

LEAF AREA CHANGES AND TRANSPIRATION IN VINEYARDS UNDER SALT STRESS.

by

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DECLARATION

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

Signature

24/11/99

Date

SUMMARY

Irrigation of vines with saline water has long been a problem in the Western Cape region. Research in this respect financed by the Water Research Commission was done on vines to test the effect of 6 levels of irrigation water quality on production. The experiment consisted of two sites namely one at the Robertson experimental farm of the ARC outside of Robertson and the other on the Nietvoorbij experimental farm outside Stellenbosch. Each site had 6 treatments replicated 4 times. The treatments consisted of water with electrical conductivities of ~40, 75, 150, 250, 350, 500 mS/m. The saline water was produced and controlled by a computerised injection system that injected a high concentration stock solution into the irrigation system. The stock solution consisted of NaCl and CaCl₂ mixed to a Na:Ca ratio.

Description of the canopy surface and structure per plant is essential to the formulation and description of plant reaction resulting from plant-environmental interaction. This study looked at measurement techniques to non-destructively describe and quantify the reaction of canopies to different saline treatments. Measurement techniques consisted of physical destructive and non-destructive light interception techniques with special reference to the use of the *Sunfleck Ceptometer* and *Licor C2000 Plant Canopy Analyser*. Destructive measurements were only done to calibrate the non-destructive techniques. The *Dynamax Heat Balance Sap Flow Meter* was used to measure differences in sap flow rate between plants from different treatments. The measured transpiration was compared with weather station derived evapotranspiration as well as the sodium absorption ratio of the different soils.

It was found that leaf area indices do show treatment effects very clearly. It was also found that by the time treatment effects were visible, leaf damage was already irreversible. The method clearly highlights treatment effects but cannot be used in a production environment to help prevent leaf damage as a management tool. Sap flow measurement was done to show that sap flow is more sensitive and that differences do occur before leaf damage is visible. Sap flow measurements can therefore be used with greater success as a management and a research tool. A good calibration exercise to determine leaf area indices non-destructively led to the ability of producing reliable transpiration and evapotranspiration data.

OPSOMMING

Besproeiing van wingerd met brakwater is reeds 'n wesenlike probleem in die Wes-Kaap Provinsie. Navorsing was deur die Waternavorsingskommissie geloods waar wingerd met ses grade van brakwater besproei was om brakwater se invloed op plantprestasie te meet. Die proef was tweeledig van aard met 'n perseel buite Robertson op die NIWW-proefplaas en 'n tweede op die Nietvoorbij proefplaas buite Stellenbosch. Daar was 6 brakwater behandelings nