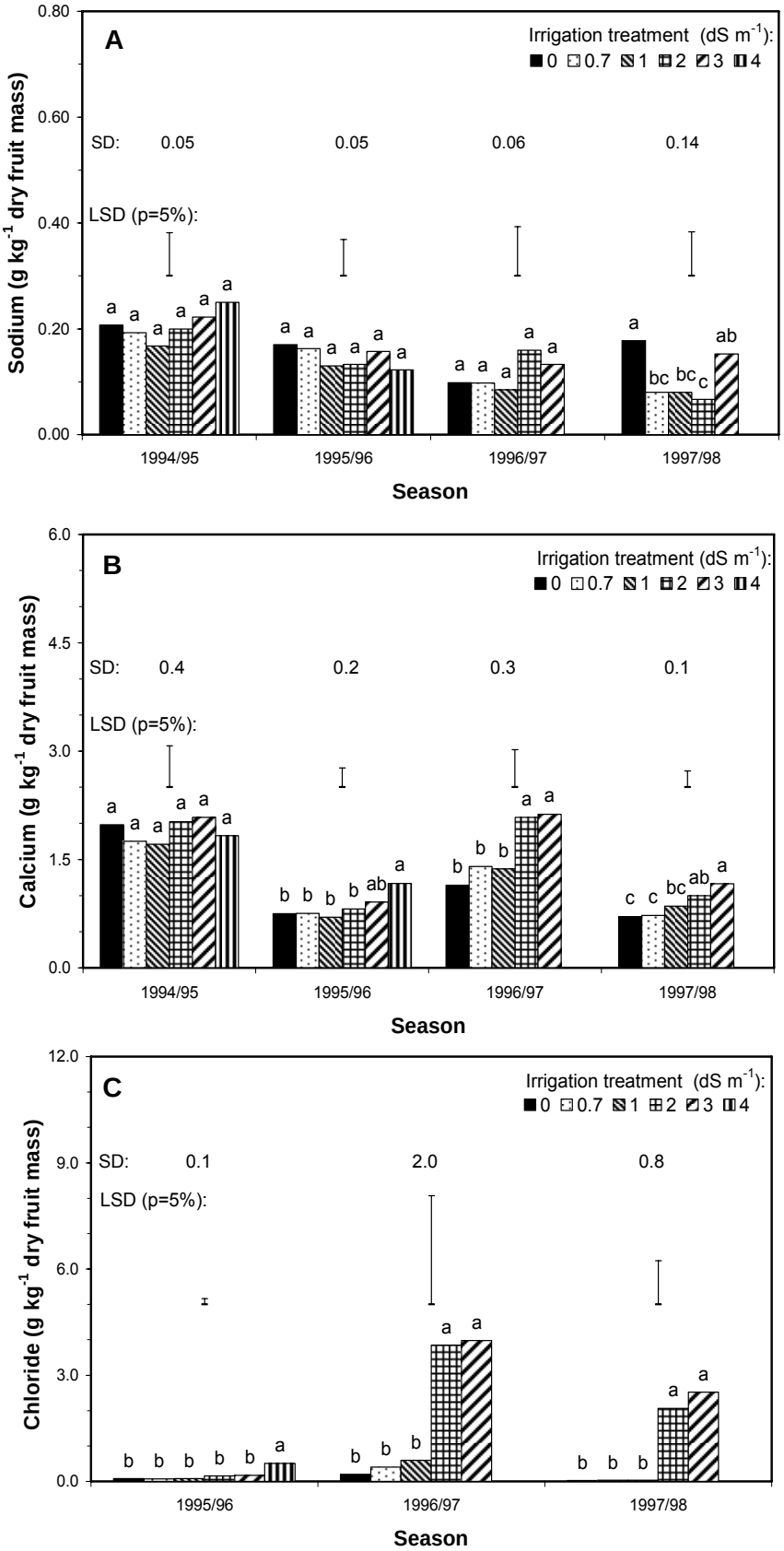


Figure 5.7. The effect of irrigation water salinity on the sodium (A), calcium (B) and chloride (C) content of Palsteyn apricot fruit after harvest during the 1994/95 (n=4), 1995/96 (n=4), 1996/97 (n=4) and 1997/98 (harmonic mean of replicate blocks = 3.75) seasons. Chloride was determined only on fruit of the last three seasons. Columns within each season capped by the same letter do not differ significantly according to Student's t-LSD calculated at a 5% significance level. The experimental standard deviation (SD) for each analysis of variance is indicated in the graph and the degrees of freedom were 15 for 1994/95 and 1995/96, 12 for 1996/97 and 11 for 1997/98.

of fruit reflected increasing salinity treatments. Chloride was significantly higher in fruit from 4 dS m^{-1} treatment during 1995/96 and the 2 and 3 dS m^{-1} treatments during the 1996/97 and 1997/98 seasons, with a distinct increase in chloride content of fruit from the treatments with more than 1 dS m^{-1} salinity during the last two seasons (Fig. 5.7C). Chloride concentrations in fruit of the 3 dS m^{-1} treatment during 1997/98 were more than twice that of calcium (0.04 in the 0 dS m^{-1} treatment) and approximately 17 times that of sodium (0.15 in the 0 dS m^{-1} treatment).

5.4 DISCUSSION

5.4.1 Irrigation and soil water concentration

The ratios of $Na^+/(Na^+ + Ca^{2+})$ of the irrigation water used in this study are similar to ratios of between 0.1 and 0.7 to which most irrigated horticultural crops are normally subjected in the field. The majority of salinity studies, including our research on apricot, used Cl^- as the sole salinising anion, despite most soil solutions containing a substantial amount of SO_4^{-2} and $HCO3^-$ (Grattan & Grieve, 1999). This is unfortunate, since sulfate can affect the absorption of Cl^- by the trees. Chloride absorption for apple, cherry, peach and grapes was apparently reduced by increasing the sulfate level in nutrient solution (Dilley *et al*., 1957). Most fruit crops are especially sensitive to sodium and chloride and, considering the long-term cumulative effect of these ions on perennial fruit crops (Bernstein, 1980; Catlin *et al*., 1993), it is even more important to use realistic salinising compositions in future studies on irrigation with saline water.

According to the irrigation water composition (Table 5.1), sodium toxicity could be expected in the 2 and 3 dS m^{-1} treatments and chloride toxicity, if rootstock is not taken into account, in all treatments except the 0 dS m^{-1} treatment (Ayers & Westcot, 1985; Kotzé, 1998). The sodium concentrations in the soil water of the 1, 2 and 3 dS m^{-1} treatments exceeded 5 mmol dm^{-3}, which has the potential to cause sodium toxicity in stone fruit trees (Rhoades & Loveday, 1990). Only the 2 and 3 dS m^{-1} salinity treatments were expected to cause chloride toxicity, since concentrations in the soil water exceeded the estimated 50 mmol dm^{-3} threshold for Marianna rootstock. This value was calculated assuming that the chloride concentration in the soil water would be twice as concentrated as that in the saturated soil water extract (Ayers & Westcot, 1985).

Palsteyn apricot on Marianna rootstock was able to tolerate the concentrations of sodium and chloride in soil water associated with treatments with salinity up to 1 dS m^{-1} (Table 5.1). Levels of sodium and chloride in irrigation water of the 1 dS m^{-1} treatment were respectively 2.9 mmol sodium dm^{-3} and 12.3 mmol chloride dm^{-3} during the last three irrigation seasons. This agrees well with sodium levels of 3 mmol dm^{-3} and the maximum chloride (12 mmol chloride dm^{-3})

internationally permissible in irrigation water to prevent leaf injury for Marianna rootstock with a leaching fraction of 0.1 (Ayers & Westcot, 1985).

5.4.2 Tree mineral content

All treatments, including the control, had less than 2 g kg^{-1} (0.2%) sodium in their leaves (Fig. 5.2), a level which is normally regarded as toxic (Bernstein, 1980). It has previously been reported that Marianna rootstock restricted sodium accumulation in scions (Bernstein *et al*., 1956; Ziska *et al*., 1991), probably by retention of sodium in the living wood parenchyma cells (Bernstein *et al*., 1956). Sodium accumulation in aboveground tree parts other than the leaves was prevented even though the sodium concentration in the roots increased significantly in the 0.7 and 1 dS m^{-1} saline irrigation treatments compared to that of the 0 dS m^{-1} treatment. The total salt content in the soil in the 2 and 3 dS m^{-1} saline irrigation treatments, however, exceeded the internationally recommended salinity threshold for apricot (data not shown, Chapter 3). The significant increase in sodium in above-ground parts of the trees when sodium levels reached 18 mmol dm^{-3} and approximately 21 mmol dm^{-3} respectively, in the soil water in the 2 and 3 dS m^{-1} saline irrigation treatments (Figs. 5.1 & 5.2) could therefore be due to the total salt content in the soil exceeding the salinity threshold for apricot, saturation of the sodium readsorptive process in Marianna rootstock or damage to cell membranes by excessive chloride levels. Sodium was also effectively excluded from leaves of the peach cultivar Golden Queen (Boland, Mitchell & Jerie, 1993) and plum trees (Santa Rosa) until substantial levels of chloride damaged leaf membranes (Hoffman *et al.,* 1989).

In roots and above-ground tree parts, except the leaves, sodium was in general concentrated to a larger extent as salinity increased (Fig. 5.1). The concentration of sodium appeared, with the exception of the bark of the scaffold, higher in roots and the perennial tissues of the 3 dS m^{-1} treatment compared to that for the mainly one-year-old long shoots, new growth and leaves (Fig. 5.2). The higher sodium concentration in the perennial tissues could be due to a carry over of accumulated salts in woody tissue and roots (Bernstein, 1980) as was found for woody tissue of peach (Boland *et al.*, 1993) and pear (Myers *et al*., 1995) trees subjected to saline irrigation. The concentration of sodium in the spurs of Palsteyn apricot in the 0.7 to 2 dS m^{-1} and 3 dS m^{-1} treatments were approximately 3-fold and 2-fold, respectively, higher than that in the long shoots, although the sodium concentration in the long shoots and spurs in the control treatment was of the same magnitude.

Retranslocation of sodium from shoots to roots may contribute to low sodium contents in shoots of salt sensitive species (Marschner, 1995) and the reabsorption process may involve exchange of potassium for sodium (Walker, 1986). The 25% increase in potassium levels in long shoots of

Palsteyn apricot in all the saline treatments compared to that in the control (data not shown) indicated that potassium is most likely exchanged for sodium in these shoots. High levels of calcium were present in Palsteyn shoots and spurs (Fig. 5.4) and, according to Marschner (1995), the presence of calcium could increase potassium: sodium selectivity for uptake by stimulation of a sodium efflux pump that counter transport potassium or hydrogen for sodium, or through its general effects on plasma membrane integrity.

The potassium levels in the spurs, however, decreased by approximately 50% in all the saline treatments compared to the control (data not shown). The absence of treatment differences in calcium concentrations of the spurs (Fig. 5.4) as well as potassium levels being decreased to the same extent for all saline treatments in these tissues, could signify increased sodium: calcium and sodium: potassium competition for cell binding sites or ion transport channels in cell membranes. Calcium and/or potassium were apparently displaced from the cells by sodium concentrations of *c.* 0.7 g kg^{-1} dry weight in Palsteyn apricot spur tissue (Fig. 5.2). Ziska *et al*. (1991) reported higher concentrations of sodium in 1 to 3-year-old twigs than in trunks and branches of saline irrigated Santa Rosa plum trees while Bernstein *et al*. (1956) found restricted sodium accumulation in twigs compared to the roots, wood and bark of saline irrigated Royal apricot.

The higher concentration of sodium in the spurs of Palsteyn apricot on Marianna rootstock could probably be ascribed to a scion specific mechanism, such as specialized cells with a recycling function, excluding sodium from the leaves (Fig. 5.2) and fruit (Fig. 5.7A) and/or the cumulative effect of saline irrigation applied during four consecutive seasons. The sodium content of spur branches was also significantly higher in cultivar Ruby and cultivar Butte almond trees on Nemaguard rootstock receiving saline water compared to those receiving non-saline water (Hutmacher *et al*., 1989). The significantly higher sodium concentration in spurs of Palsteyn apricot in the 2 and 3 dS m^{-1} treatments (Fig. 5.2) could have been enhanced by chloride-damaged cell membranes and decreased retention of sodium in the rootstock. The distribution pattern of sodium in Palsteyn apricot tree parts affirm the conclusion of Walker (1986) from work on *Citrus* that there are complex interactions between the scion and the rootstock and it appears that both modulate sodium levels in shoots and leaves.

Structural wood of peach trees acted as a sink and took up large amounts of sodium and chloride ions under saline irrigation, with a higher ratio of Na to Cl in the wood compared to the leaves (Boland *et al*., 1993). Ziska *et al*. (1991) similarly concluded that sodium was retained to a greater extent than chloride in the trunk and branches of plum trees on Marianna 2624 rootstock exposed to high irrigation water salinity. Only 29% of the total amount of chloride per tree accumulated in Palsteyn apricot on Marianna rootstock trees receiving the 3 dS m^{-1}

treatment was found in wood of the scaffold, wood of the trunk and lateral branches (data not shown) while 80% percent of the total amount of sodium accumulated in these tissues. These results support the perception of Ziska *et al*. (1991) that woody tissue is the primary repository of sodium and is in agreement with work of Myers *et al*. (1995) where saline irrigation increased the sodium concentrations in the sapwood and heartwood of mature pear trees of the cultivar Williams Bon Cretien. The decrease in concentration of chloride in the different tree parts in the most saline treatment (Fig. 5.2) furthermore agrees with the findings of Bernstein *et al*. (1956) that in general, chloride concentration per dry-weight tends to be the highest in the leaves and the lowest in the wood. Although conversion from saline to non-saline irrigation water showed potential for revival of plum trees (Catlin *et al.,* 1993), the retention of sodium in permanent parts of trees is still a cause for concern. Accumulation of excessive amounts of sodium in Palsteyn apricot trees must therefore rather be prevented to avoid the detrimental effect of sodium in the long term.

Transport of both sodium and chloride from roots to leaves of citrus grown under saline conditions was found to be effectively reduced by calcium (Grattan & Grieve, 1999 and references therein). The calcium concentration in Palsteyn apricot trees increased significantly with severity of salinity, and more calcium than sodium or chloride was accumulated at comparable soil water concentrations (Figs. 5.1, 5.3 & 5.5). The large difference in accumulation rates of calcium compared to that of sodium and chloride may be ascribed to Marianna rootstock that restricts sodium and chloride accumulation (Bernstein *et al*., 1956). The calcium concentration in leaves of all trees (Fig. 5.6) was more than that reported by Jones (1985) to be needed for adequate nutritional levels. The significantly higher calcium concentration in the leaves, new growth and long shoots in the 2 and 3 dS m^{-1} treatments compared to all less saline treatments reflected the higher calcium concentration found in these treatments in the roots (Fig. 5.2).

The lack of any trend in calcium concentrations in the lateral branches and spurs of the different treatments (Fig. 5.4) could probably be attributable to one of the following reasons: 1) Presumably precipitated calcium may have been released, most likely in the lateral branches, to the transpiration stream by some or other transport mechanism such as growth regulator stimulated pH-driven calcium channels in the plasma membrane (Felle, 1988). This release of calcium probably did not occur to the same extent for all salinity treatments as the calcium concentrations in the lateral branches and spurs did not differ significantly between treatments although it did in the wood of the scaffold. 2) The product of decreased transpiration rates and higher calcium concentrations in high salinity treatments could be similar to that of higher transpiration rates and lower calcium concentrations in less saline treatments. The transpiration rates of Palsteyn apricot trees in saline treatments decreased relative to that in the 0 dS m^{-1}

treatment (see Chapter 4) and could therefore have had an affect on ion concentrations. 3). Sodium accumulated in the lateral branches and spurs of saline treatments (Fig. 5.2) and the sodium could have competed with calcium for binding sites or replaced the calcium from cell membranes (Rengel, 1992) resulting in a decline in calcium concentration in these tree parts.

The calcium concentration in the bark of the trunk and scaffold of all treatments was several orders of a magnitude higher than that in other tree parts and significantly higher in the bark of the scaffold in the saline treatments compared to that in the 0 dS m^{-1} treatment (Fig. 5.2). Although substantial calcium concentrations may be found in the phloem sap, the calcium concentration in the phloem sap of plants is in general very low and it is a mineral with very low phloem mobility (Marschner, 1995). The high calcium levels in the bark and leaves of Palsteyn apricot on Marianna rootstock could, however, indicate the presence of calcium salts of low solubility. Although a high proportion of the total calcium in plant tissue is bound to cell walls, calcium oxalate crystals may increase in the vacuoles of leaf cells or in the apoplasm if calcium is abundant (Marschner, 1995). The precipitation of calcium in the leaf apoplasm is seen as a mechanism to prevent excessive solute accumulation in the leaf apoplasm and to cope with continuous xylem import of calcium which is not readily exported in the phloem and where the ionic concentrations in the symplasm have to be kept very low (Marshner, 1995). Such a strategy is used particularly for the removal of soluble calcium in gymnosperms, as calcium oxalate crystals are plentiful in the cell walls of the mesophyll and particularly the phloem and in the outer wall of the epidermis of gymnosperm needles (Fink, 1991). In plants low concentrations of cytosolic calcium is needed to prevent precipitation of phosphate, competition with magnesium for binding sites and is a prerequisite for the function of calcium as second messenger of environmental signals, while only very low levels of free calcium can be present in the phloem sap for the normal functioning of long-distance transport (Marschner, 1995).

Chloride, like calcium, is transported readily in the transpiration stream of plants and the concentration was higher in the leaves compared to all other tree parts except the bark of the trunk. The leaves of the control treatment had 0.7 g chloride kg^{-1} dry weight, which was comparable to values of between 0.4 to 1.8 g chloride kg^{-1} dry weight reported by Bernstein, Brown & Hayward (1956) in leaves in the control treatment of several stone fruit species. The high chloride concentrations observed in the leaves of the 2 and 3 dS m^{-1} treatments exceeded the documented 5 g kg^{-1} (0.5%) limit for leaf burn of stone fruit (Bernstein, 1980) and a 10 g kg^{-1} (1%) limit for leaf burn of apricot trees (Bernstein, Brown & Hayward, 1956). The highest levels of chloride accumulated in leaves of Royal apricot on Lovell root irrigated with water of salinity of 5.1 dS m^{-1}, varied between 11 and 12 g chloride kg^{-1} dry weight (Bernstein, Brown & Hayward, 1956) which is lower than the chloride concentrations found in the leaves of Palsteyn apricot on Marianna rootstock in the 2 and 3 dS m^{-1} treatments.

The 4-fold and 7-fold increase in concentration of chloride levels in roots and leaves respectively, of Palsteyn apricot on Marianna rootstock between the 1 to the 2 dS m^{-1} treatments (Fig. 5.6) reflected increases in chloride concentrations in the soil water exceeding the chloride tolerance threshold for Marianna rootstock of 50 mmol chloride dm^{-3} (Fig. 5.5) and was ascribed to the total salt content in the soil exceeding the salinity threshold for apricot, damaged cell membranes and disrupted specific-ion uptake processes. High levels of chloride were also found in Santa Rosa plum on Marianna 2624 rootstock for irrigation treatments of 2 dS m^{-1} and higher (Catlin *et al*., 1993). The increase in leaf chloride levels from the 1 to the 2 dS m^{-1} treatment was in that case, however, only approximately 4-fold.

5.4.3 Ion composition of fruit

Levels of sodium as low as 0.7% of TCC in the fruit (Fig. 5.7A) as well as low sodium concentrations in leaves and new growth (Fig. 5.2) confirmed that transport of sodium was restricted to the main frame and rootstock of the tree. This was in contrast with work of Boland *et al*. (1993) on peach, who reported that saline irrigation increases both sodium and chloride levels in fruit, with sodium in a higher proportion to chloride in fruit compared to the leaf. Van Zyl (1997) reported that 17% of the total sodium and 12% of the total chloride per Colombar/99R vine was removed with grapes at harvest from a 3.5 dS m^{-1} treatment. Sodium in the higher salinity treatments apparently moves more readily to the grapes and leaves, where it is then removed from the plant at harvest and during leaf fall respectively. This was, however, not the case with Palsteyn apricot on Marianna rootstock. Sodium was probably prevented from entering the fruit (Fig. 5.7A) by the same mechanism that prevented accumulation in leaves and caused sodium accumulation in the spurs (Fig. 5.2).

The calcium concentration in fruit harvested during the 1997/98 season followed the same trend as found in roots, leaves, new growth and long shoots (Fig. 5.2), increasing with irrigation water salinity (Fig. 5.7B). The concentration of calcium in the roots and above-ground tree parts was considerably higher than that of sodium and chloride (Figs. 5.2, 5.4 & 5.6). In contrast, the calcium concentration in the fruit was approximately half of the concentration of chloride, which indicates that transport of chloride to the fruit is probably more effective than that of calcium (Fig. 5.7B & C). Sodium and chloride may be present at high concentrations in the phloem sap (Hocking, 1980) and are highly mobile in the phloem, in contrast to calcium, which has low mobility and very low concentrations in the phloem sap. Due to its low concentrations in the phloem sap the import of calcium into fruits is mostly restricted to the xylem. Fleshy fruits, however, are supplied with solutes predominantly via the phloem and low rates of transpiration and inherently low rates of xylem volume flow (Marschner, 1995) could explain the lower calcium levels in fruit compared to that of chloride.

The distinct increase in chloride content of fruit from the treatments with more than 1 dS m^{-1} salinity during the 1996/97 and 1997/98 seasons (Fig. 5.7C) correlated well with the drastic increase in chloride levels found in the roots and leaves between the 1 dS m^{-1} and 2 dS m^{-1} treatments (Fig. 5.6) and confirms the possibility that the salinity threshold and/or chloride tolerance levels of the rootstock was exceeded. Leaf chloride of Marsh Seedless grapefruit and Washington navel orange on three rootstocks was highly correlated to fruit juice chloride (Levy & Shalevet, 1990) and according to Storey and Walker (1999), it could indicate that influx of chloride into leaves parallels influx of chloride into fruit.

5.5 CONCLUSIONS

The salt accumulation in Palsteyn apricot on Marianna rootstock confirmed the internationally allowed sodium levels of 3 mmol dm^{-3} and the maximum chloride (12 mmol chloride dm^{-3}) permissible in irrigation water to prevent leaf injury for Marianna rootstock with a leaching fraction of 0.1. Marianna rootstock and the scion Palsteyn effectively excluded and/or recycled toxic ions until chloride levels in the soil water in the 2 and 3 dS m^{-1} saline irrigation treatments exceeded the tolerance level of Marianna rootstock of *c.* 50 mmol chloride dm^{-3}. Disruption of the rootstock/scion tolerance was probably due to the total salt content in the soil exceeding the salinity threshold for apricot, chloride damaged cell membranes and interference with the ion-specific uptake processes. These conditions resulted in a drastic increase in chloride in trees, and especially in leaves and fruit and accumulation of significant amounts of sodium in woody parts of the tree. Leaves did not show excessive levels of sodium until harvest after nearly four years of saline irrigation and this indicated that the capacity of the tree frame to store these toxic ions was not exceeded. The majority of sodium was retained in the woody tree parts and, based on results of other authors regarding the retention of sodium in perennial fruit trees after changing to non-saline irrigation, it is recommended that conditions that promote accumulation of sodium in Palsteyn apricot should rather be avoided to prevent yield decrease and ultimately, tree loss in the end.

5.6 REFERENCES

Anon., 1973. The determination of chloride in plants and feedingstuffs. *In*: Ministry of Agriculture, Fisheries and Food (ed.). The analysis of agricultural materials: A manual of the analytical methods used by the agricultural development and advisory service. Tech. Bull. No. 27. London: Ministry of Agriculture, Fisheries and Food.

Ayers, R.S. & Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome:FAO.

Bernstein, L., 1980. Salt tolerance of fruit crops. *USDA Agric. Inf. Bull*. 292: 1-8

Bernstein, L., Brown, J.W. & Hayward, H.E., 1956. The influence of rootstock on growth and salt accumulation in stone fruit trees and almonds. *Proc. Am. Soc. Hort. Sci.*, 68: 86-95.

Boland, A.M., Mitchell, P.D. & Jerie, P.H., 1993. Effect of saline water combined with restricted irrigation on peach tree growth and water use. *Aust. J. Agric. Res.,* 44: 799-816.

Catlin, P.B., Hoffman, G.J., Mead, R.M. & Johnson, R.S., 1993. Long term response of mature plum trees to salinity. *Irrig. Sci.*, 13: 171-176.

Dilley, D.R., Kenworthy, A.L., Benne, E.J. & Bass, S.T., 1958. Growth and nutrient absorption of apple, cherry, peach, and grape plants as influenced by various levels of chloride and sulphate. *Proc. Am.Soc. Hort. Sci*., 72: 64-73.

Ehlig, C.F. & Bernstein, L., 1959. Foliar absorption of sodium and chloride as a factor in sprinkler irrigation. *Proc. Am. Soc. Hort Sci.,* 74: 661-670.

Felle, H., 1988. Cytoplasmic free calcium in *Riccia fluitans* L. and *Zea mays* L.: Interaction of Ca^{2+} and pH? *Planta,* 176: 248-255.

Fink, S., 1991. Comparative microscopical studies on the patterns of calcium oxalate distribution in the needles of various conifer species. *Bot. Acta*, 104: 306-315.

Grattan, S.R. & Grieve, C.M., 1999. Salinity-mineral nutrient relations in horticultural crops. *Sci. Hort.,* 78: 127-157.

Hocking, P.J., 1980. The composition of phloem exudate and xylem sap from tree tobacco (*Nicotiana glauca* Groh). *Ann. Bot. (London)*, 45: 633-643.

Hoffman, G.J., Catlin, P.B., Mead, R.M., Johnson, R.S., Francois, L.E. & Goldhamer, D., 1989. Yield and foliar injury responses of mature plum trees to salinity. *Irrig. Sci.,* 10: 215-229.

Hutmacher, R.B., Nightingale, H.I., Vail, S.S., Dale, F., Rolston, D.E., Peters, D.W., Brown, P.H., Pflaum, T., Bravo, A.D. & Biggar, J.W., 1989. Salinity and boron distribution in microirrigated almonds: soil and plant accumulations. *In*: F.R.Lamm (ed.). Microirrigation for a Changing World: Conserving Resources/ Preserving the Environment. Proc. of the Fifth International Microirrigation Congress, April 2-6, 1995. Orlando, Fla: ASAE, p. 110-115

Jones, J.B. (JR), 1985. Soil Testing and Plant Analysis: Guides to the Fertilization of Horticultural Crops. *Hort. Rev.*, 7: 1-68.

Kotzé, W.A.G., 1998. Water quality for irrigation with particular emphasis on fruit trees. INFRUITEC, Private Bag X 5026, Stellenbosch, South Africa.

Levy, Y. & Shalevet, J., 1990. Ranking the salt tolerance of citrus rootstocks by juice analysis. *Sci. Hort..,* 45: 89-98.

Marschner, H., 1995. Mineral Nutrition of Higher Plants, 2nd Ed. New York: Academic Press.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J., Meiri, A. & Moolman, C.G., 1999. The use of saline water for irrigation of grapevines and the development of crop salt tolerance indices. WRC Report No. 303/1/98. Pretoria: Water Research Commission.

Murray, Biesenbach & Badenhorst Inc., 1989. A pilot study of the irrigated areas served by the Breede River (Robertson) irrigation canal. Part 1: Technical Report. Water Research Commision Report No. 184/1/89. Pretoria: Water Research Commission.

Myers, B.A., West, D.W., Callinan, I. & Hunter, C.C., 1995. Long term effects of saline irrigation on yield and growth of mature Williams pear trees. *Irrig. Sci.*, 16: 35-46.

Rengel, Z., 1992. The role of calcium in salt toxicity. *Plant Cell Environ.,* 15: 625-632.

Research Institute for Fruit and Fruit Technology, 1983. Anorganic fertilization of deciduous fruit. *Inf. Bull.* 512. Stellenbosch: Dept. of Agriculture.

Rhoades, J.D. & Loveday, J., 1990. Salinity in irrigated agriculture. *Agronomy,* 30: 1089-1142.

Storey, R. & Walker, R.R., 1999. Citrus and salinity. *Sci. Hort.,* 78: 39-81.

Van Zyl, E., 1997. Seasonal distribution of salts in the plant organs of *Vitis* v*inifera* L. (cv. Colombar) irrigated with saline water. M.Sc Thesis, University of Stellenbosch, Stellenbosch, South Africa.

Victor, J., 1995. The Apricot Industry in South Africa. *In*: R.Gülcan & U.Aksoy (eds). Tenth International Symposium on Apricot Culture. Izmir,Turkey. 20-24 September 1993. Acta Horticulturae*,* 384: 163-167.

Walker, R.R., 1986. Sodium exclusion and potassium-sodium selectivity in salt-treated trifoliate orange (*Poncirus trifoliata*) and Cleopatra mandarin (Citrus reticulata) plants. *Aust. J. Plant Physiol*., 13: 93-303.

Ziska, L.H., DeJong, T.M., Hoffman, G.F. & Mead, R.M. 1991., Sodium and chloride distribution in salt-stressed *Prunus salicina*, a deciduous tree species. *Tree Physiol.*, 8: 47-57.

CHAPTER 6

The effect of saline irrigation water on plant physiological processes, vegetative and reproductive growth and fruit quality of Palsteyn apricot

6.1 INTRODUCTION

Soil salinisation is the most prevalent and widespread problem limiting crop production in irrigated agriculture (Shalevet, 1994). Sustained and profitable production of crops on salt-affected soils is, however, possible if appropriate on-farm management decisions are made. In order to be successful, producers require an understanding of how plants respond to salinity, the relative tolerances of different crops and their sensitivity at different stages of growth, and how different soil and environmental conditions affect salt-stressed plants (Francois & Maas, 1994). Due to their perennial nature, fruit trees and vines are a long-term investment for producers and it is therefore important to establish the effect of prolonged exposure to salinity on the growth, production and longevity of the trees. *Prunus* species are generally considered to be sensitive to salinity compared to most fruit crops (Maas & Hoffman, 1977) and apricot considered to be more sensitive than other *Prunus* species (Bernstein, Brown & Hayward, 1956).

Deciduous fruit trees are sensitive to salinity and will suffer yield reductions if irrigation water becomes more saline (Hoffman *et al*., 1989). In general, growth inhibition and yield reduction on saline substrates may be the result of osmotic inhibition of water absorption, oxidative stress and specific ion effects on key physiological processes (Orcutt & Nilsen, 2000). Soil salinity results in a decreased osmotic potential of the soil water that reduces plant available water (Dudley, 1994) and could cause osmotic adjustment, turgor reduction and decreased cell wall elasticity (Orcutt & Nilsen, 2000), thereby depressing growth. Water deficit could, furthermore, reduce stomatal conductivity by means of hydraulic signals and/or endogenous phytohormone signals from the roots to shoots (Jones, 1998; Munns, 1993; Poljakoff-Mayber & Lerner, 1994; Schulze, 1986) and consequently decrease production of assimilates by photosynthesis. In addition to effects on leaf expansion, water deficits can reduce the number of growing points and thus leaves produced (Jones & Tardieu, 1998) as was found for young peach trees subjected to water stress under non-saline conditions (Steinberg, Miller & McFarland, 1990).

Specific ion effects may involve direct toxicity or nutritional disturbances (Bernstein & Hayward, 1958). Toxic chloride, sodium and boron are of specific importance in the case of deciduous fruit trees (Bernstein, 1980; Hoffman *et al*., 1989) and the detrimental direct effects of ions manifest at the level of enzyme activity, membrane function and several important metabolic

processes, including photosynthesis and respiration (Orcutt & Nilsen, 2000). Photosynthesis may be decreased through stomatal and/or non-stomatal limitations (Ziska, Seeman & DeJong, 1990). An osmotic related specific ion effect could occur if excessive levels of specific ions are transported to leaves and inadequately balanced and/or compartmented. Accumulation of excessive amounts of ions in the apoplast will withdraw water from the protoplasts and cause loss of turgor, cellular desiccation and ultimately death (Flowers & Yeo, 1986), thereby causing leaf burn and reducing the effective leaf area for photosynthesis. Dry matter production of horticultural crops is primarily driven by photosynthesis, which to a great extent depends on the interception of light (Marcelis, Heuvelink & Goudriaan, 1998). Leaf area is an important determinant of light interception and thus foliar damage and premature leaf senescence of deciduous fruit trees caused by salinity (Catlin *et al*., 1993; Myers *et al.*, 1995) directly affect assimilate production and carbohydrate reserves of perennial tissues. Studies on perennial fruit and vine crops indicated that limited carbohydrate reserves as well as a carry-over effect of specific ions in perennial tissues between growing seasons may affect performance and longevity of trees (Catlin *et al*., 1993; Myers *et al*., 1995; Moolman *et al*., 1999; De Clercq *et al*., 2001).

Nutritional disorders can develop and crop growth may be reduced under saline conditions, which are characterised by low nutrient ion activities and extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+} and Cl^-/NO_3^-. These nutrient imbalances may result from the effect of salinity on nutrient availability, competition during ion uptake and altered ion transport or partitioning within the plant. The ultimate effect of salinity-nutrient interactions on crop yield or quality depends upon the salinity level and the composition of salts, the crop species, the nutrient in question and a number of environmental factors (Grattan & Grieve, 1994). The relative contribution of the osmotic and specific ion effects to growth inhibition at high salinity levels, are influenced by ion concentrations and relations in the substrate, duration of exposure, plant species, cultivar and rootstock, stage of plant development, plant organ and environmental conditions (Marschner, 1995).

The average root zone salinity, measured by electrical conductivity of the saturated extract of the soil (EC_e), has been used to define salt tolerance of a variety of agricultural crops (Maas & Hoffman, 1977). Grapevine yields decreased progressively above an EC_e of 0.75 dS m^{-1} when cultivated in a region of South Africa with a rainfall of 200 to 300 mm combined with hot dry summers (Moolman *et al*., 1999). These grapevines were thus more sensitive to salinity than those reported on by Maas & Hoffman (1977). The rate of yield decrease was three times faster than that previously reported by Maas & Hoffman (1977) and could partially be attributed to specific ion effects (Moolman *et al*., 1999). According to Maas & Hoffman (1977) apricot trees, like grapevines, are also sensitive to salinity and a decrease in the vegetative growth of

apricot may be expected at EC_e values that exceed 1.6 dS m^{-1}. Apricot growth apparently ceases at an EC_e of approximately 5.8 dS m^{-1}. If a leaching fraction of 0.1 is assumed, irrigation water of 0.76 dS m^{-1} should be used when no growth decrease is desired, while irrigation water with salinity exceeding 2.76 dS m^{-1} will probably cause tree death in the end. A yield reduction of approximately 10% can be expected at a root zone salinity where the EC_e is 2.5 dS m^{-1} (Bernstein, 1980) with serious financial implications for farmers when combined with low profit margins. Thus it is important to establish a salinity threshold value for a locally important apricot cultivar under a different set of climatic conditions.

The objective of this investigation was to describe the response of selected plant physiological processes, vegetative and reproductive growth and the resulting fruit quality of Palsteyn apricot trees grafted on Marianna rootstock to saline irrigation and to identify causal factors contributing to the response. The locally determined salinity threshold value for yield decrease was compared with the internationally published threshold value for salinity management purposes, and salinity and specific ion toxicity response functions for vegetative growth and yield presented.

6.2 MATERIALS AND METHODS

6.2.1 Plant material and cultivation

The irrigation trial was conducted at Stellenbosch, in the Western Province of the Republic of South Africa in 24 drainage lysimeters. Five-year-old *Prunus armeniaca L.* (cultivar Palsteyn) trees on Marianna rootstock (*Prunus cerasifera* x *Prunus munsoniana*) were grown in sandy loam soil in the lysimeters (2 trees per lysimeter; area per tree 1.4 m x 1.5 m and 1.2 m deep) for use in this experiment. Trees were pruned during winter and summer pruning was performed when necessary. Trees were hand-thinned in the spring and a standard fertilising (Fruit and Fruit Technology Research Institute, 1983) and pest and disease control program was followed throughout the season.

6.2.2 Experimental design

The experimental design consisted of six treatments replicated four times. Salinity treatments included municipal water, referred to as the "0 dS m^{-1} treatment", and irrigation waters of target salinity levels (EC_{iw}) of 0.7, 1, 2, 3 and 4 dS m^{-1}. Different salinity levels were achieved by mixing different volumes of a stock solution of 1:1 M NaCl:$CaCl_2$ with municipal treatment water and the salt concentration of the solutions corresponding to the EC_{iw} were 0; 2.2; 3.3; 7.1; 10.8 and 14.6 mM. A full description of the irrigation system and detailed irrigation procedures for each season from 1993/94 to 1997/98 was included in a previous paper (Chapter 3). Irrigation

was supplied on a weekly basis from the beginning of October in 1995 and 1996 and from September in 1997 and a leaching fraction of 0.1 was applied.

6.2.3 Irrigation water and soil-related measurements

Irrigation water of the different treatments was sampled at all irrigation events and the electrical conductivity determined with a HI 8820 Bench Conductivity meter (Hannah, Italy). Soil water was extracted at selected dates 24 h after irrigation throughout the season at 150, 300, 600 and 900 mm depths to determine the total salinity, measured as electrical conductivity. Soil solution samples were retrieved directly after collection for determination of the electrical conductivity of the soil solution and cation concentrations. The soluble cations (Ca^{+2}, Mg^{+2}, Na^{+}) in the extract were determined using an inductive coupled plasma atomic emission spectrometer (Liberty 200 ICP, Varian Australia Pty Ltd, Australia). Soil water salinity (EC_{sw}) values were integrated over time and over depth of the root zone according to Moolman *et al*. (1999) for each season, excluding the period when trees were dormant and are referred to as EC_{sw}'. Soil water osmotic potential at field capacity was estimated according to Maas (1987). The electrical conductivity of an extract of a saturated-soil paste (EC_e) was estimated as $EC_e' = 0.3751EC_{sw}'$ ($R^2 = 0.73$, $p<0.001$, $n=12$) for 1995/96, and as $EC_e' = 0.4567EC_{sw}'$ ($R^2 = 0.92$, $p<0.001$, $n=12$) for the 1996/97 and 1997/98 seasons in order to calculate the depth weighted seasonal average soil water osmotic potential in MPa at field capacity as $\psi_{o,FC} = (-0.725 \times EC_e'^{(1.06)})/10$. Soil water content was monitored at 200, 300, 600 and 900 mm depths once a week before irrigation by means of a neutron water meter (CPN 503DR Hydroprobe® Moisture gauge, Boart Longyear Company, California, USA) in order to estimate water consumption and irrigation amounts needed.

6.2.4 Physiological measurements

Plant physiological measurements were performed fortnightly during the 1995/96 season (10 days in total) one day before irrigation. During the 1996/97 season measurements were performed one day after irrigation and restricted to the beginning of the season (October), before harvest (November/December) and after harvest (February). Measurements included net carbon dioxide assimilation (10h00-12h00); leaf water potential (04h00, 10h00-12h00) and osmotic potential (04h00, 10h00-12h00). An LCA2 or LCA3 photosynthesis system (ADC, Herts, England) was used to determine the net photosynthesis, stomatal conductance and transpiration of three leaves per tree from the middle of extension shoots. During 1995/96 the LCA2 was used and inlet air dried by means of silica gel. During the 1996/97 season ambient air was used by the LCA3 and the incoming humidity recorded.

Leaf water potential was determined on the same three leaves per tree as used for photosynthetic measurements with an Arimad pressure chamber following the method of

Scholander *et al*. (1965). Directly afterwards the leaves were snap frozen in liquid nitrogen. Leaves were later defrosted and osmotic potential of the expressed cell sap determined with a Wescor Model 5 500 Vapour pressure osmometer (Wescor Inc., Logan, Utah, USA). Relative water content was determined on ten leaves per tree at selected intervals from the middle of extension shoots at the beginning of the season, before harvest and after harvest during 1996/97. Relative water content was determined by punching disks from the leaves at 05h00 and determining fresh, turgid and dry mass of disks according to the method of Turner (1981).

6.2.5 Vegetative characteristics

*V*egetative growth was evaluated by measuring the leaf area index by means of the LAI2000 plant canopy analyser (Li-Cor, Lincoln, Nebraska, USA) before summer pruning in 1995/96 (January), monthly during the 1996/97 season from November until April (excluding December) and during 1997/98 from October until December. During the 1995/96 and 1996/97 seasons the summer-pruned leaves and wood were separated, dried for 48 h at 70°C, and weighed. Vegetative growth was also evaluated by measuring the seasonal increase in stem circumference during winter (June).

The foliar damage of trees was assessed visually using the rating scale as described by Hoffman *et al*. (1989). During 1995/96 trees were monitored fortnightly for foliar damage. During the 1996/97 season, foliar damage was assessed fortnightly from mid-October until mid-November and at least at monthly intervals thereafter. Ten leaves per tree were sampled monthly from the middle of extension shoots in order to monitor mineral content (Na^+, Ca^{2+} and Cl^-) and average area per leaf. Foliar damage assessment of trees during 1997/98 was done monthly from mid-October until the end of November and leaves were sampled in order to monitor mineral content and average area per leaf. Leaf areas were determined by means of the Li-Cor C3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA).

Leaves were washed with a diluted detergent solution, rinsed once with tap water and three times with deionised water to remove dirt from the outside surfaces and dried to a constant dry mass in a forced-draft oven at 65°C. Leaves were milled in a stainless steel mill (Wiley) and passed through a 40-mesh screen prior to re-drying. Samples of 1 g were weighed directly after cooling and dry incinerated in a microwave oven at 480°C for 45 minutes. The resultant ash was dissolved in 5 ml 5 M HCl and diluted to 50 ml with deionised water. Sample solutions were filtered through Whatman no.2 filter paper before determination of K, Ca, Mg, P, Na, Mn, Fe, Cu, Zn and B concentrations by means of the inductive coupled plasma atomic emission spectrometer (Liberty 200 ICP, Varian Australia Pty Ltd, Victoria, Australia). Nitrogen concentrations were determined with a LECO N-analyser (FP428 Determinator, ®LECO

Corporation, United States of America) and chloride concentrations were determined by titration (Anon, 1973).

Specific leaf area was determined on ten leaves per tree at selected intervals from the middle of extension shoots before and after harvest during 1996/97 and before harvest during 1997/98. The leaf area was determined by means of the Li-Cor C3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA) before leaves were dried for 48 h at 70°C, cooling allowed and weighed. Specific leaf area was calculated as the ratio of leaf area to leaf weight.

6.2.6 Phenology, reproductive growth and fruit quality

During the 1995/96 season the flower index (number of flower buds : number of flower and vegetative buds at full bloom) and flower density (flower buds : shoot length) were monitored on three short shoots (< 15 cm), three long shoots (>20 cm) and three segments (*c*. 30 cm) on lateral branches of two trees per plot from approximately 5% bloom until full bloom. During the 1996/97 and 1997/98 seasons the flower index and flower density were monitored on two segments (±30 cm) on lateral branches of two trees per plot at full bloom. Percentage fruit set, number of fruit thinned and average fruit size were determined at thinning during the 1996/97 and 1997/98 seasons.

Fruit was harvested at optimum maturity, according to the Unifruco AP.1 colour chart Print 3 (Unifruco Research Services, 1996) for Palsteyn, at the beginning of December 1995, January 1997 and end November 1997 and total fruit mass and number of fruit per tree were recorded. Maturity standards for export of Palsteyn consider predominantly yellow fruit with a light green seam suitable for harvest (Unifruco, 1994). During 1996/97 fruit quality parameters were recorded and the fruit colour, percentage of total dissolved solids and total titratable acids of fruit were determined at harvest to determine levels of maturity.

Fruit colour was determined by comparison of individual fruit colour of twenty fruit to the Unifruco colour chart AP.1 (Unifruco Research Services, 1996). Wedges of fruit were sampled and fruit juice extracted by means of a blender. Total dissolved solids were determined on a drop of fruit juice by means of an Atago DBX-55 Digital Refractometer (Atago Co Ltd, Tokyo, Japan). Titratable acids were determined by titrating with NaOH (pH 8.2) as described by Van der Merwe (1996), using a Metrohm 719S Titrino automatic titrator (Metrohm, Herisau, Switzerland). A separate sample of fruit was stored for a period of four weeks at –0.5°C and a further period of ten days at 10°C to mimic conditions exported fruit would be exposed to, after which fruit was evaluated to quantify the effect of salinity on woolliness, gel breakdown and decay.

6.2.7 Salt tolerance

The salt tolerance of Palsteyn apricot was estimated by means of piecewise linear response functions (Maas & Hoffman, 1977; Van Genuchten, 1983) from plant data of the 1996/97 season and soil salinity of the 1995/96 and 1996/97 seasons. Depth-weighted seasonal soil water salinity values were converted to saturated soil extract salinity values as described in section 6.2.3 for the calculation of soil water osmotic potential. The relative yield response to soil salinity can be calculated as $RY = 100 – s(x - c_t)$ in which x is the depth-weighted average root-zone salinity (EC_e') during the period concerned, c_t = the threshold, the maximum EC_e' without yield reduction as compared to yield under non-saline conditions; and s = the slope, the percentage yield decrease per unit salinity increase. The effect of salinity on absolute yield or other plant parameters (Y) can be estimated as $Y = Y_m – s(x-c_t)$ in which Y_m represents the non-saline control yield or plant parameter (Van Genuchten, 1983). The response of leaf area, summer pruning mass, fruit number, yield expressed as total mass of fruit harvested per tree and relative yield, respectively, to mean EC_e' of the 1995/96 and 1996/97 seasons, was evaluated according to these functions. In addition, the abovementioned plant data were corrected for differences in soil water depletion level from field capacity by means of covariance analysis (refered to as SWDadj) and the response to mean EC_e' of the 1995/96 and 1996/97 seasons was also evaluated. Parameters for the response functions were estimated by means of a non-linear least squares statistical procedure (SAS, 1999). Sensitivity of Palsteyn apricot to chloride ions was established by means of linear regression between the above-mentioned plant parameters and leaf chloride concentrations at harvest of the 1996/97 season. Linear regression relationships were also obtained for the SWDadj plant parameters with leaf chloride concentrations.

6.3 RESULTS

6.3.1 Soil water osmotic potential at field capacity

The depth-weighted seasonal average $\psi_{o,FC}$ decreased with increasing irrigation water salinity and ranged between -0.014 and -0.355 MPa during the three seasons (Fig. 6.1). The average $\psi_{o,FC}$ for the seasons monitored for the 0, 0.7, 1, 2, 3 and 4 dS m^{-1} treatments was -0.013, -0.056, -0.096, -0.163, -0.225 and -0.232 MPa, respectively.

6.3.2 Plant water relations

Pre-dawn leaf water potential during 1995/96 measured one day before irrigation was lower than that measured during 1996/97 one day after irrigation (Fig. 6.2A & B). Pre-dawn leaf water potential decreased in general with increasing salinity and was significantly lower at the beginning of the 1995/96 season in treatments receiving saline irrigation water equal to or

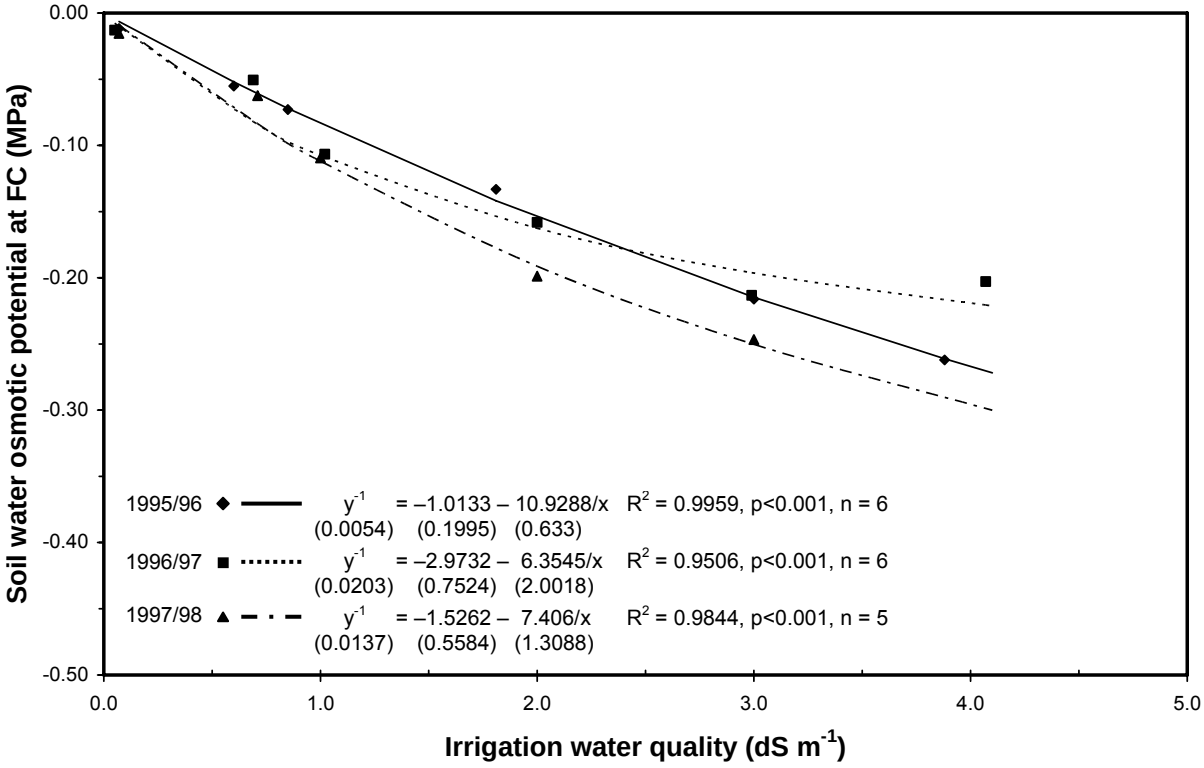
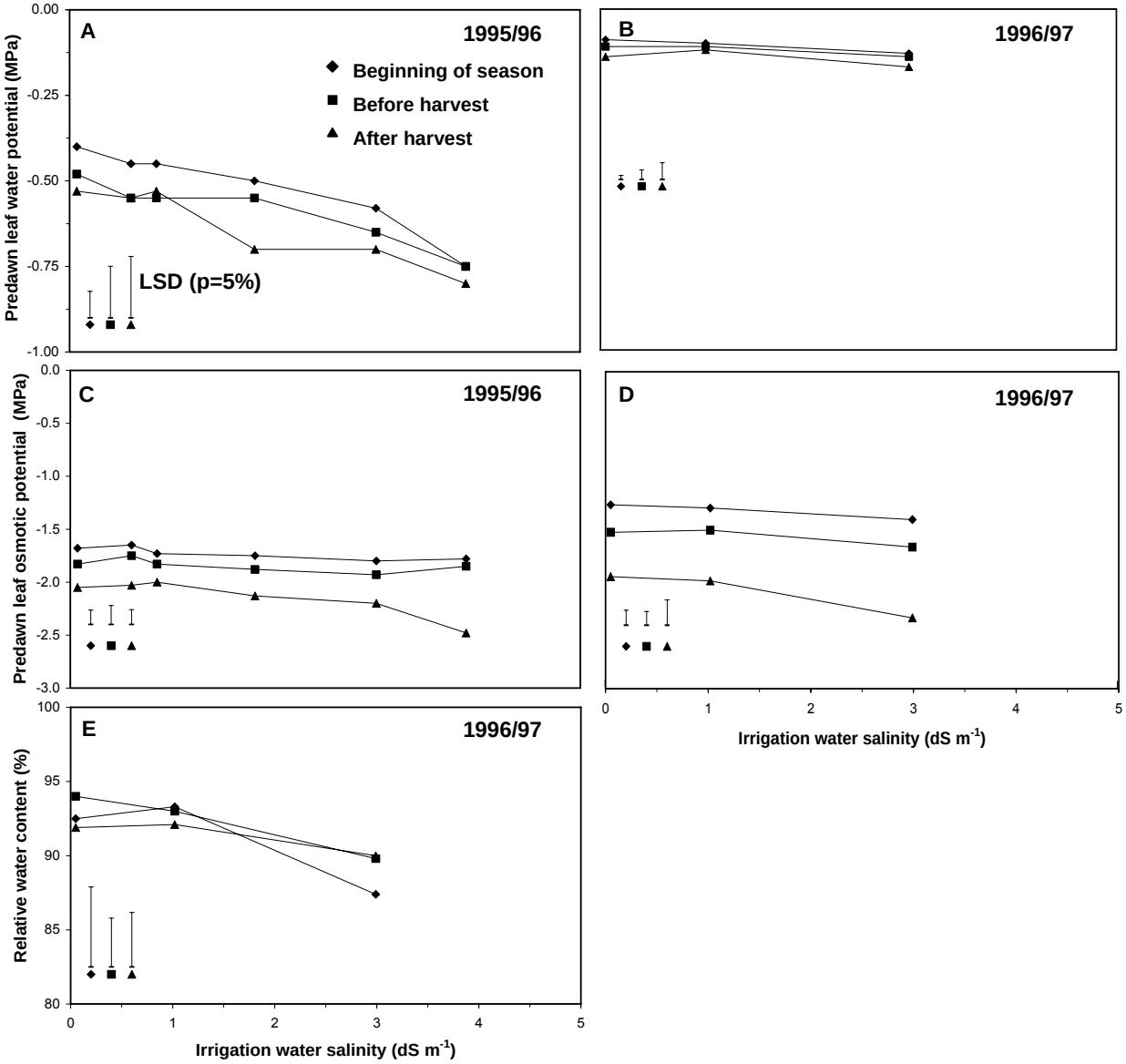


Figure 6.1. The estimated depth weighted seasonal average osmotic potential of the soil water at field capacity (FC) for the different saline irrigation treatments during the 1995/96, 1996/97 and 1997/98 seasons. Irrigation was terminated for the 4 dS m^{-1} treatment at the end of the 1996/97 season and for all treatments December 1997. Soil water osmotic potential data were estimated from the depth weighted seasonal average electrical conductivity of the soil water of the total soil profile (0-900 mm, n=4). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.



Stage	Experimental standard deviation				
	Predawn leaf water potential		Predawn leaf osmotic potential		Relative water content
	1995/96	1996/97	1995/96	1996/97	1996/97
BS	0.05	0.02	0.1	0.2	3
BH	0.10	0.04	0.1	0.2	2
AH	0.12	0.07	0.1	0.4	2
Df	15	6	15	6	6
N	4	23.6 or 24	4	24	4

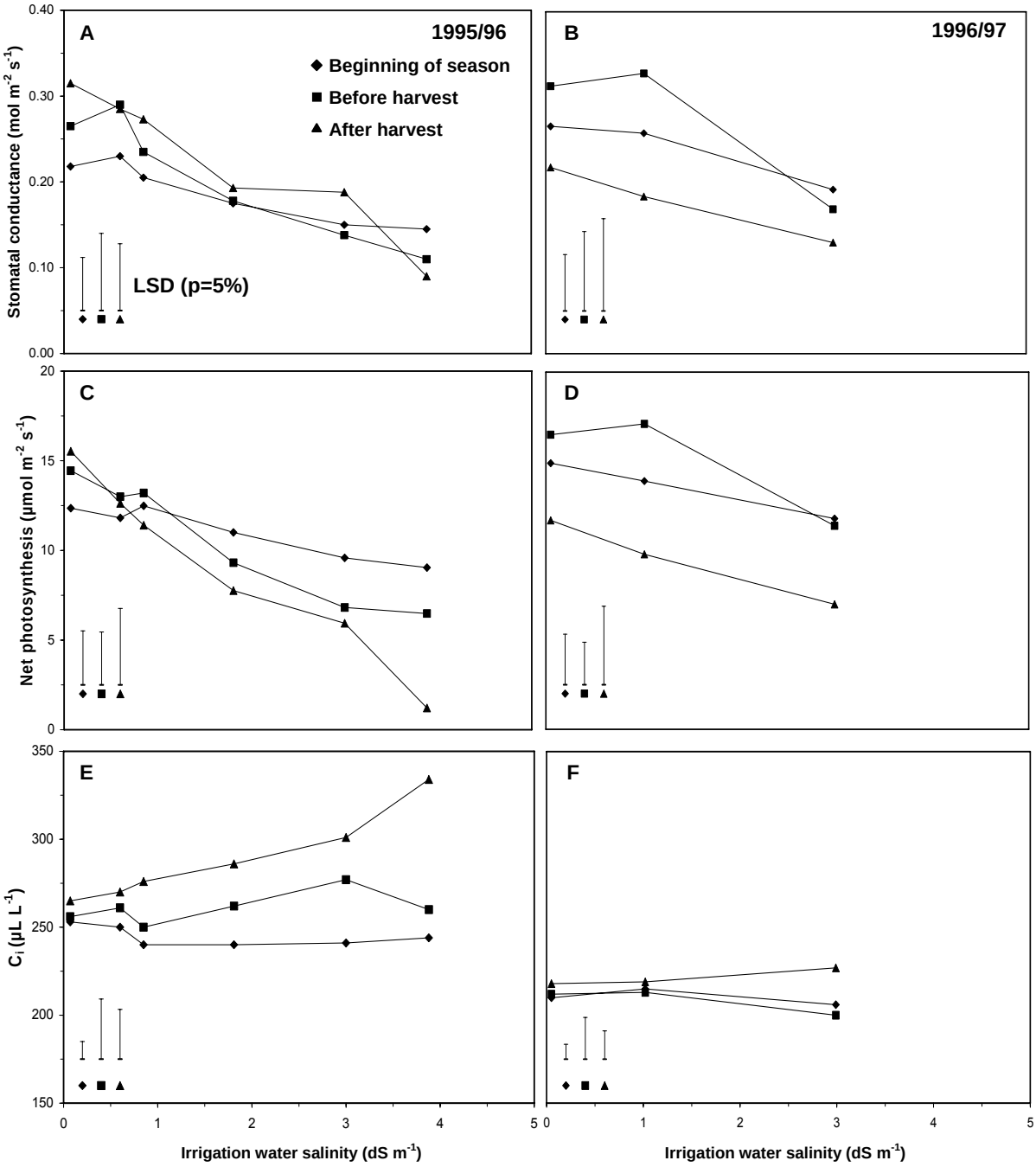
Figure 6.2. The effect of saline irrigation on predawn water potential (A, B), predawn osmotic potential (C, D) and relative water content (E) of leaves of Palsteyn apricot determined at the beginning of the season, before harvest and after harvest of the 1995/96 and/or 1996/97 seasons. Measurements were performed one day before irrigation during the 1995/96, and one day after irrigation during the 1996/97 season. The least significant difference (LSD) between treatments is indicated on the graphs and the experimental standard deviation and degrees of freedom tabled below the graphs for each period (BS, BH and AH) during each season.

exceeding a specific electrical conductance of 2 dS m^{-1}, when compared to the 0 dS m^{-1} treatment (Fig. 6.2A). Before harvest the 3 and 4 dS m^{-1} treatments and after harvest only the 4 dS m^{-1} treatment were significantly lower than the treatment receiving municipal water. The larger differences between treatments at the beginning of the season thus tended to become smaller later in the season. During 1996/97 the 3 dS m^{-1} treatment was significantly lower than the 0 and 1 dS m^{-1} treatments until before harvest, after which it differed only significantly from the 1 dS m^{-1} treatment (Fig. 6.2B). Predawn leaf osmotic potential early in the growing season was not affected by saline irrigation and generally tended to become significantly lower later in the season. At high irrigation water salinity treatments the predawn leaf osmotic potential tended to become significantly lower earlier in the season during sequential seasons. During 1995/96 the 3 dS m^{-1} treatment was significantly lower than the 1 dS m^{-1} treatment after harvest and during the 1996/97 season, from the period before harvest (Fig. 6.2C & D). The relative water content of leaves tended to decrease with increasing irrigation water salinity. The relative water content of leaves of the 3 dS m^{-1} treatment was significantly lower than that of the 0 dS m^{-1} treatment only in the period before harvest, but was also significantly lower than that of the 1 dS m^{-1} treatment at the beginning of the 1996/97 season (Fig. 6.2E). Leaf curling was observed one day after irrigation in the 3 and 4 dS m^{-1} treatments during the 1996/97 and in the 2 and 3 dS m^{-1} treatments during the 1997/98 season.

6.3.3 Gas exchange

The stomatal conductance and net photosynthesis rate of leaves generally decreased with increasing irrigation water salinity (Fig. 6.3). The stomatal conductance of treatments receiving irrigation water salinity equal to or exceeding 2 dS m^{-1} was significantly lower earlier in the growing season compared to that of the lower salinity treatments (Fig. 6.3A & B). The net photosynthesis rate of leaves in the high irrigation water salinity treatments also was significantly lower earlier in the growing season compared to that of the 0, 0.7 and 1 dS m^{-1} treatments. During 1995/96 the net photosynthesis rate of leaves in the 4 dS m^{-1} treatment decreased significantly at the beginning of the season, while that in the 2 and 3 dS m^{-1} treatments was only significantly lower from before harvest when compared to the 0 dS m^{-1} treatment (Fig. 6.3C).

The net photosynthesis rate of leaves in the 1 dS m^{-1} treatment was lowered later in the season, causing significant differences to higher salinity treatments to disappear. The net photosynthesis rates of the 2, 3 and 4 dS m^{-1} treatments were significantly lower than that of the 1 dS m^{-1} treatment during the period before, but not after harvest during 1995/96. At the beginning and before harvest of the 1996/97 season, the net photosynthesis rate in the 3 dS m^{-1} treatment was significantly lower than that of both the 0 and 1 dS m^{-1} treatments (Fig. 6.3D). After harvest it was only significantly lower than that of the 0 dS m^{-1} treatment.



Stage	Experimental standard deviation					
	Stomatal conductance		Net photosynthesis		C_i	
	1995/96	1996/97	1995/96	1996/97	1995/96	1996/97
BS	0.04	0.02	0.1	0.7	7	4
BH	0.06	0.05	0.1	1.2	23	12
AH	0.05	0.06	0.1	2.5	19	9
df	15	6	15	6	15	6

Figure 6.3. The effect of irrigation water salinity on the stomatal conductance (A, B), net photosynthesis rate (C, D) and substomatal cavity carbon dioxide concentration or C_i (E, F) of Palsteyn apricot leaves at the beginning, before harvest and after harvest of the 1995/96 and 1996/97 (n=4) seasons. Measurements were performed one day before irrigation during the 1995/96, and one day after irrigation during the 1996/97 season. The least significant difference (LSD) between treatments is indicated on the graphs and the experimental standard deviation and degrees of freedom tabled below the graphs for each period (BS, BH and AH) during each season.

In general the substomatal cavity carbon dioxide concentration (C_i) of leaves was lower at the beginning of the season compared to that after harvest (Fig. 6.3E & F). After harvest during the 1995/96 season, the C_i increased with increasing salinity and was significantly higher in the 4 dS m^{-1} treatment compared to all other treatments (Fig. 6.3E). There were no significant differences in C_i between treatments after harvest 1996/97 (Fig. 6.3F). The net photosynthesis rate of leaves showed a poor relationship to C_i at the beginning and before harvest of the 1995/96 season and for all stages measured during the 1996/97 season. After harvest of the 1995/96 season the net photosynthesis rate was negatively correlated with C_i (Fig. 6.4A & B). The net photosynthesis rate of leaves was positively correlated with stomatal conductance within the 1995/96 and 1996/97 seasons (Fig. 6.5A & B). No significant differences were found between slopes of regression lines for the beginning of the season and that before harvest and data were combined to obtain one mathematical function for the pre-harvest period. The slope of the regression line after harvest was significantly higher compared to that for pre-harvest during both seasons. The photosynthesis rate at a specific stomatal conductance was lower after harvest compared to that at the beginning of the season and before harvest for both the 1995/96 and 1996/97 seasons.

6.3.4 Vegetative characteristics

The leaf area index of trees was lower during the 1996/97 season compared to the 1995/96 and 1997/98 seasons (Fig. 6.6). Leaf area index, measured shortly after harvest, decreased significantly with increasing irrigation water salinity during the 1995/96, 1996/97 and 1997/98 seasons. The average area per leaf decreased as irrigation water salinity increased (Fig. 6.7). Average area per leaf of the treatments receiving irrigation water salinity of 1 dS m^{-1} or higher, was significantly lower than that of the 0 and 0.7 dS m^{-1} treatments prior to harvest during 1996/97. In the period after harvest the leaf area in the 2 and 3 dS m^{-1} treatments differed significantly from that in the 0, 0.7 and 1 dS m^{-1} treatments. During 1997/98, the leaf area of only the 3 dS m^{-1} treatment differed significantly from that of the 0 dS m^{-1} before harvest. Specific leaf area (data not shown) did not differ significantly at any of the stages monitored during the 1996/97 and 1997/98 seasons.

Summer pruning weight during 1995/96 was 2 to 3-fold that removed during 1996/97. Saline irrigation during the 1995/96 season did not affect summer pruning weight until irrigation water salinity equaled or exceeded 2 dS m^{-1}. In constrast, a constant decrease in summer pruning weight with increasing irrigation water salinity was observed during 1996/97 (Fig. 6.8). The increase in stem circumference was significantly reduced at all treatments receiving irrigation water with salinity equal to or exceeding 2 dS m^{-1} during the 1995/96, 1996/97 and 1997/98 seasons (Fig. 6.9).

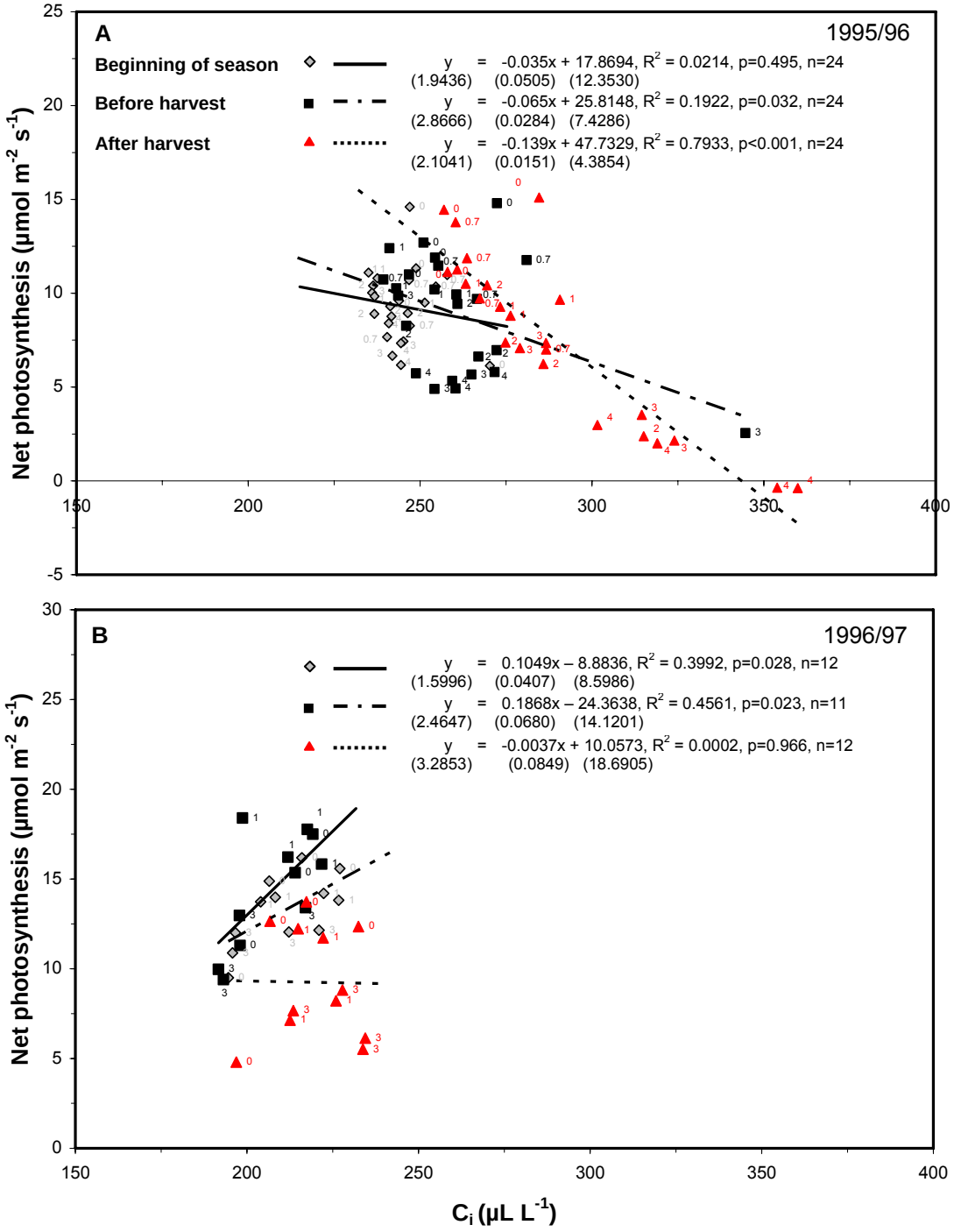


Figure 6.4. Relationships between net photosynthesis rate and substomatal cavity carbon dioxide concentration (C_i) of Palsteyn apricot leaves at the beginning of the season, before harvest and after harvest of the 1995/96 (A) and 1996/97 (B) seasons. Measurements were performed one day before irrigation during the 1995/96, and one day after irrigation during the 1996/97 season. Data are the means per replicate block of 3 leaves from 1 tree for 1995/96 and of 3 leaves from 2 trees for 1996/97. Data point labels indicate the target irrigation water salinity of treatments (dS m^{-1}). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.

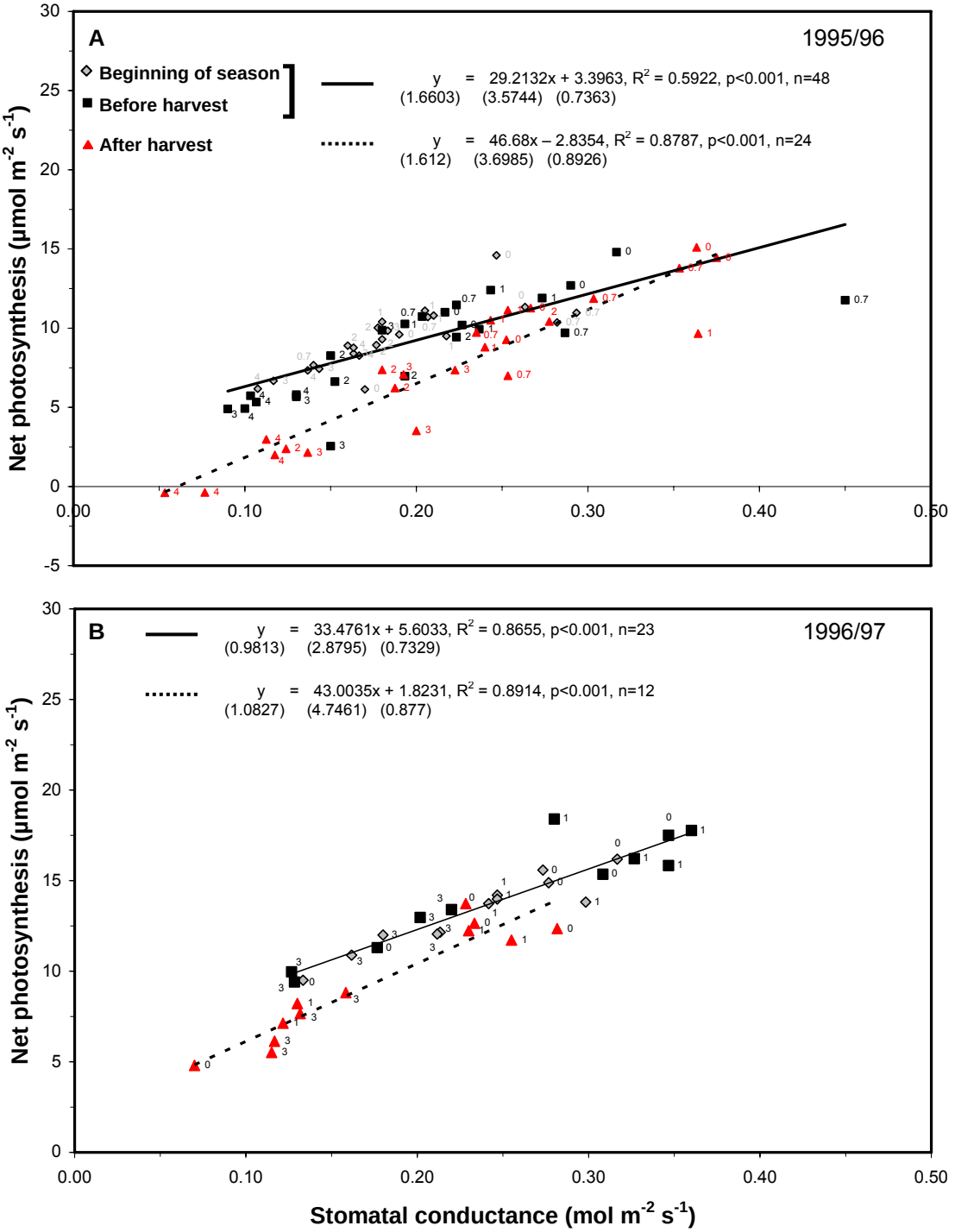


Figure 6.5. Relationships between net photosynthesis rate and stomatal conductance of Palsteyn apricot leaves during the pre-harvest period and after harvest of the 1995/96 (A) and 1996/97(B) seasons. Data from the beginning of the season and before harvest was combined to fit a mathematical function for the pre-harvest period for each season. Measurements were performed one day before irrigation during the 1995/96, and one day after irrigation during the 1996/97 season. Data are the means per replicate block of 3 leaves from 1 tree for 1995/96 and of 3 leaves from 2 trees for 1996/97. Data point labels indicate the target irrigation water salinity of treatments (dS m^{-1}). The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.

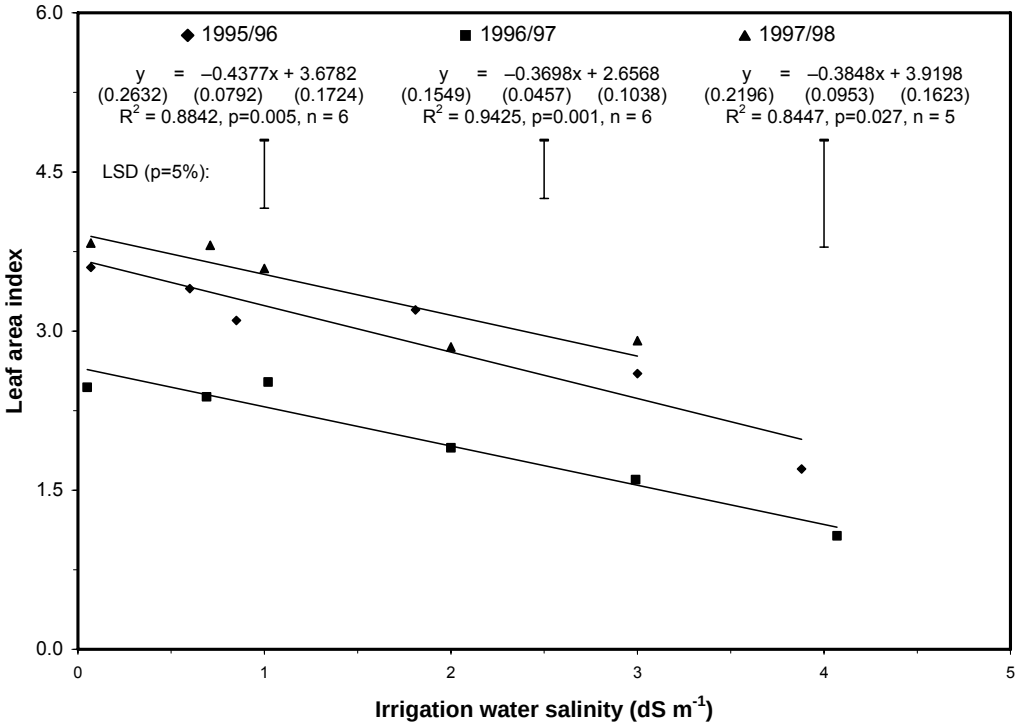


Figure 6.6. The effect of irrigation water salinity on the leaf area index of Palsteyn apricot trees measured after harvest during the 1995/96, 1996/97 and 1997/98 seasons. Data are the means of 4 replicate blocks (2 trees per block) and the least significant difference between treatments is indicated for each season on the graph. The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.

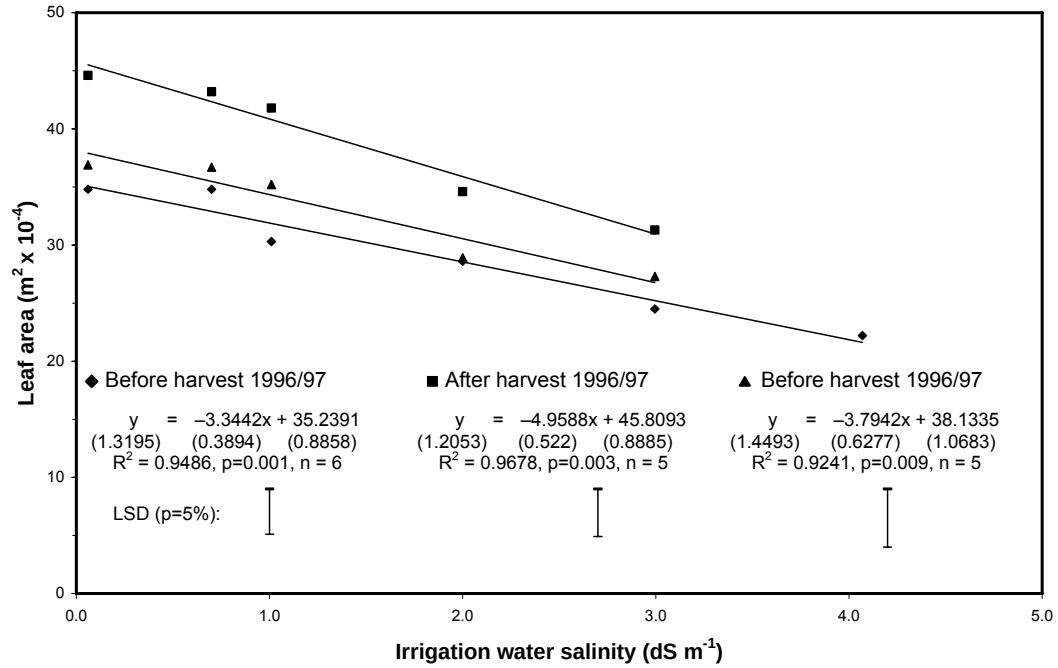
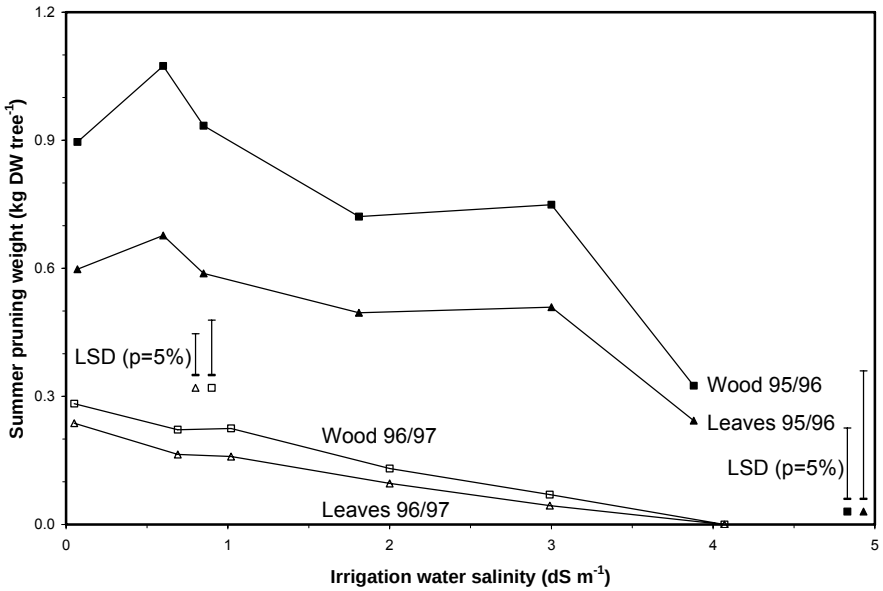
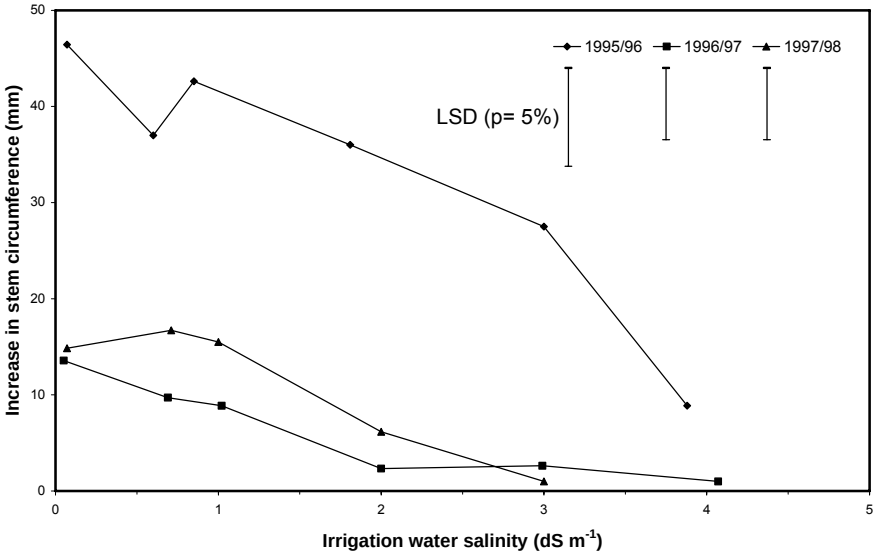


Figure 6.7. The effect of irrigation water salinity on the average area per leaf sampled from the middle of extension shoots of Palsteyn apricot in the period before and after harvest during the 1996/97 season and before harvest during the 1997/98 season. Data are the means of replicate blocks and the least significant difference (LSD) between treatments for each of the periods is indicated on the graphs. The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.



Tree part	Experimental standard deviation (degrees of freedom = 15)	
	1995/96	1996/97
Leaves	0.2826	0.0955
Wood	0.4656	0.1406

Figure 6.8. The effect of saline irrigation on dry weight (DW) of leaves and wood of summer pruned shoots of Palsteyn apricot during the 1995/96 and 1996/97 seasons. Data are the means of replicate blocks, 2 trees per block (harmonic mean of replicate blocks = 7.81) and the least significant difference (LSD) between treatments is indicated on the graphs.



Experimental standard deviation (degrees of freedom)		
1995/96	1996/97	1997/98
0.9268 (15)	0.6342 (14)	0.5464 (13)

Figure 6.9. The effect of saline irrigation on the increase in trunk circumference of Palsteyn apricot trees during the 1995/96 (harmonic mean of replicate blocks (n_h) = 7.47), 1996/97 (n_h = 6.65) and 1997/98 (n_h = 5.79) seasons. Measurements were taken during dormancy (June) each year except for 1997/98 when it was measured in December before destructive harvest of trees. The least significant difference (LSD) between treatments is indicated on the graphs.

Foliar damage was observed during April of the 1994/95, 1995/96 and 1996/97 seasons in all saline irrigation treatments where irrigation water salinity exceeded 1 dS m^{-1} (Fig. 6.10). The magnitude of the foliar damage generally increased with salinity of irrigation water and with each subsequent season. Foliar damage developed earlier in the season in the 4 dS m^{-1} treatment compared to the 3 dS m^{-1} treatment during both the 1995/96 and 1996/97 seasons and approached the maximum faster (Fig. 6.11). Foliar damage in the 4 dS m^{-1} treatment appeared earlier each subsequent season from 1994/95 (data not shown) to 1996/97. Foliar damage was correlated with an increase in leaf chloride levels (Fig. 6.12), but sodium was mainly excluded from the leaves and there was no significant correlation between Na and foliar damage (data not shown).

6.3.5 Yield and fruit quality

Trees were bearing alternately (biennially) and the total mass and number of fruit on trees were much lower in the 1995/96 and 1997/98 seasons compared to that of the 1996/97 season (Fig. 6.13). The 1996/97 season was the only season where saline irrigation water had a significant effect on the total mass and number of fruit harvested per tree (Fig. 6.13A & B). The total fruit mass of fruit harvested in treatments receiving irrigation water of salinity of 2 dS m^{-1} or higher was significantly lower than that of plants receiving 1 dS m^{-1} or lower. The 4 dS m^{-1} treatment was the only treatment that produced a significantly lower number of fruit than the control treatment (Fig. 6.13B). The 0.7 dS m^{-1} treatment had the highest number of fruit and it was significantly higher compared to the 2, 3 and 4 dS m^{-1} treatments. Average fruit mass was already significantly lower in the 4 dS m^{-1} treatment compared to all other treatments in 1995/96 (Fig. 6.13C). In the subsequent seasons, average fruit mass tended to be lower whenever irrigation water salinity exceeded 1 dS m^{-1}. In 1996/97, the fruit in the 3 and 4 dS m^{-1} treatments were significantly smaller than that in the 0, 0.7 and 1 dS m^{-1} treatments, but in 1997/98 no significant differences in fruit size were found.

The total mass of fruit and number of fruit harvested increased with increasing leaf area index during the 1996/97 season (Fig. 6.14A & B). During seasons with low crop loads on trees, however, this relationship was poor. The relationship of average fruit mass to leaf area index did not seem to be influenced that much by crop load, although fruit mass decreased with increased crop load (Fig. 6.14C). Fruit mass increased with increasing leaf area index during all three seasons.

Dry fruit mass decreased and the ratio of dry mass to fresh mass generally increased significantly in treatments receiving irrigation water of salinity higher than 1 dS m^{-1} (Table 6.1). Fruit colour at harvest was significantly reduced in the 3 dS m^{-1} treatment, with non-uniform coloration of fruit, while total dissolved solids increased and total titratable acids decreased

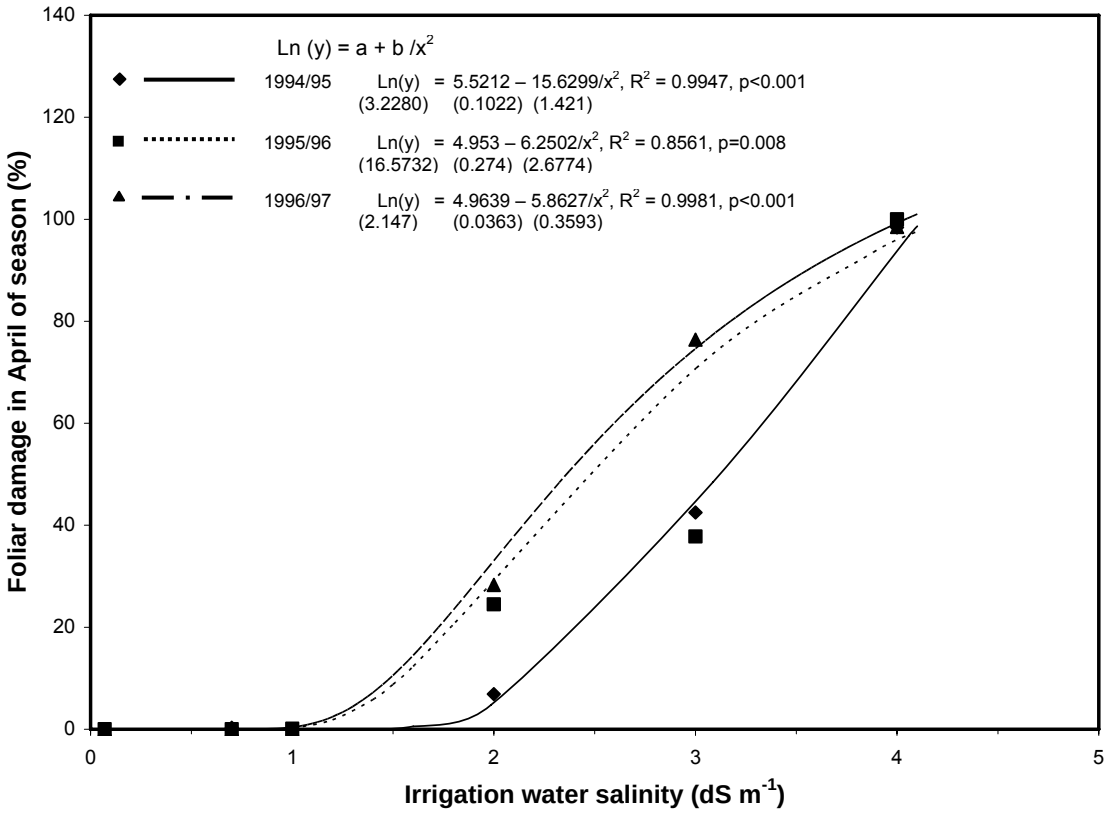


Figure 6.10. The effect of long-term saline irrigation on foliar damage as observed near the end of the season (April for the 1994/95, 1995/96 and 1996/97 seasons) on Palsteyn apricot trees on Marianna rootstock (n=6). Data are the means of four replicate blocks. The standard errors of the estimate and coefficients of the mathematical functions are displayed below each equation in brackets.

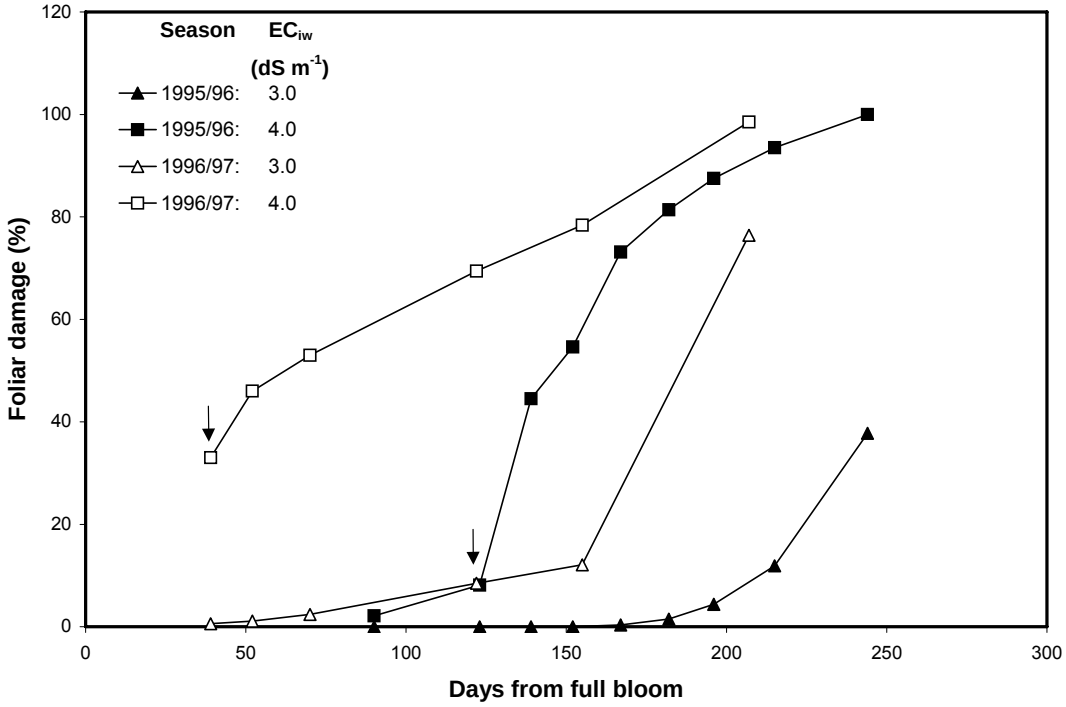


Figure 6.11. The long-term effect of saline irrigation on development of foliar damage of Palsteyn apricot trees on Marianna rootstock at the 3 dS m^{-1} and 4 dS m^{-1} treatments as measured during the 1995/96 and 1996/97 seasons. EC_{iw} in the graph legend stands for irrigation water salinity. The arrows indicate the relative stage of the season when leaf fall started at the 4 dS m^{-1} treatment during the two seasons. Data are the means of four block replicates.

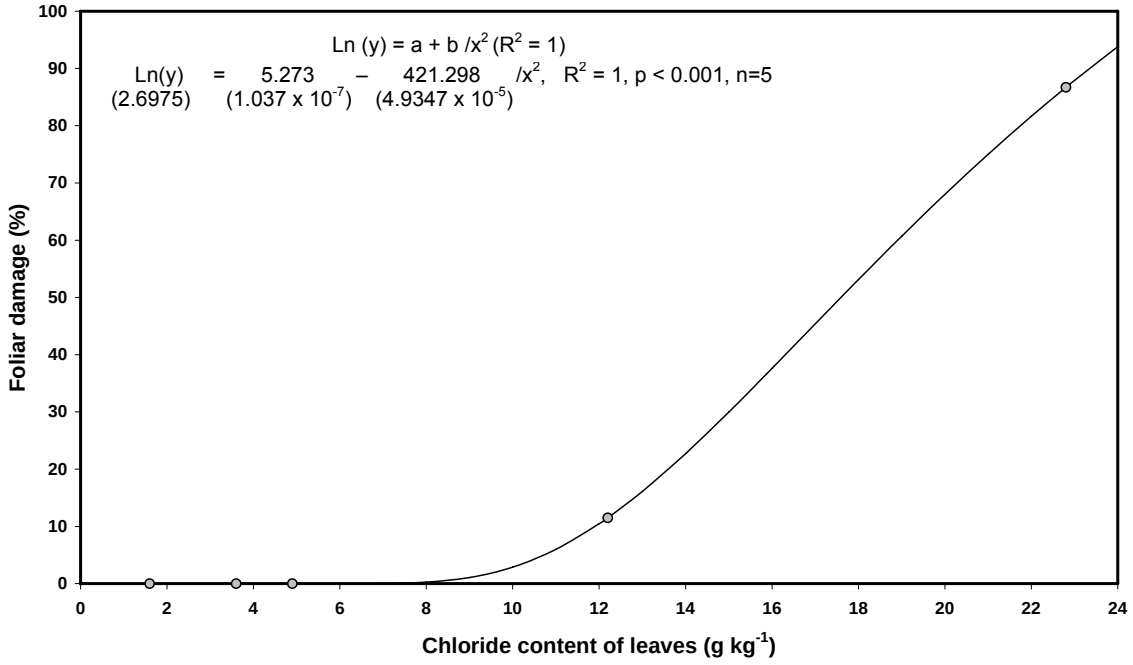


Figure 6.12. The effect of chloride content of leaves on foliar damage of Palsteyn apricot trees as measured during April of the 1996/97 season after approximately three seasons of saline irrigation. Data are the means of replicate blocks. The standard errors of the estimate and coefficients of the mathematical function are displayed below the equation in brackets.

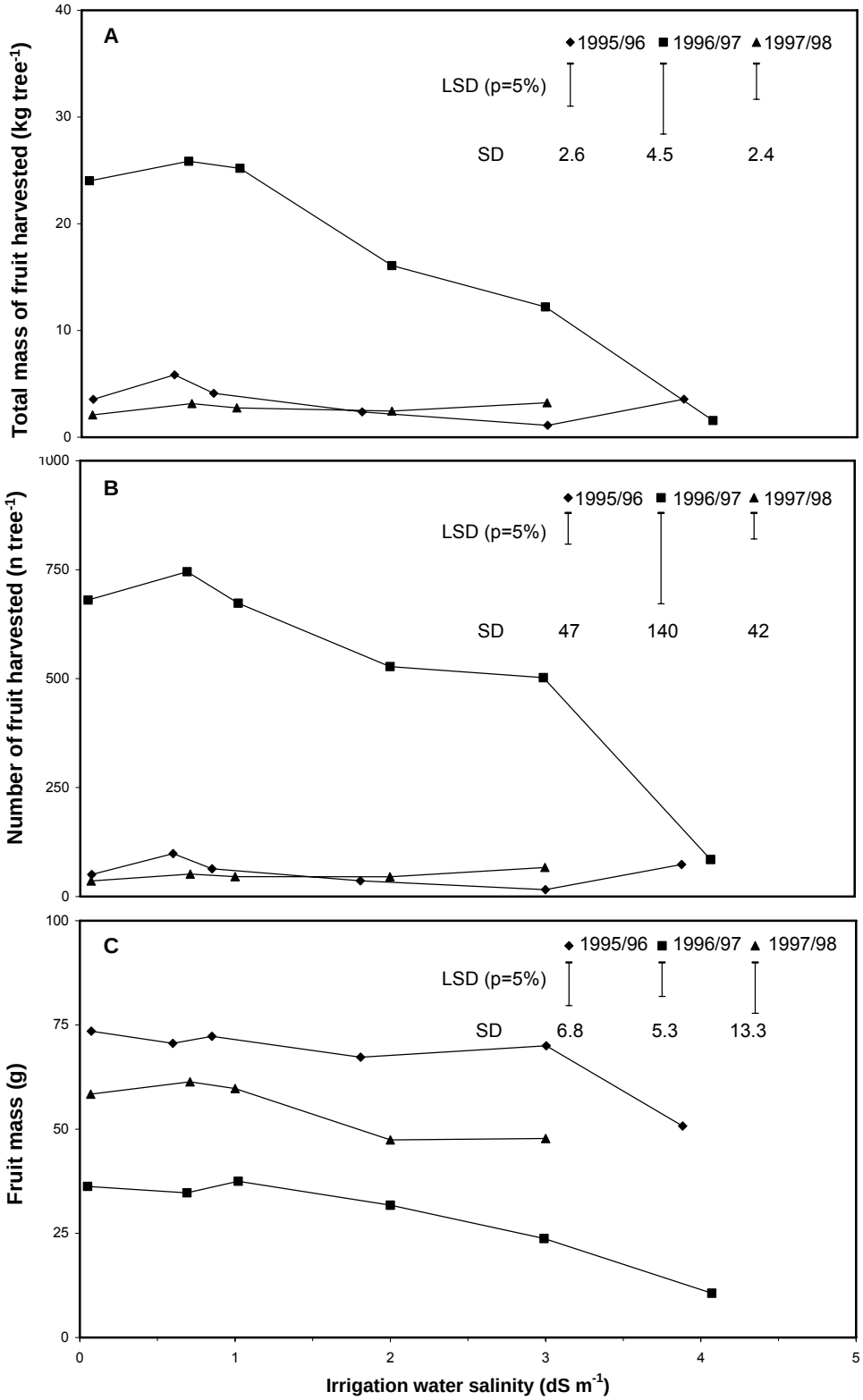


Figure 6.13. The effect of saline irrigation water on (A) the total mass of fruit harvested, (B) the total number of fruit harvested and (C) average fruit size of Palsteyn apricot trees during the 1995/96, 1996/97 and 1997/98 seasons (n=4). The experimental standard deviation (SD) for each variable for each season is indicated on the graph and the degrees of freedom were 15 for 1995/96 and 1996/97 and 12 for 1997/98.

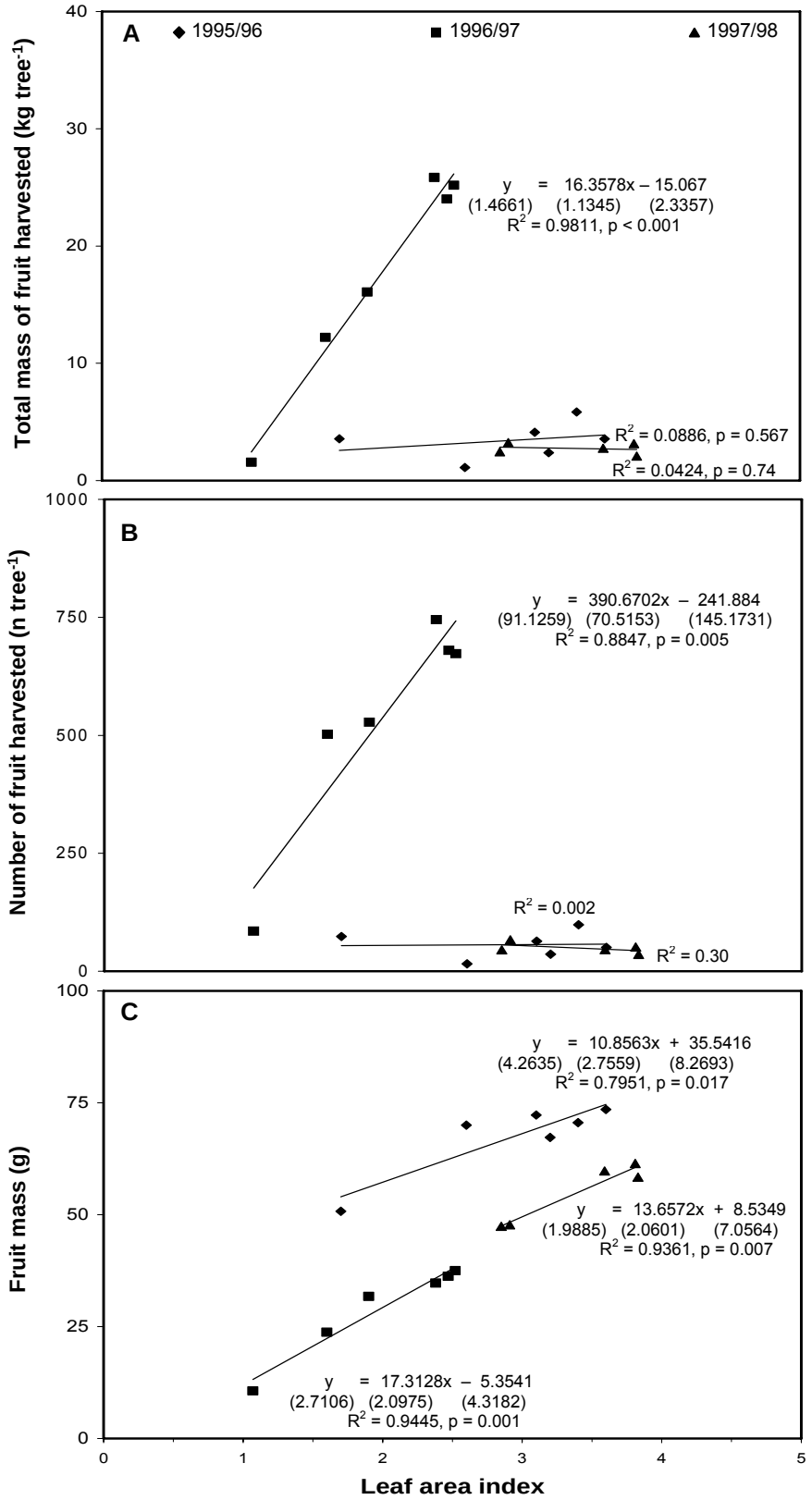


Figure 6.14. The relationship between (A) total mass of fruit harvested, (B) total number of fruit harvested and (C), the average fruit mass to leaf area index of Palsteyn apricot trees subjected to different levels of saline irrigation water during the 1995/96 (n=6), 1996/97 (n=6) and 1997/98 (n=5) seasons. Mathematical functions are displayed on graphs only for linear regression relationships that are statistically significant at a 95% confidence level and the standard errors of the estimate and coefficients are indicated below each equation in brackets. Data are the means of replicate blocks.

Table 6.1. The effect of irrigation water salinity on fruit quality of Palsteyn apricot trees as determined during the 1996/97 season included the effect on fruit dry mass (DM) and the DM/FM ratio as well as fruit colour, total dissolved solids and total titratable acids at harvest. The effects on development of decay, gel breakdown and woolliness during cold storage were also monitored. Values in columns followed by the same letter do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and quality parameters were tested separately. The LSD, experimental standard deviation (SD), degrees of freedom (df) and mean or harmonic mean number of replicates (n or n_h) for all variables are indicated at the bottom of the table

EC_{iw} ($dS\ m^{-1}$)	Fruit dry mass (g)	DM/FM ratio	Colour	Total dissolved solids (%)	Total titratable acids (%)	Decay (%)	Gel breakdown (%)	Woolliness (%)
0	6.1 [a]	0.134 [c]	10.6 [a]	9.2 [bc]	2.3 [a]	2.6 [a]	35.2 [a]	76.0 [a]
0.7	5.9 [ab]	0.138 [c]	10.4 [a]	8.8 [c]	2.2 [b]	5.7 [a]	53.0 [a]	70.6 [a]
1	6.1 [a]	0.140 [c]	10.8 [a]	9.6 [ab]	2.3 [ab]	3.3 [a]	28.0 [a]	62.5 [a]
2	5.1 [bc]	0.153 [b]	10.5 [a]	10.0 [a]	1.9 [c]	2.7 [a]	73.5 [a]	77.1 [a]
3	4.5 [c]	0.162 [a]	9.8 [b]	10.1 [a]	1.8 [d]	1.8 [a]	67.4 [a]	66.2 [a]
LSD	0.98	0.8521	0.57	0.67	0.13	4.09	40.96	24.16
SD	0.6	0.553	0.4	0.4	0.1	3.6	35.6	21.0
df	12	12	12	12	12	12	12	12
n or n_h	4	4	4	4	4	7.18	7.18	7.18

significantly in treatments receiving saline irrigation water of 2 dS m^{-1} or higher. The percentage decay, gel breakdown and woolliness of fruit after cold storage did not differ significantly.

6.3.6 Phenology

During 1995/96 the 4 dS m^{-1} treatment displayed the highest flower index and flower density (Table 6.2). Significant differences during this season were, however, not related to salinity treatment effects. During the 1996/97 season, the flower index and flower density in the 4 dS m^{-1} treatment were significantly lower than those in the other treatments. The flower density in the 2 dS m^{-1} treatment was also significantly lower compared to the 0.7 dS m^{-1} treatment, which had the most flowers per cm shoot length.

The 0.7 dS m^{-1} had the highest percentage of fruit set as well as the highest number and mass of fruit removed by thinning during the 1996/97 season (Table 6.3). Average size of thinned fruit, however, was still the highest in the 0 dS m^{-1} treatment and fruit size tended to decrease with increasing irrigation water salinity. The number of fruit, with the exception of the 0 dS m^{-1} treatment, also tended to decrease with increasing irrigation water salinity. The percentage of fruit set, number and total mass of thinned fruit was significantly reduced in the 4 dS m^{-1} treatment during this season compared to all other treatments. The percentage of fruit set and number of fruit thinned in the 3 dS m^{-1} treatment was not significantly lower than that of the 0 dS m^{-1} treatment, but the total mass decreased significantly. No significant differences were found for any of the parameters during the 1997/98 season.

Out of season growth and flowering was observed during 1995/96 in the 4 dS m^{-1} treatment. Blooms as well as new vegetative growth were observed at fifty percent of trees during March 1996 and at all trees at this treatment in May 1996. Some trees in the 4 dS m^{-1} treatment started the 1996/97 season with vegetative growth that originated from the previous season. Vegetative growth was generally poor and growth buds tended to be aborted. During January 1997, shortly after harvest, bud abscission was observed in trees in the 2, 3 and 4 dS m^{-1} treatments. During April until June 1997, out of season flowering and vegetative growth was observed in trees from the 2, 3 and 4 dS m^{-1} treatments.

6.3.7 Salt tolerance

The profile mean soil water depletion from field capacity (% v/v) for treatment replicates for the 1995/96 and 1996/97 seasons ranged from 1.8% to 7.8% and was significantly lower for the 1995/96 season at the 4 dS m^{-1} treatment, and for the 1996/97 season at the 3 and 4 dS m^{-1} treatments, compared to that of all the remaining treatments (data not shown). The profile mean soil water depletion for the 1995/96 and 1996/97 seasons combined was significantly higher in the 0.7, 1 and 2 dS m^{-1} treatments compared to those in the 3 and 4 dS m^{-1} treatments and that

Table 6.2. Effect of irrigation water salinity on the flower index and flower density during 1995/96 and 1996/97 seasons. Values in seasons followed by the same letter do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and seasons were tested separately. The LSD, experimental standard deviation (SD, degrees of freedom = 15) and mean or harmonic mean number of replicates (n or n_h) for the flower index and flower density within each season are indicated at the bottom of the table

EC_{iw} (dS m^{-1})	**Flower index[1]**		**Flower density[2]**	
	1995/96	**1996/97**	**1995/96**	**1996/97**
Control	0.11 [b]	0.84 [a]	0.05 [ab]	0.67 [ab]
0.7	0.16 [ab]	0.85 [a]	0.07 [ab]	0.78 [a]
1.0	0.14 [ab]	0.84 [a]	0.06 [ab]	0.71 [ab]
2.0	0.10 [b]	0.80 [a]	0.04 [ab]	0.54 [b]
3.0	0.07 [b]	0.82 [a]	0.03 [b]	0.63 [ab]
4.0[3]	0.23 [a]	0.66 [b]	0.09 [a]	0.23 [c]
LSD	0.114	0.128	0.055	0.218
SD	0.11	0.09	0.05	0.14
n or n_h	7.81	4	7.81	4

[1] (Number of flower buds)/(Number of flower buds + Number of vegetative buds).

[2] Flower buds cm^{-1} shoot length.

[3] Irrigation terminated end of season 1996/97.

Table 6.3. Effect of irrigation water salinity on fruit set and the number, total mass and average size of Palsteyn apricot fruit thinned during the 1996/97 and 1997/98 seasons. Values in seasons followed by the same letter do not differ significantly (Student's t-Least Significant Difference (LSD), p=0.05) and seasons were tested separately. The LSD, experimental standard deviation (SD), degrees of freedom (df) and mean or harmonic mean number of replicates (n or n_h) for the flower index and flower density within each season are indicated at the bottom of the table

EC_{iw} ($dS\ m^{-1}$)	Fruit set (%)		Number of fruit		Total mass of fruit (g)		Fruit size (g)	
	1996/97	1997/98	1996/97	1997/98	1996/97	1997/98	1996/97	1997/98
0	22.3 [b]	24.3 [a]	134 [b]	1.8 [a]	1238 [b]	14.9 [a]	9.4 [a]	5.9 [a]
0.7	33.5 [a]	29.4 [a]	211 [a]	4.3 [a]	1762 [a]	45.9 [a]	8.4 [ab]	8.5 [a]
1.0	28.8 [ab]	26.4 [a]	151 [b]	3.3 [a]	1306 [ab]	36.3 [a]	8.7 [ab]	6.2 [a]
2.0	22.1 [b]	27.2 [a]	114 [b]	6.1 [a]	883 [bc]	63.8 [a]	7.7 [b]	3.1 [a]
3.0	28.6 [ab]	22.9 [a]	99 [b]	4.8 [a]	650 [c]	41.5 [a]	6.5 [c]	4.4 [a]
4.0	4.7 [c]	-[1]	9 [c]	-[1]	56 [d]	-[1]	6.1 [c]	-[1]
LSD	0.10	23.03	58.5	8.44	457.8	89.43	1.10	6.54
SD	0.1	26.8	54	7.0	425	72.8	0.9	5.6
df	15	12	15	12	15	12	14	12
n or n_h	4	12.9	7.8	7.8	7.8	7.8	6	7.8

[1] Irrigation terminated end of season 1996/97.

in the 0 dS m^{-1} treatment did not differ significantly from soil water depletion of any of the treatments (data not shown). Linear regression between yield for the 1996/97 season and soil water depletion from field capacity for the 1995/96, 1996/97 and the mean of both seasons respectively, indicated statistically significant relationships with yield declining as the soil water depletion level decreased (Fig. 6.15). Similar positive linear regression relationships were obtained for leaf area index measured in April 1997, summer pruning mass and number of fruit harvested during the 1996/97 season respectively, with soil water depletion from field capacity (data not shown). The coefficients of determination and statistical level of significance for the linear regression relationships of these plant variables with the mean soil water depletion of the 1995/96 and 1996/97 seasons (n=6) were R^2=0.73, p=0.029; R^2 = 0.72, p=0.034 and R^2 = 0.87, p=0.006, respectively (data not shown). Use of the mean soil water depletion of the two seasons instead of that for the 1996/97 season alone, resulted in improved regression relationships between the respective abovementioned plant variables and soil water depletion from field capacity (Fig. 6.15, data not shown).

Multiple linear regression results indicated that depthweighted profile average soil salinity and profile mean soil water depletion from field capacity for the 1995/96 and 1996/97 seasons combined, accounted for more than 75%, 80% and 90% of the variation in summer pruning mass (R^2 = 0.76, p<0.001, n=23), number of fruit (R^2 = 0.85, p<0.001, n=23), and yield (R^2 = 0.94, p<0.001, n=23), respectively (data not shown). Depthweighted profile average soil salinity and profile mean soil water depletion from field capacity of the 1995/96 and 1996/97 seasons combined resulted in better coefficients of determination for the abovementioned multiple linear regression relationships than these data for the 1996/97 season only (data not shown). Soil water depletion from field capacity was not a significant independant variable in the multiple linear regression between leaf area index with depthweighted profile average soil salinity and profile mean soil water depletion from field capacity (data not shown), despite the significant linear relationship between leaf area index and soil water depletion level. Profile averaged soil water depletion from field capacity as covariate affected summer pruning mass (p =0.035), number of fruit (p = 0.001) and yield (p = 0.006), but not leaf area index, significantly at a 5% statistical significance level.

The salt tolerance response functions for yield decrease and other plant parameters of Palsteyn apricot on Marianna rootstock were based on approximately three years of saline irrigation. The salt tolerance response functions for leaf area index, summer pruning mass, fruit number and yield to the mean EC_e' of the 1995/96 and 1996/97 seasons displayed increasing salinity threshold values for a decrease in leaf area index, summer pruning mass, yield and fruit number (Fig. 6.16A, C, E & G). The salinity threshold value for relative yield decrease was 1.87 dS m^{-1} and the slope 70 percent per dS m^{-1} salinity increase (Fig. 6.17).

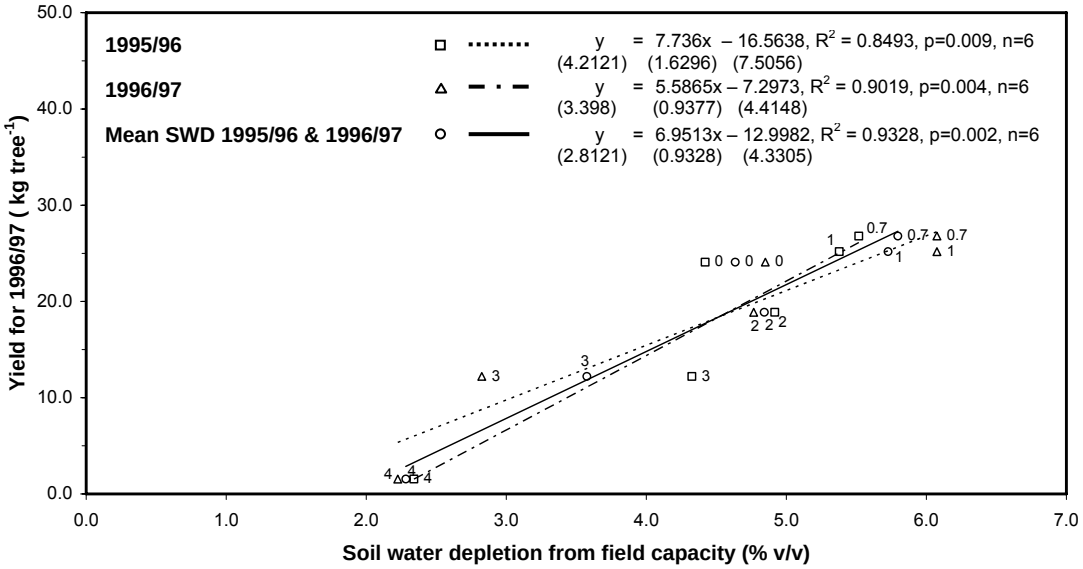


Fig. 6.15. The effect of profile mean soil water depletion (SWD, %v/v) from field capacity for the 1995/96, 1996/97 and the mean of both seasons (n=6) on yield of the 1996/97 season. Data are the means of replicate blocks and data point labels indicate the target irrigation water salinity in dS m^{-1}. Mathematical functions are displayed on graphs only for regression relationships that are statistically significant at a 95% confidence level and the standard errors of the estimate and coefficients are indicated below each equation.

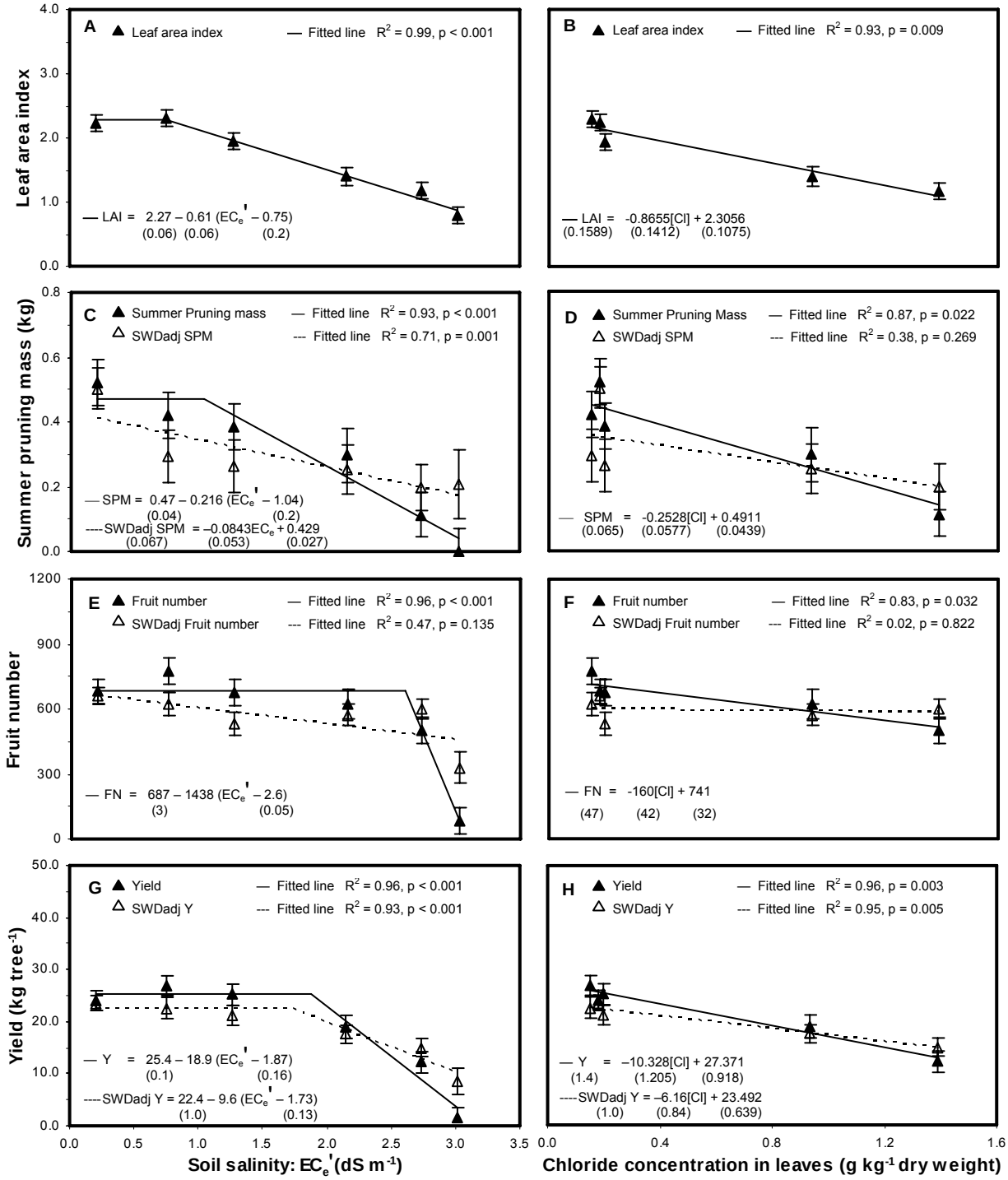


Figure 6.16. The effect of mean depth-weighted soil salinity of the saturated soil paste extract or EC_e' for the 1995/96 and 1996/97 seasons (A, C, E & G) and leaf choride concentrations or [Cl] at harvest (B, D, F & H) on leaf area index (LAI) (A & B), summer pruning mass (SPM) (C & D), fruit number (FN) (E & F) and yield (Y) (G & H) of Palsteyn apricot as determined for the 1996/97 season. Mathematical functions are displayed on graphs only for non-linear and linear regression relationships that are statistically significant at a 95% confidence level and the standard errors of the estimate and/or coefficients are indicated below each equation. Regression relationships are also presented for summer pruning mass (SPM) (C & D), fruit number (FN) (E & F) and yield (Y) data that were adjusted by means of covariance for differences in soil water depletion level (SWDadj).

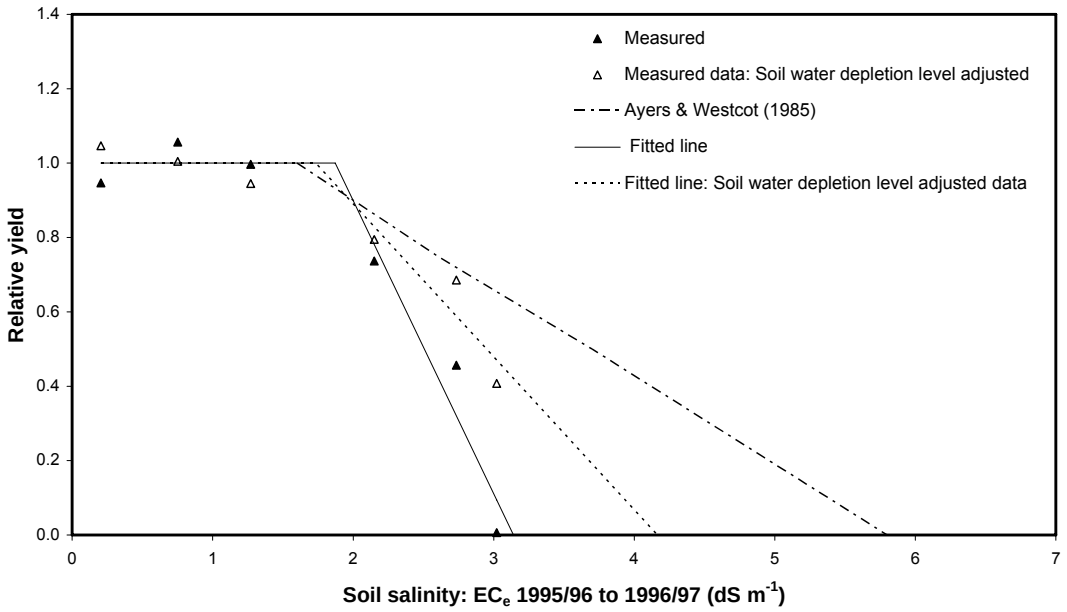


Figure 6.17. The effect of mean depth-weighted soil salinity of the saturated soil extract of the 1995/96 and 1996/97 seasons on the relative yield of Palsteyn apricot trees on Marianna rootstock compared to the internationally salinity threshold for vegetative growth published for apricot by Ayers & Westcot (1985). The regression relationship is also shown for relative yield data adjusted by means of covariance analysis for differences in soil water depletion (SWDadj). The salt tolerance equation for relative yield is $Y_r = 100 - 70(EC_e - 1.87(SE\pm0.18))$ and for SWDadj relative yield, SWDadj $Y_r = 100 - 41(EC_e - 1.73(SE\pm0.23))$.

The salt tolerance response functions for SWDadj summer pruning mass and SWDadj fruit number data to the mean EC_e' of the 1995/96 and 1996/97 seasons changed to single linear mathematical functions, with no significant effect of increasing EC_e' on SWDadj fruit number (Fig. 6.16C & D). The slope of the linear mathematical function for SWDadj summer pruning mass to EC_e' was significantly less steep compared to the slope beyond the threshold of the joint-point salinity response function for summer pruning mass to EC_e' (Fig. 6.16C). The salt tolerance response function of SWDadj yield to the mean EC_e' of the 1995/96 and 1996/97 season resulted in a lower salinity threshold and significantly lower rate of decrease in yield per unit salinity increase compared to that for yield not adjusted for differences in soil water depletion (Fig. 6.16G). The salinity threshold value for relative SWDadj yield decrease was 1.73 dS m^{-1} and the slope 41 percent per dS m^{-1} salinity increase (Fig. 6.17).

The leaf area index, summer pruning mass, fruit number and yield decreased with increasing chloride levels in leaves (Fig. 6.16B, D, F & H). The rate of decrease in relative leaf area index, relative summer pruning mass and relative yield respectively, with increasing leaf chloride levels (g kg^{-1} dry weight) was 39, 49 and 43 percent per unit increase in leaf chloride concentration, respectively. These values were not significantly different (data not shown). Relative fruit number was reduced at a significantly lower rate and decreased by 24 percent per unit chloride increase in leaves (data not shown). The linear regression relationships between SWDadj summer pruning mass and SWDadj fruit number respectively, with leaf chloride levels, were not significant (Fig. 6.16D & F) and the rate of SWDadj yield decrease with increasing leaf chloride levels was not significantly lower at a 5% statistical significance level compared to that for yield not adjusted for differences in soil water depletion levels (Fig. 6.16H).

6.4 DISCUSSION

6.4.1 Osmotic and specific ion toxicity stress and plant physiology

The growth of Palsteyn apricot on Marianna rootstock responded to the osmotic pressure of salt outside the plant and to excess levels of salt inside the plant. Pre-dawn leaf water potential measured one day before irrigation during the 1995/96 season indicated that trees in the 2, 3 and 4 dS m^{-1} treatments experienced a water deficit compared to the 0 dS m^{-1} treatment (Fig. 6.2A). Ruiz-Sánchez, Domingo, Torrecillas & Pérez-Pastor (2000), in a study on water stress preconditioning in 1-year-old apricot plants (*Prunus armeniaca* L., cv. Búlida on *P.domestica* L. rootstock) grown under field conditions in 35-l pots, indicated that pre-dawn leaf water potential values of c. -0.7 MPa correspond to moderate and -1.1 MPa to more severe plant water deficits. The relatively high pre-dawn leaf water potential values for Palsteyn apricot from the beginning of the season to the period after harvest indicated only mild water stress.

The leaf water potential, measured before irrigation, however, reflected the contributing effects of soil matric potential as well as soil osmotic potential to soil water potential. Development of a water deficit and thus low soil matric potential in the soil, could cause concentration of salts in the soil and a concurrent decrease in the osmotic potential of the soil solution.

In order to ensure that the physiological responses were to increasing soil osmotic potential rather than a combination of this and water stress, measurements were performed one day after irrigation during 1996/97. It was assumed that the soil matric potential was not significantly different between treatments shortly after irrigation and that soil osmotic potential was not affected by water deficit per se. The estimated depth-weighted seasonal averaged osmotic potential of the soil water at field capacity decreased with increasing salinity (Fig. 6.1), surpassing -0.15 MPa for the 2 dS m^{-1} and -0.2 MPa for both the 3 and 4 dS m^{-1} treatments during the 1996/97 season. Significantly lower pre-dawn water potential (Fig. 6.2B) and relative water content (Fig. 6.2E) of leaves in the 3 dS m^{-1} treatment compared to the 0 and 1 dS m^{-1} treatments before harvest indicated that the osmotic component of salinity did contribute significantly to the water deficit in the trees. Water plays a key role in cell expansion and growth (Jones & Tardieu, 1998) and growth rate is a function of cell wall plasticity, turgor and a threshold turgor for cell enlargement (Cramer & Bowman, 1994; Jacoby, 1994). According to Jones, Lakso & Syvertsen (1985), relative water content is closely related to turgor and cell volume, while leaf water potential is presumably only directly relevant to water flow and not necessarily the best indicator of physiological stress. Turgor, that is necessary for cell expansion, can nonetheless be estimated from the difference between leaf water potential and leaf osmotic potential (Kramer, 1983).

Decreased pre-dawn leaf water potential may indicate either loss of turgor and/or a decrease in osmotic potential as a result of active accumulation of organic osmolytes/ ions in the cytoplasm and vacuole. Various organic ions as well as mineral ions, particularly sodium, potassium and chloride, are accumulated in plants during turgor or volume regulation (Jacoby, 1994). Osmotic adjustment in fruit trees is commonly either by passive concentration of solutes in cells by dehydration or partial active adjustment (Jones *et al*., 1985), and both occurred in seven-year-old apricot trees (Loveys, Robinson & Downton, 1987). Osmotic adjustment of between 0.27 and 0.6 MPa as a result of active accumulation of solutes has also previously been documented for 1.5-year-old apricot plants (*Prunus armeniaca* L., cv. Búlida on Real Fino apricot rootstock) exposed to two successive cycles of water stress and recovery periods under glasshouse conditions (Torrecillas, Galego, Pérez-Pastor & Ruiz-Sánchez, 1999). Control plants received daily irrigation to keep the soil matric potential at c. –0.02 MPa, while no water was applied to stressed plants until a pre-dawn leaf water potential of between –2.0 MPa and –2.5 MPa was reached. Leaf osmotic potential at full turgor, determined by pressure volume analysis of

leaves, was compared between control plants and water stressed plants. For Palsteyn apricot, the pre-dawn leaf osmotic potential decreased progressively in all treatments from the beginning of the season, before harvest and after harvest, with the largest decrease in the 3 dS m^{-1} treatment (Fig. 6.2D). The pre-dawn leaf osmotic potential of the 3 dS m^{-1} treatment was 0.14 MPa and 0.39 MPa lower than that of the control before and after harvest, respectively, during the 1996/97 season, indicating possible active osmotic adjustment. The water deficit in the 3 dS m^{-1} treatment (Fig. 6.2B & E) occurred before harvest despite the significantly lower pre-dawn osmotic potential of leaves (Fig. 6.2D) and could indicate inadequate osmotic adjustment by the plant. The water deficit after harvest was, however, not significantly different from that of the control and coincided with a substantial decrease in pre-dawn leaf osmotic potential.

The methodology used in our research to determine the leaf osmotic potential could, however, not distinguish between active osmotic adjustment through organic solutes/ mineral ions and accumulation of high concentrations of ions in the cell walls and thus precluded conclusions regarding osmotic adjustment or dehydration of individual cells. Killing of tissue by freezing to measure the osmotic potential could cause mixing of symplastic water, which is mainly vacuolar sap, with apoplastic or cell wall water (Kramer, 1983). The apoplastic water component could cause a significant dilution of symplastic water if the cell walls contain 10 to 30% of water in cells (Markhart, Sionit & Siedow, 1981) and research for young Búlida apricot plants indicated that the relative apoplastic water content of leaves ranged from 27 to 42% (Torrecillas, Galego, Pérez-Pastor, Ruiz-Sánchez, 1999). On the contrary, if salts accumulated in the cell wall or apoplast, it could result in the withdrawal of symplastic water from the cells (Flowers & Yeo, 1986). Estimated leaf turgor values for Palsteyn apricot for the 1996/97 season indicated that leaves of the high salinity treatment had higher turgor (data not shown) which apparently contradicted the significantly lower relative water content found in the 3 dS m^{-1} treatment (Fig. 6.2E). The lower pre-dawn osmotic potential was probably caused by high concentrations of salt in the cell walls, and thus caused overestimation of turgor. Another explanation for the higher turgor at the high salinity treatment may be the assumption that the osmotic potential in the xylem sap was negligible compared to the water potential and therefore was not taken into account in the calculation of turgor. This also may lead to significant overestimates of cell turgor pressure (Murphy & Smith, 1994).

Chloride most likely contributed to the lower osmotic potential in Palsteyn apricot leaves, because chloride concentrations in leaves from the 2 and 3 dS m^{-1} treatments, after four seasons of saline irrigation, increased considerably as the chloride concentration in the soil water exceeded the tolerance level of Marianna rootstock and chloride levels in leaves exceeded the 10 g kg^{-1} dry weight limit for leaf burn of apricot trees (See Chapter 5). A rapid

rise in salt concentrations in cell walls or the cytoplasm when the vacuoles could no longer sequester incoming salts (Munns, 1993), probably led to foliar damage at high chloride levels in leaves during the 1996/97 season (Fig. 6.12). Bingham, Fenn & Oertli (1968) compared chloride concentrations in cell sap of marginal and midsection tissue and xylem fluid of mature avocado tree (*Persea americana* cv. Hass on Mexican race rootstock) leaves. Leaf damage was attributed to extracellular accumulation of chloride in leaves, the ensuing osmotic gradient from symplast to apoplast and the resultant desiccation of cells that interferes with normal metabolism. Greenway & Munns (1980) furthermore proposed that the most effective contribution of mineral ions to osmotic potential is an increase in both total cations and in chloride, but in non-halophytes, chloride may increase without concurrent increases in cations. In the latter case, chloride apparently replaces divalent organic acids, though this has never been validated. Lower osmotic potential in the case of Palsteyn apricot could therefore indicate accumulation of ions in the apoplast/ cytoplasm/ vacuole or of organic osmolytes in the cytoplasm/ vacuole or any combination thereof.

Several studies on fruit crops reported on water relations and salt accumulation in order to identify physiological causes for growth and yield decrease under saline conditions. Ziska *et al*. (1989) used the same methodology of fast-freezing through nitrogen, thawing and expressing sap from leaf tissue to determine “bulk leaf cellular osmotic potential”. They concluded that it is possible that exposure to salinity of 28 mM and a corresponding EC_{iw} of 4 dS m^{-1} over a long period resulted in osmotic adjustment and positive leaf turgor potential of *Prunus salicina* (L.) cv. Santa Rosa on *Prunus cerasifera* L. cv. Mariana 2624 rootstock under field conditions. They deduced that the decline in plum tree growth could not be attributed to reduced leaf turgor. Ziska *et al*. (1991), utilizing X-ray micro-analysis, furthermore determined that the leaf mesophyll cells of the plum trees displayed an ability to sequester chloride in the vacuoles away from chloroplasts and the cytoplasm. This could prevent excessive salt accumulation in the apoplast, a mechanism that apparently was not as effective in avocado leaves (Bingham *et al*., 1968). Lloyd, Kriedemann & Aspinall (1990) found that rootstock affected scion leaf apoplastic water volume and inferred from psychrometric and pressure-volume curve-determined leaf osmotic potentials that some apoplastic accumulation of sodium and chloride occurred in two-year-old citrus plants after 49 days of exposure to sodium chloride salinity. According to Storey & Walker (1999), however, the majority of studies on citrus and salinity indicated that leaf turgor potential is maintained at similar levels to non-salinised control plants and the sodium and chloride that is accumulated, contribute to the osmotic adjustment process by being effectively balanced and compartmented. It is thus clear that fruit crops differ in their ability to adjust their internal osmotic potential to facilitate water uptake under saline conditions and regarding exclusion, retention and compartmentation of or tissue tolerance to excessive levels of specific ions. It is concluded that Palsteyn apricot experienced water deficit and accumulated excessive

levels of chloride in leaves after exposure to saline irrigation water of 3 dS m^{-1} for three-and-a-half years.

Salinity can cause lower rates of carbon dioxide assimilation during the light period through water deficit and partial stomatal closure, loss of turgor from mesophyll cells through salt accumulation in the apoplast or direct toxic effects of ions (Marschner, 1995). The significant decrease in stomatal conductance (Fig. 6.3A & B) and net photosynthesis rate (Fig. 6.3C & D) of Palsteyn apricot leaves in the 2, 3 and 4 dS m^{-1} treatments could be ascribed to a combination of water deficit and specific ion effects. Low osmotic potential in the soil water where saline irrigation exceeded 1 dS m^{-1} (Fig. 1) lowered the total soil water potential and probably restricted root water uptake and hydraulic conductivity, which reduced stomatal conductivity (Fig. 6.3A & B), presumably by means of hydraulic signals and/or endogeneous phytohormone signals from the roots to shoots (Jones, 1998; Munns, 1993; Poljakoff-Mayber & Lerner, 1994; Schulze, 1986). Boland, Mitchell and Jerie (1993) attributed a reduction in photosynthesis in peach trees to water deficit and partial stomatal closure, but also to the direct adverse effects of chloride. Stomatal conductance decreased with increased levels of chloride in leaves (Boland *et al*., 1993).

Regressions of chloride with net photosynthesis rate (R^2 = 0.86) and stomatal conductance (R^2 = 0.73) respectively after harvest during the 1995/96 season, were strongly negative (data not shown) for Palsteyn apricot leaves. A significantly lower slope for photosynthesis rate compared to that for stomatal conductance implies that chloride not only affected stomatal factors, but also non-stomatal factors determining carbon dioxide assimilation (data not shown). The basis for the non-stomatal effects may lie in the altered transport parameters for carbon dioxide from the intercellular space to the chloroplasts or in altered ability of the chloroplasts to photosynthesise as either would decrease mesophyll conductance (Hsiao & Acevedo, 1974). The carbon dioxide assimilation capacity of leaves of salt-treated plum trees grown in the field was found to be highly sensitive to changes in leaf chloride content and whole leaf carbon dioxide assimilation declined linearly when leaf chloride levels increased above 2.6 g Cl^- kg^{-1} dry weight (Ziska *et al*., 1990).

Approximately 10% of the decline in carbon dioxide assimilation in the abovementioned plum trees could be attributed to a rise in leaf dark respiration associated with increasing leaf chloride levels and the energy required for ion compartmentation and/or osmotic adjustment (Ziska *et al.*, 1990). The decline in assimilation in response to salinity was not due to carbohydrate feedback inhibition, but a direct effect of chloride on the non-stomatal components of photosynthesis. The authors concluded that the reduction in leaf carbon dioxide assimilation resulting from salinisation of *P. salicina* was a consequence of a decline in the amount of

ribulose bisphosphate carboxylase (RuBPcase) per unit leaf area. The specific activity of RuBPcase decreased with increased levels of salt and time of exposure with the exception of the highest salinity level where non-uniform stomatal closure apparantly occurred (Ziska *et al*., 1990).

The photosynthesis rate of Palsteyn apricot leaves appeared to be influenced by the level, as well as the period of exposure, to salinity. The photosynthesis rates in the 4 and 3 dS m^{-1} treatments were already significantly reduced at the beginning of the 1995/96 and 1996/97 seasons respectively and the effect of salinity on photosynthesis rate appeared to become more pronounced later in the season (Fig. 6.3C & D). Net photosynthesis was closely related to stomatal conductance and the latter played a more important role after harvest compared to before harvest in determining the photosynthesis rate (Fig. 6.5). The decline in photosynthesis rates in the high salinity treatments at the beginning of the season could most likely be explained by the water deficit in leaves (Fig. 6.2A, B & E) caused by the low soil osmotic potential in these treatments (Fig. 6.1) and probably high levels of chloride in leaves at the start of the season that reduced both stomatal and non-stomatal components of photosynthesis. Chloride levels in leaves of the 2, 3 and 4 dS m^{-1} treatments already exceeded apricot tissue tolerance levels (Fig. 6.12) during October 1996 (data not shown).

The more pronounced decrease in photosynthesis rates later in the season could be due to the lower photosynthesis rate per unit stomatal conductance after harvest compared to that of pre-harvest for both seasons (Fig 6.5A & B) and the additive effects of salt accumulation, especially chloride, in the leaves that have transpired for an increasingly longer period as the season progressed. The increase in C_i with increasing salinity during the latter part of the 1995/96 season could indicate that non-stomatal factors of net photosynthesis were negatively affected by salinity (Fig. 6.3E). Correlation of net photosynthesis with leaf osmotic potential (R^2 = 0.56, $p < 0.001$) and C_i with leaf osmotic potential (R^2 = 0.51, $p < 0.001$) after harvest during 1995/96 indicated that net photosynthesis decreased, while C_i increased with lower leaf osmotic potential. The C_i increased in high salinity treatments, despite lower net photosynthesis rates (Fig. 6.3C, Fig. 6.4A) and decreased stomatal conductance (Fig. 6.3A). It thus follows that there was a carboxylation resistance apart from the stomatal conductance that reduced the net photosynthesis in high salinity treatments after harvest during the 1995/96 season. This conclusion concurs with that of Farquhar and Sharkey (1982) that stomatal closure is of secondary importance in causing the reduction of assimilation rate where C_i is, despite reduced stomatal closure, higher after water stress than in controls. Similar conclusions may be drawn when C_i is little changed despite reductions in assimilation rate and stomatal conductance (Farquhar & Sharkey, 1982). The latter scenario suited especially high salinity treatments during the beginning and before harvest of the 1995/96 season (Fig. 6.3A, Fig. 6.4A) and after

harvest of the 1996/97 season (Fig. 6.3B, Fig. 6.4B) where C_i remained within a relatively narrow range despite the decreased net photosynthesis rate.

Myers *et al*. (1995) attributed the long-term decline in yield and vigour of salt-treated pear trees partially to a cumulative effect of salinity resulting from the suppression of assimilation rates late in the season. Ziska *et al*. (1990) provides a possible explanation for changes in non-stomatal reduction of photosynthesis with increased salinity and time of exposure by establishing the order of limitations to the photosynthetic process with increasing chloride by utilising the sequences of biochemical changes. Reductions in the biochemical components of carbon dioxide assimilation may furthermore be related to a net reduction in soluble and insoluble carbohydrates with increased salinity and time of exposure. Such changes in total carbohydrates may impact negatively on carbohydrate utilisation and partially explain reductions in growth and reproduction.

6.4.2 Effects on vegetative growth and reproductive growth

Both leaf area index (Fig. 6.6) and area per leaf (Fig. 6.7) decreased significantly with increasing salinity. Regressions of chloride content with area per leaf (R^2 = 0.91) and leaf area index (R^2 = 0.84) during April of the 1996/97 season were negative (data not shown). Increased chloride concentration also reduced leaf expansion and subsequently, leaf area of plum trees (Ziska *et al*., 1990). Salinity resulted in significantly smaller mid-lateral leaves and reduced shoot growth of pear trees (Myers *et al*., 1995) and also reduced leaf area index of peach trees significantly (Boland *et al*., 1993). Lack of differences in specific leaf area of Palsteyn apricot was due to tendencies of both leaf area and dry weight to decrease with increasing irrigation water salinity (Figure 6.7; leaf DW data not shown). Significantly lower summer pruning weights of Palsteyn apricot trees with treatments receiving saline irrigation water of equal to or exceeding 2 dS m^{-1} confirmed the negative effect of salinity on vegetative growth of trees (Fig. 6.8). Trunk growth was reduced in all treatments receiving irrigation water with salinity equal to or exceeding 2 dS m^{-1} (Fig. 6.9). A similar reduction in pruning weights have been reported for plums (Hoffman *et al*., 1989) and also for peaches where increases in trunk cross sectional area were also adversely affected by salinity (Boland *et al*., 1993). Reduced light interception due to decreased leaf area index (Fig. 6.6) and the lower photosynthesis rate later in the season (Fig. 6.3C & D) in the high salinity treatments thus hampered production of assimilates for transport to perennial tree parts in the post harvest period.

Chloride could have contributed to leaf necrosis and chlorosis in treatments in which the irrigation water salinity exceeded 1 dS m^{-1}. According to Bernstein *et al*. (1956), chloride causes marginal leaf chlorosis in apricot leaves when the concentration exceeds 10 g kg^{-1} of dry weight. According to our data, visible damage (> 1%) could occur when chloride levels in

leaves exceed 9 g kg^{-1} of dry weight (Fig. 6.12). Apricot leaves are apparently able to tolerate higher levels of chloride in leaves than that of fruit crops in general, before visible damage set in. A high apoplastic water volume, as was found for Búlida apricot leaves (Torrecillas *et al*., 1999), may probably contribute to such tolerance. According to Bernstein (1980), leaf injury in fruit crops can usually be attributed to chloride toxicity if affected leaves are found to contain more than 5 g kg^{-1} chloride. Curling, necrosis, chlorosis and fall of Palsteyn apricot leaves were aggravated by increased salt concentrations in the irrigation water and occurred earlier in the highest salinity treatments as seasons progressed (Figs. 6.10 & 6.11). Premature leaf fall consequently resulted in reduced leaf area duration as salinity increased. Catlin *et al*. (1993) observed the same phenomenon in the 4 dS m^{-1} salinity treatment on plum trees. The authors attributed damage at the start of the season to mobilization of chloride and/or sodium from within the tree to the foliage and flowers. In the case of Palsteyn apricots, however, sodium was mainly excluded from the leaves before harvest and foliar damage was mainly attributable to chloride accumulation (Chapter 5). Occurrence of leaf damage and defoliation of Palsteyn apricot (Figs. 6.10 & 11) support the hypothesis of Catlin *et al*. (1993) that irrigation with lower salt concentrations ultimately led to responses similar to those obtained with shorter periods of exposure with higher salinity water.

Alternate bearing of trees complicated interpretation of the effect of salinity on reproductive growth and production and thus only the 1996/97 season, which had acceptable crop yield is further discussed (Fig. 6.13). The main reason for lower production in high salinity treatments was attributed to the reduced leaf area. It was already found that leaf area index decreased with increasing irrigation water salinity (Fig. 6.6). The relationship between the total mass of fruit, total number of fruit and average fruit mass to leaf area index indicated that production parameters increased with increasing leaf area index during the 1996/97 season (Fig. 6.14). During seasons of low crop load, however, fruit set may be the primary factor determining production.

The decreased leaf area as well as smaller fruit size in the 2, 3 and 4 dS m^{-1} treatments could additionally be attributed to the specific partitioning of assimilates. A part of the photosynthate produced by the plant is diverted from growth to osmotic adjustment and ion balance regulation that is needed to maintain normal metabolism under low to moderate salinity (Subbarao & Johansen, 1994). The dilution/ concentration effect of cell wall water on leaf osmotic potential measurements of Palsteyn apricot precludes any conclusion regarding the presence and degree of osmotic adaptation of leaves. The specific solutes involved in osmotic adjustment were not determined in our research, but other research indicated that apricot leaves do adjust osmotically when subjected to water stress in the field by net synthesis and accumulation of sorbitol together with passive concentration of ionic constituents (Loveys *et al*., 1987).

Accumulation of organic solutes in saline conditions occurs in response to the osmotic effects of the soil solution and is not a response to specific ions (Jeffries, Rudmik & Dillon, 1979). The specific organic osmolytes accumulated for osmotic adjustment could therefore be similar under water and salinity stress. Relative water content of leaves indicated water deficit in leaves in the 3 dS m^{-1} treatment (Fig. 6.2F) and osmotic adjustment in leaves of Palsteyn apricot through accumulation of organic solutes under saline conditions therefore remains a strong possibility.

Further expenditure of energy is to be expected for ion regulation purposes of Marianna rootstock that restricts sodium and chloride accumulation in other stone fruit (Bernstein *et al*., 1956; Bernstein, 1980). The mechanisms that restrain sodium ions from entering the leaves could be energy dependent ion exclusion and/or sodium reabsorption from the xylem and retranslocation to the roots via the phloem (Jacoby, 1994; Orcutt & Nilsen, 2000). Ottman and Byrne (1988) indicated that the subtle role of energy expenditure for exclusion and compartmentalization of sodium was most likely underrated relative to the effect of chloride toxicity on leaves in Prunus species. However, continued retranslocation of sodium back to the roots is expected to be inadequate under conditions of high salinity (Flowers & Yeo, 1986) and ineffective in response to long-term salinity, because sodium toxicity in roots would develop rapidly (Orcutt & Nilsen, 2000). It is therefore deduced that the processes of ion regulation and possibly osmotic adaptation during the season could have reduced the amount of assimilates available for allocation to apricot vegetative and fruit growth.

Fruit size of the 2, 3 and 4 dS m^{-1} treatments at thinning was already significantly smaller than that in the 0 dS m^{-1} treatment (Table 6.3). Possible explanations for the smaller fruit size in the higher salinity treatments early in the season could be limited carbohydrate reserves, early cessation of fruit cell division or utilization of carbohydrate reserves for ion regulation of a carry-over specific ion toxicity effect in perennial plant parts, resulting from irrigation with saline water during the previous seasons. Carbohydrate reserves in storage cells of the branches, trunk and roots of trees provide in the initial energy and nutrition demands for vegetative growth and flowering until newly formed leaves become independent and begin exporting photosynthates to meet demands of the various sinks. Heavy fruit set concurrent to a limited reserve supply of nutrients could cause cell division to cease early, further limiting the growth potential of fruit (Ryugo, 1988). The amount of carbohydrates stored in apricot trees subjected to increased salinisation could be decreased by reduced leaf area duration (Fig. 6.11), lower photosynthesis rates late in the season (Fig. 6.2 C & D) as well as hydrolysis of starch to sugars in branches subtending fruit shortly before harvest. These sugars are supplementary to current photosynthates, which usually do not meet the sugar demand in stone fruit during the maturation period (Ryugo, 1988). The possibility of heavy fruit set in combination with low carbohydrate reserves decreasing cell division in fruits seems unlikely, because the maximum

fruit set percentage achieved for both seasons that it was monitored was 33.5% (Table 6.3). With regard to the specific ion toxicity carry-over effect, Catlin *et al*. (1993) reported substantial chloride toxicity to flowers of plum in the 4 dS m^{-1} salinity treatment affecting fruit number and size at harvest. However, the effect on fruit size early in the season was not mentioned. Destructive harvest of Palsteyn apricot trees on Marianna rootstock irrigated for four years with water of salinity of 2 dS m^{-1} and higher, indicated progressive accumulation of sodium in the perennial tree parts as salt concentrations in the irrigation water increased (Chapter 5). The sodium, however, was restricted from entering the leaves and new growth, probably by exclusion and/or recycling processes. These energy-dependent ion regulation processes as well as low carbohydrate reserves could be the main reasons for inhibited fruit growth early in the season in the saline treatments.

In summary, high irrigation water salinity levels resulted in an osmotically induced water deficit, a lower photosynthesis rate, reduced leaf area, foliar damage and premature leaf fall that in combination produced less assimilates for growth. This already diminished assimilate pool could further be reduced by partitioning of assimilates to osmotic adjustment and energy-dependent ion regulation processes. It is thus concluded that osmotic as well as specific ion effects of high salinity water on plant physiological characteristics underpinned reduced vegetative and reproductive growth.

6.4.3 Effects on phenology

The number of flower buds induced during bud initiation in and out of season and vegetative growth out of season could also affect the production of the trees. Hoffman *et al*. (1989) concluded that many potential fruiting buds of plum trees were not formed, or failed to develop in the 6 dS m^{-1} and 8 dS m^{-1} salinity treatments after three years of saline irrigation, thereby impacting severely on the yield of trees. The flower index and flower density of Palsteyn apricot (Table 6.2) was significantly reduced and less fruit thinned from trees (Table 6.3) in the 4 dS m^{-1} treatment during the 1996/97 season. Poor fruit set, which could probably be ascribed to toxicity of chloride and/or sodium to flowers, further contributed to reduced yields in this treatment (Table 6.3). Catlin *et al*. (1993) attributed substantial toxicity occurring to flowers of plum in the 4 dS m^{-1} salinity treatment in the fourth year of irrigation, which resulted in fewer and smaller fruit compared to less saline treatments, to mobilization of chloride and/or sodium from within the tree to the foliage and flowers.

In addition to specific ion effects, the osmotic effects of salinity in the high salinity treatments could probably mimic the effect of water stress induced during one and a half months after harvest that reduced fruit set of Búlida apricots the following season (Torrecillas, Domingo, Galego & Ruiz-Sánchez, 2000). Flower bud induction and/or the floral differentiation processes

that occur during this period could be affected (Uriu, 1964), promoting young fruit drop and also cause lower germination potential in the pollen of the following year's bloom (Ruiz-Sánchez, Egea, Galego, & Torrecillas, 1999). In a study regarding high abscission rates of flower buds in apricots, Martínez-Gómez, Dicenta, Ruiz & Egea (2002) concluded that damage to the canopy of 'Guillermo' apricot in the autumn, or early defoliation, had no important influence on flower bud abscission, although a higher percentage of buds abscised was observed in defoliated branches. Out of season flowering and vegetative growth was observed at trees from the 2, 3 and 4 dS m^{-1} treatments and it could be indicative of a disturbed hormonal balance in the trees (Poljakoff-Mayber & Lerner, 1994). Initiation of vegetative growth near the end of the season concurrent to leaf fall is undesirable because it utilizes metabolites and nutrients that should be reserved for flower bud development during winter and flowering and growth of the following season.

6.4.4 Fruit quality

Quality of Palsteyn apricot fruit harvested during the 1996/97 season was significantly affected by treatments receiving saline irrigation exceeding 1 dS m^{-1} (Table 6.1). Fruit dry mass was decreased in the 2 dS m^{-1} and 3 dS m^{-1} treatments, probably due to inadequate partitioning of photosynthates from leaves and storage carbohydrates from shoots subtending the fruit. The increased ratio of dry mass to fresh mass in these treatments could indicate less succulent fruit in the more saline treatments. Increased total dissolved solids and reduced acid content in the 2 and 3 dS m^{-1} treatments indicated advanced maturity of these fruit compared to the less saline treatments. However, ground colour development of fruit in the 3 dS m^{-1} treatment was delayed and non-uniform colouration of fruit occurred concurrent to increased maturity of these fruit.

Ryugo (1988) indicated that the degradation of chlorophyll and the onset of carotene synthesis in yellow peach and apricot cultivars are delayed by heavy applications of nitrogenous fertilizers, and that heavy pre-harvest drop of straw-coloured, but physiologically mature fruit may occur if harvest is delayed for the purpose of colour development. The mechanism of the non-uniform colouration in Palsteyn apricot fruit is unclear, but it is possible that high chloride concentrations in Palsteyn apricot fruit (Chapter 5) affected nitrogen metabolism, which in turn could have affected hormonal balance and thereby colouration of fruit (Marschner, 1995). Hoffman *et al*. (1989) reported that salinity hastened maturity for plums. In the case of Palsteyn apricot receiving irrigation water of 3 dS m^{-1} salinity, however, fruit colouration effects tended to delay the date of harvest although other maturity indexes indicated advanced fruit maturity.

Lack of a specific salinity effect regarding decay and physiological disorders could possibly be attributed to the increased calcium levels in the fruit of the higher salinity treatments (Chapter 5). The proportion of calcium pectate in cell walls is of importance for the susceptibility

of the tissue to fungal and bacterial infections and for ripening of fruit (Marschner, 1995) and could possibly explain the low levels of decay. Woolliness, a disorder normally found in peaches and nectarines (Von Mollendorff, 1987), was also observed in Palsteyn apricot fruit. Pectic substances are the main substances involved in woolliness and calcium, that may influence pectic substances, may also have an effect on the onset of woolliness (Von Mollendorff, 1987). Specific information on the presence, form and concentration of calcium that could possibly explain its role in woolliness, however, is lacking. Gel breakdown of apricots is another physiological disorder associated with the reaction of pectic compounds with water (Von Mollendorff, Jacobs & De Villiers, 1992) and the disorder is enhanced in fruit harvested at post-optimum maturity (Van der Merwe, 1996). High salinity levels, specifically sodium, could affect cell membrane permeability. Sodium was, however, not imported in fruit and high chloride levels in fruit (Chapter 5) had no significant effect regarding gel breakdown.

6.4.5 Salt tolerance

Although commercial crop yield is considered to be the only agronomically significant criterion for establishing salt tolerance (Maas & Hoffman, 1977), evaluation of vegetative growth in the case of *Prunus* species could be important. According to Catlin *et al*. (1993), reduced shoot growth appeared to be an early indicator that conditions developed within plum trees that would later result in yield reductions. These authors found that a fifty percent reduction in shoot growth preceded reduced yields the following year. Amongst the plant parameters evaluated for Palsteyn apricot, leaf area index was the most sensitive to salinity and started to decline at 0.75 dS m^{-1}, while soil salinity of 1.04 dS m^{-1} affected summer pruning mass (Figs. 6.17A & C). Yield was less sensitive to salinity compared to vegetative growth and an increase of EC_e' above 1.87 dS m^{-1} would decrease yield per tree by 18.9 kg (70%) per unit increase in salinity (Fig. 6.17G). The processes determining fruit number appeared to be even less sensitive to salinity than yield as the threshold for reduction of fruit number was 2.6 dS m^{-1} (Fig. 6.17E).

Yield losses from fruit and nut trees are often greater than those predicted from osmotic effects alone and the salinity tolerance data for fruit crops are only valid if the rootstocks do not accumulate sodium and chloride rapidly, or when these ions do not predominate in the soil. If either ion is present in excessive amounts in the soil solution or plant tissue, specific ion toxicity should be taken into account (Maas & Hoffman, 1977). In contrast to sodium, chloride was accumulated in leaves of Palsteyn apricot and caused a significant effect on vegetative growth response and yield (Fig. 6.17B, D & H). The effect of leaf chloride levels on yield and leaf area index was similar (Fig. 6.17B & H), thereby confirming the importance of the photosynthetic area for yield of Palsteyn apricot. Fruit number appeared to be less sensitive to increasing chloride levels compared to vegetative growth and yield (Fig. 6.17B, D, H & F) with the regression line displaying a less steep slope. It is concluded that osmotic effects of salinity, as

well as direct toxic effects of specific ions should be amongst factors taken into account when the salt tolerance of *Prunus* fruit species is considered.

Water stress due to periodic waterlogging is another factor that may affect the salt tolerance response (Maas & Grattan, 1999) as the combined effects of salinity and oxygen deficiency in a water saturated soil profile can adversely affect selective ion transport processes in the plant (Drew *et al*., 1988) and shoot growth (Aubertin *et al*., 1968). The mean profile soil water depletion level from field capacity before irrigation for the 1995/96 and 1996/97 seasons combined was significantly lower at the 3 dS m^{-1} and 4 dS m^{-1} treatments compared to that in the 0.7, 1 and 2 dS m^{-1} treatments (data not shown) and periodic waterlogging may have occurred for an unknown period after irrigation in these treatments. Summer pruning mass as well as yield decreased significantly less per unit increase in salinity beyond the threshold, while fruit number was no more significantly affected by soil salinity after the data were adjusted for differences in soil water depletion from field capacity (Fig. 6.17C, G & H). It follows that summer pruning mass, fruit number and yield increased in sensitivity to soil salinity at low levels of soil water depletion, which resulted in a more severe salt tolerance response for the respective plant variables.

Soil water depletion adjusted summer pruning mass and fruit number respectively, were not significantly affected by chloride levels in the leaves (Fig.6.17 D & F), which indicate that summer pruning mass and fruit number became more sensitive to chloride levels in the leaves at low soil water depletion levels. The rate of SWDadj yield decrease with increasing chloride concentration in the leaves appeared to be lower, but did not differ significantly from rate of yield decrease for yield data that were not adjusted for soil water depletion differences (Fig. 6.17H). The relationship between chloride levels in the leaves and yield was therefore not significantly altered by low levels of soil water depletion.

For agricultural management purposes, and specifically for intercrop comparisons for decision making, the use of the relative yield response to salinity is considered more appropriate than absolute yield or growth data (Maas & Hoffman, 1977; Maas, 1987). The salinity threshold value for relative yield decrease of apricot was 1.87 dS m^{-1} and the rate of yield decrease 70% per dS m^{-1} increase in salinity (Fig. 6.17). This threshold was c. 17% higher than that reported by Maas & Hoffman (1977) for a decrease in shoot growth of apricot and the yield decrease per unit increase in salinity beyond the threshold, was much steeper than the 24% indicated by the authors. A 10% decrease in apricot fruit yield could be expected at an EC_e of 2.0 dS m^{-1}, which indicates that trees were more sensitive than the value of 2.5 dS m^{-1} reported by Bernstein (1980). The salt tolerance of crops, however, can be influenced by many environmental, soil as well as management factors (Maas, 1987; Moolman *et al*., 1999; Shalevet, 1994). A reasonable

explanation for the difference in our results to that of Maas & Hoffman (1977) and Bernstein (1980) could be that the irrigation methodology we followed namely, to irrigate according to the replicate plot with the highest water deficit, resulted in waterlogging of some replicate plots for an unknown period of time after irrigation. Adjustment of yield data for differences in soil water depletion from field capacity resulted in a different threshold and slope for the salt tolerance function (Fig. 6.18). The threshold of 1.73 dS m^{-1} did not differ significantly from that reported by Maas & Hoffman (1977), but the yield decrease of 41% per unit increase in salinity beyond the threshold, was still steeper than that indicated by the authors.

Furthermore, the weekly irrigation interval used in our study could have caused the development of significant matric potential during summer and specific ion toxicity effects due to high chloride concentrations could have contributed to the increased rate of yield decrease. De Clercq *et al*. (2001), from recent research on grapevines (cv. Colombar) concluded that, irrespective whether the inhibitory effect of saline irrigation on yield is osmotic, toxic, or both, the salinity threshold level remains the same for a number of seasons. The sensitivity of the crop to levels beyond the threshold, however, increases with exposure and the slope reflects the additive effect of saline/sodic/chlorodic water on plants. The yield response of Palsteyn apricot, integrating saline irrigation effects of three seasons, seems to fit this inference, the salinity threshold level for Palsteyn apricot being effectively the same, but the slope almost double that found for apricot by Maas & Hoffman (1977). The salinity response function, however, is based on the yield data of only one year after approximately three years of saline irrigation, which is a rather limited dataset and short period for evaluating the effects of water salinity in the intermediate salinities and the interesting range for apricot.

The irrigation water salinity that could be used without yield loss was estimated as $EC_{iw} = EC_e$ (dS m^{-1})/2.1 (Ayers & Westcot, 1985) where 2.1 represent a concentration factor where a leaching fraction of 0.1 was applied. The calculated value of 0.82 dS m^{-1} was similar to the 0.76 dS m^{-1} that resulted from the EC_e of 1.6 dS m^{-1}, published in Ayers & Westcot (1985) at a leaching fraction of 0.1. A high degree of irrigation uniformity and control of irrigation is, however, needed to achieve a leaching fraction of 0.1 and a more realistic leaching fraction for farmers would be between 0.15 to 0.20. The irrigation water salinity that could be used without yield loss at these leaching fractions was estimated as 1.08 dS m^{-1} and 1.33 dS m^{-1}. Rainfall in the Little Karoo can, however, depending on rainfall effectivity, result in additional leaching which may decrease the leaching requirement or increase the allowed salinity in irrigation water. The long term averaged rainfall during winter varies from *c*. 85 mm to *c*. 147 mm and during the season from *c.* 178 mm to *c*. 300 mm if the areas of Ashton, Barrydale, Montagu and Robertson are considered.

6.5 CONCLUSIONS

Osmotic and specific ion effects of high salinity water on plant physiological characteristics underpinned reduced vegetative and reproductive growth of Palsteyn apricot. High salinity treatments decreased effective leaf area through foliar damage as well as reduced unit leaf area. The reduced effective canopy area in the higher salinity irrigation water treatments intercepted less light and, in combination with lower stomatal conductance and decreased net photosynthesis rate, led to reduced vegetative growth and final fruit size. It is hypothesized that energy-dependant osmotic adjustment and ion regulation processes further reduced the amount of assimilates available for partitioning to vegetative and reproductive growth. In Palsteyn apricot on Marianna rootstock, accumulation of excessive amounts of specific ions in perennial tissues of trees could result in advanced and accelerated reduction of photosynthesis rates, appearance of foliar damage and depletion or inadequate supplementation of the carbohydrate reserves of the trees. The rate of demise of trees is ultimately being determined by the effect of soil water and salinity levels, period of exposure and rootstock/scion salt tolerance on accumulation of carbohydrate reserves that are necessary for early season growth and long-term survival of trees in successive seasons.

The salinity threshold value for yield decrease of Palsteyn apricot was after adjustment for soil water depletion effects very similar to the internationally-determined salinity threshold for vegetative growth decrease of apricot. The yield decrease according to the salinity threshold value for Palsteyn, however, was 32% compared to the 10% previously reported for apricot at an EC_e value of 2.5 dS m^{-1}. A drastic decrease in yield beyond the locally determined threshold was ascribed to a weekly irrigation interval that could have caused the development of significant matric potential during summer and specific ion toxicity effects due to high chloride concentrations. Low soil water depletion levels further increased the sensitivity of Palsteyn apricot trees to high soil salinity levels and altered the salt tolerance response, resulting in a yield decrease of 44% at an EC_e value of 2.5 dS m^{-1}. Growers are advised not to use irrigation water with a salinity which exceeded an electrical conductivity of 0.82 dS m^{-1} for irrigation of Palsteyn apricot on Marianna rootstock where a leaching fraction of 0.1 was applied. The irrigation water salinity that could be used without yield loss at leaching fractions of 0.15 to 0.20 was estimated as 1.08 dS m^{-1} and 1.33 dS m^{-1}. Effective rainfall during the growing season and winter in the Little Karoo could further increase the leaching fraction, which may allow the use of irrigation water with higher salinity or application of less water to effect the same leaching.

6.6 REFERENCES

Anon., 1973. The determination of chloride in plants and feedingstuffs. *In*: Ministry of Agriculture, Fisheries and Food (ed.). The analysis of agricultural materials: A manual of the analytical methods used by the agricultural development and advisory service. Tech. Bull. No. 27. London: Ministry of Agriculture, Fisheries and Food.

Aubertin, G.M., Rickman, R.W. & Letey, J., 1968. Differentialsalt-oxygen levels influence plant growth. *Agron. J*., 60:345-349.

Ayers, R.S. & Westcot, D.W., 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: FAO.

Bernstein, L., 1980. Salt tolerance of fruit crops. *USDA Agric. Inf. Bull*. 292: 1-8.

Bernstein, L., Brown, J.W. & Hayward, H.E., 1956. The influence of rootstock on growth and salt accumulation in stone fruit trees and almonds. *Proc. Am. Soc. Hort. Sci*., 68: 86-95.

Bernstein, L. & Hayward, H.E., 1958. Physiology of salt tolerance. *Ann. Rev. Plant Physiol*., 9: 25-46.

Bingham, F.T., Fenn, L.B. & Oertli, J.J., 1968. A sandculture study of Chloride Toxicity to Mature Avocado Trees. *Soil. Sci. Soc. Am. Proc.,* 32: 249-252.

Boland, A.M., Mitchell, P.D. & Jerie, P.H., 1993. Effect of saline water combined with restricted irrigation on peach tree growth and water use. *Aust. J. Agric. Res.,* 44: 799-816.

Catlin, P.B., Hoffman, G.J., Mead, R.M. & Johnson, R.S., 1993. Long term response of mature plum trees to salinity. *Irrig. Sci.,* 13: 171-176.

Cramer, G.R. & Bowman, D., 1994. Cell elongation Control Under Stress Conditions. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 303-320.

De Clercq, W.P., Fey, M.V., Moolman, J.H., Wessels, W.P.J., Eigenhuis, B. & Hoffman, J.E., 2001. Experimental irrigation of vineyards with saline water. WRC Report No. 522, 695/1/01. Pretoria: Water Research Commission.

Drew, M.C., Guenther, J. & Läuchli, A., 1988. The combined effects of salinity and root anoxia on growth and net Na+ and K+ accumulation in Zea mays grown in solution culture. *Ann. Bot*., 61: 41-43.

Dudley, L.M., 1994. Salinity in the Soil Environmen. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 13-30.

Farquhar, G.D. & Sharkey, T.D., 1982. Stomatal conductance and Photosynthesis. *Ann. Rev. Plant Physiol*., 33: 317-345.

Flowers, T.J. & Yeo, A.R., 1986. Ion Relations of Plants under Drought and Salinity. *Aust. J. Plant Physiol*., 13: 75-91.

Francois, L.E. & Maas, E.V., 1994. Crop Response and Management on Salt-Affected Soils. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker: 149-181.

Fruit and Fruit Technology Research Institute, 1983. Anorganic fertilization of deciduous fruit. *Inf. Bull*. 512. Stellenbosch: Dept. of Agriculture.

Grattan, S.R. & Grieve, C.M., 1999. Salinity-mineral nutrient relations in horticultural crops. *Sci. Hort.*, 78: 127-157.

Greenway, H. & Munns, R., 1980. Mechanisms of salt tolerance in non-halophytes. *Ann. Rev. Plant Physiol*., 31: 149-190.

Hoffman, G.J., Catlin, P.B., Mead, R.M., Johnson, R.S., Francois, L.E. & Goldhamer, D., 1989. Yield and foliar injury responses of mature plum trees to salinity. *Irrig. Sci.,* 10: 215-229.

Hsiao, T. & Acevedo, E., 1974. Plant responses to water deficits, water use efficiency and drought resistance. *Agric. Meteorol.*, 14: 59-84.

Jacoby, B., 1994. Mechanisms involved in Salt Tolerance by Plants. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 97-123.

Jeffries, R.L., Rudmik, T. & Dillon, E.M., 1979. Responses of halophytes to high salinities and low water potentials. *Plant Physiol.,* 64: 989-994.

Jones, H.G., 1998. Stomatal control of photosynthesis and transpiration*. J.Exp. Bot.*, 49: 387-398.

Jones, H.G., Lakso, A.N. & Syvertsen, J.P., 1985. Physiological Control of Water Status in Temperate and Subtropical Fruit Trees. *Hort. Rev.*, 7: 301-343.

Jones, H.G. & Tardieu, F., 1998. Modelling water relations of horticultural crops: a review. *Sci. Hort.*, 74: 21-46.

Kramer, P.J., 1983. Water relations of plants. Florida: Academic Press.

Lloyd, J., Kriedemann, P. & Aspinall, D., 1990. Contrasts between *Citrus* species in response to salinisation: An analysis of photosynthesis and water relations for different rootstock-scion combinations. *Physiol. Plant*., 78: 236-246.

Loveys, B.R., Robinson, S.P. & Downton, W.J.S., 1987. Seasonal and diurnal changes in abscisic acid and water relations of apricot leaves (*Prunus armeniaca* L.). *New Phytol*., 107: 15-27.

Maas, E.V., 1987. Salt Tolerance of Plants. *In*: B.R. Christie (ed.). CRC Handbook of Plant Science in Agriculture – CRC Series in Agriculture Vol. II. Boca Raton, Fla: CRC Press, p. 57-75.

Maas, E.V. & Hoffman, G.J., 1977. Crop salt tolerance-current assessment. *J. Irrig. Drain Div. ASCE,* 103: 115-134.

Maas, E.V. & Grattan, S.R., 1999. Crop yields as affected by salinity. *Agronomy*, 38: 55-108.

Marcelis, L.F.M., Heuvelink, E. & Goudriaan, J., 1998. Modelling biomass production and yield of horticultural crops: a review. *Sci. Hort.*, 74: 83-111.

Markhart, A.H. (III), Sionit, N. & Siedow, J.N., 1981. Cell water dilution: An explanation of apparent negative turgor potentials. *Can. J. Bot*., 59: 1722-1725.

Marschner, H., 1995. Mineral Nutrition of Higher Plants, 2nd Ed. New York: Academic Press.

Martínez-Gómez, P., Dicenta, F., Ruiz, D. & Egea, J., 2002. Flower bud abscission in apricot: Competition between vegetative and flower buds, and effects of early defoliation and high pre-blossom temperatures. *J. Hort. Sci. Biotech.*, 77(4): 485-488.

Moolman, J.H., De Clercq, W.P., Wessels, W.P.J., Meiri, A. & Moolman, C.G., 1999. The use of saline water for irrigation of grapevines and the development of crop salt tolerance indices. WRC Report No. 303/1/98. Pretoria: Water Research Commission.

Munns, R., 1993. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell Environ.*, 16: 15-24.

Murphy, R. & Smith, J.A.C., 1994. A critical comparison of the pressure-probe and pressure-chamber techniques for estimating leaf-cell turgor pressure in *Kanlanchoë daigremontiana*. *Plant Cell Environ.* 17: 15-29.

Myers, B.A., West, D.W., Callinan, I. & Hunter, C.C., 1995. Long term effects of saline irrigation on yield and growth of mature Williams pear trees. *Irrig. Sci.,* 16: 35-46.

Orcutt, D.M. & Nilsen, E.T., 2000. Physiology of plants under stress. New York: John, Wiley & Sons, Inc.

Ottman, Y. & Byrne, D.H., 1988. Screening Rootstocks of Prunus for Relative Salt Tolerance. *HortSci.*, 23(2): 375-378.

Poljakoff-Mayber, A. & Lerner, H.R., 1994. Plants in saline environments. *In*: M. Pessarkli (ed.). Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 65-96.

Ruiz-Sánchez, M.C., Domingo, R. J., Torrecillas, A. & Pérez-Pastor, A., 2000. Water stress preconditioning to improve drought resistance in young apricot plants. *Plant Sci.*, 156: 245-251.

Ruiz-Sánchez, M.C., Egea, J., Galego, R. & Torrecillas, A., 1999. Floral biology of 'Búlida' apricot trees subjected to postharvest drought stress. *Ann. Appl. Biol*., 135: 523-528.

Ryugo, K., 1988. Fruit Culture: Its Science and Art. New York: John Wiley.

SAS, 1999. SAS Institute Inc., SAS/STAT® User's Guide, Version 8. Cary, NC: SAS Institute Inc.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemmingsen, E.A., 1965. Sap pressure in vascular plants. *Science*, 148: 339-46.

Schulze, E.D., 1986. Carbon dioxide and water vapor exchange in response to drought in the atmosphere and in the soil. *Ann. Rev. Plant Physiol.*, 37: 247-274.

Shalevet, J., 1994. Using water of marginal quality for crop production: major issues. *Agric. Water Man.*, 25: 233-269.

Steinberg, S.L., Miller, J.C. & McFarland, M.J., 1990. Dry matter partitioning and vegetative growth of young peach trees under water stress. *Aust. J. Plant Physiol.,* 17: 23-36.

Storey, R. & Walker R.R., 1999. Citrus and salinity. *Sci. Hort.,* 78: 39-81.

Subbarao, G.V. & Johansen, C., 1994. Strategies and Scope for Improving Salinity Tolerance in Crop Plants. *In*: M. Pessarkli (ed*.).* Handbook of Plant and Crop Stress. New York: Marcel Dekker, p. 559-579.

Torrecillas, A., Domingo, R., Galego, R. & Ruiz-Sánchez, M.C., 2000. Apricot tree response to withholding irrigation at different phenological periods. *Sci. Hort.*, 85: 201-215.

Torrecillas, A., Galego, R., Pérez-Pastor, A. & Ruiz-Sánchez, M.C., 1999. Gas exchange and water relations of young apricot plants under drought conditions. *J. Agric. Sci.,* 132: 445-452.

Turner, N.C., 1981. Techniques and experimental approaches for the measurement of plant water status. *Plant Soil*, 58: 339-366.

Unifruco, 1994. Unifruco Producer's Guide: Apricot. Bellville: UNIFRUCO.

Unifruco Research Services, 1996. Colour charts for maturity indexing. Oakdale: Unifruco Research Services.

Urui, K., 1964. Effect of post-harvest soil moisture depletion on subsequent yield of apricots. *J. Hort. Sci*., 84: 93-97.

Van der Merwe, J.A., 1996. Maturity standards for deciduous fruit. *In*: J.C. Combrink (ed.). Integrated management of post-harvest quality*.* Paarl: Paarl Printing, p. 25-32.

Van Genuchten, M. Th., 1983. Analyzing crop salt tolerance data: Model description and user's manual. Research report No.120., U.S. Salinity Laboratory. California: USDA/ARS.

Von Mollendorff, L.J., 1987. Woolliness in peaches and nectarines: A review. 2. Biochemical and antomical changes. *Hort. Sci.,* 5: 5-6.

Von Mollendorff, L.J., Jacobs, G. & De Villiers, O.T., 1992. The effect of storage temperature and fruit size on firmness, extractable juice, woolliness and browning in two nectarine cultivars. *J. Hort. Sci.,* 67: 647-654.

Ziska, L.H., DeJong, T.M., Hoffman, G.F. & Mead, R.M., 1991. Sodium and chloride distribution in salt-stressed *Prunus salicina*, a deciduous tree species. *Tree Physiol.*, 8: 47-57.

Ziska, L.H., Hutmacher, R.B., Hoffman, G.J. & DeJong, T.M., 1989. Changes in leaf water status associated with salinity in mature, field grown *Prunus salicina*. *Physiol. Plant.*, 77: 141-149.

Ziska, L.H., Seeman, J.R. & DeJong, T.M., 1990. Salinity-induced limitations on photosynthesis in Prunus salicina, a deciduous tree species. *Plant Physiol.,* 93(3): 864-870.

GENERAL CONCLUSIONS AND RESEARCH RECOMMENDATIONS

In an extremely competitive and high technologically driven deciduous fruit industry lower net returns, amongst other factors, necessitate producers to minimise risk. Taken the high cost of establishment of perennial fruit trees, with a lifespan of between *c*. 14 to 20 years, being a long-term investment, it makes sense to minimise salinity related risk that can reduce production and/or longevity of orchards. In general, growth inhibition and yield reduction on saline soils can be ascribed to osmotically induced water deficit, oxidative stress or specific ion toxicity effects on important plant physiological processes. It is thus of extreme importance to assess water quality and selected soil properties when purchase of land for the purpose of deciduous fruit production or establishment of new orchards are considered and to manage irrigation of orchards with saline water such that production is not reduced and result in optimum economical benefit.

Whenever saline irrigation water is used for production of crops, leaching is eventually inevitable to maintain productivity. The importance of leaching for successful crop production with saline water has been stressed by several authors and the infiltration rate and hydraulic conductivity of the soil need be adequate to allow movement of water through the soil for effective removal of excess salts that could otherwise decrease yield. With the information on water quality and soil characteristics in hand, the potential effect of the irrigation water quality on the infiltration rate and hydraulic conductivity of the soil can be made with the aid of simple calculations or with more complicated mathematical models. This is done by predicting the soil salinity and sodicity for the soil profile after irrigation has been applied and its potential effects on the swelling and/or dispersion of the clay fraction of the soil. The potential effect of SAR on the soil properties is considered together with the EC of the irrigation water. The literature review as well as observations in the current study have shown that the detrimental effects of salinity on soil properties are not restricted to low salinity and high SAR, but that clay dispersion may occur where irrigation water with a SAR of below or about 1 and EC of less than 0.1 dS m^{-1} is applied to soil. In such cases mechanical energy may be determining the clay dispersion process.

Higher salinity levels in the soil counteract the detrimental effects of the exchangeable sodium on the clay fraction of the soil. The salinity levels of the soil water of all saline irrigation treatments with irrigation water salinity of between 0.7 and 4 dS m^{-1} in our study were adequate to counter dispersion of the soil in presence of the generally low SAR values (SAR < 8) in the soil and excessive clay swelling was not considered a problem. Low infiltration rate or hydraulic conductivity was thus not considered to be factors affecting plant response in the saline irrigation treatments. It should be kept in mind that several inherent soil properties such as

texture, clay mineralogy, organic material content, pH and sesquioxides could either enhance or decrease the mutual effect of sodicity and salinity on soil permeability. Furthermore, rainfall and soil, water and crop management factors such as cultivation, irrigation method and wetting rate, previous soil water content and time since cultivation are other factors that can alleviate or aggravate the effects of sodicity and salinity on soils. None of these, however, were investigated in the current study.

Whether a specific water quality can be used for the production of deciduous fruit, will apart from its effects on permeability of the soil and leaching, depend on the salt tolerance of the available cultivar/rootstock combinations that are suitable for cultivation in the specific area. In order to prevent salinity related growth reduction and subsequent effects on transpiration and evapotranspiration, the soil water salinity in the upper soil layers should be managed such that it remains below the appropriate salinity threshold value for the specific crop and specific ion toxicity symptoms should remain absent. Under such conditions, evapotranspiration calculations for irrigation scheduling purposes for non-saline conditions can still be applied when saline irrigation water is used. Whenever salinity exceeds the salt tolerance threshold, osmotic effects will probably significantly influence canopy size and density and the resultant erroneous estimation of water consumption will cause increased leaching.

Continuous excessive leaching with low quality water poses a threat to the environment. The South African government, but also international organisations (e.g. International Food Policy Research Institute, International Water Management Institute) are becoming more aware of environmental concerns regarding large volumes of low quality irrigation return flows. Producers presently need to conform to certain requirements of international programs, such as Eurepgap, regarding the quality of leached water in order to receive a premium for “environmentally friendly” production of fruit in the export market. It will most likely not be profitable or “environmentally friendly” to produce a crop with saline irrigation water if the leaching fraction needed to keep the soil salinity below the crop salinity threshold for yield reduction is higher than 0.2. In order to decide what crops can realistically be produced the quality of water available and information regarding the salt tolerance of the crop is needed. The soil salinity levels at which yield decrease can commence has been published for several perennial fruit crops with certain caveats. The absolute tolerances may vary depending on climate, soil conditions and cultural practices. Also, the salinity threshold values are applicable where rootstocks that do not accumulate sodium and chloride rapidly are used and where these ions do not predominate in the soil. If sodium and chloride, however, are present in excessive amounts in the soil, specific ion tolerance of the cultivar/rootstock combination becomes important.

Given the ongoing deterioration of water quality in the Little Karoo region where a large percentage of South African apricots are currently produced, it was deemed necessary to evaluate the salt tolerance of the cultivar Palsteyn which at present comprises approximately 55% of fresh apricot export volumes. The salt accumulation in Palsteyn apricot on Marianna rootstock confirmed the internationally permissible sodium levels of 3 mmol dm^{-3} and the maximum chloride (12 mmol dm^{-3}) permissible in irrigation water to prevent leaf injury for Marianna rootstock with a leaching fraction of 0.1 under the conditions of our study. Concentrations of sodium and chloride ions exceeding these levels in irrigation water or application of less leaching could lead to accumulation of these ions in perennial tree organs over the long term and result in the eventual death of trees. In Palsteyn apricot on Marianna rootstock, accumulation of excessive amounts of specific ions in perennial tissues of trees could result in advanced and accelerated reduction of photosynthesis rates, appearance of foliar damage and depletion or inadequate supplementation of the carbohydrate reserves of the trees necessary for early season growth and long-term survival of trees in successive seasons. The rate of demise would be determined by the level of salinity, period of exposure and rootstock/ scion salt tolerance.

The soil salinity threshold value for yield decrease of Palsteyn apricot determined in this study was after adjustment for soil water depletion effects in the root zone very similar to the internationally-determined salinity threshold for vegetative growth decrease of apricot. The rate at which yield decreased in the current study was, however, much higher than that previously reported for vegetative growth of apricot. A drastic decrease in yield beyond the threshold was ascribed to a weekly irrigation interval that could have caused the development of significant matric potential during summer and specific ion toxicity effects due to high chloride concentrations. Low soil water depletion levels further increased the sensitivity of Palsteyn apricot trees to high soil salinity levels and altered the salt tolerance response. Based on this study, growers were advised not to use irrigation water with a salinity which exceeded an electrical conductivity of 0.82 dS m^{-1} for irrigation of Palsteyn apricot on Marianna rootstock where a leaching fraction of 0.1 was applied. The irrigation water salinity that could be used without yield loss at leaching fractions of 0.15 to 0.20 was estimated as 1.08 dS m^{-1} and 1.33 dS m^{-1}, respectively. Effective rainfall during the growing season and winter in the Little Karoo could further increase the leaching fraction, which may allow the use of irrigation water with higher salinity or application of less water to effect the same leaching.

Research recommendations

Several computerized mathematical models are available to evaluate the potential effects of saline irrigation and leaching on soil and crops. As water resources are limited and water

quality is deteriorating, it may be of value to the deciduous fruit industry if such a model, with preferably limited input data requirements, is evaluated. The main purpose, if such a model is validated, would be to use the model to generate site-specific management guidelines where saline irrigation water is applied and/or for reclamation of salt-affected soils. It follows that the selected model should take the effect of rainfall during the season and winter on the leaching of salts into account in estimation of the maximum allowed irrigation water salinity.

The salinity response function for Palsteyn apricot on Marianna rootstock is based on the yield data of only one year after approximately three years of saline irrigation and additional evaluation of the response to salinity over a longer period of saline irrigation and with more yield years is warranted. However, both the scion and the rootstock modulate the salt tolerance of fruit trees and Marianna rootstock is, due to its shallow root system, not always considered the best rootstock to use. Furthermore, Marianna rootstock was found to be incompatible with several apricot cultivars, including Bulida. Bulida, which is mainly produced for the canning and dried fruit industry, covers *c.* 50% of hectares planted to apricots, of which 97% are located in the Little Karoo. A Royal interstem can be used to promote compatibility between specific cultivars and Marianna rootstock, but it takes longer to create such a tree in the nursery and is therefore more expensive. Apart from Marianna, G677 rootstock that is ideally suited for calcareous soils is recommended for certain cultivars on saline soils, but with limited success. There is thus a definite need in South Africa for the evaluation of the salt tolerance of other apricot, peach and nectarine cultivars that is compatible to Marianna rootstock and all stone fruit on other salt tolerant clonal rootstocks for the Little Karoo area, which is characterised by increasing salinisation and calcareous soils.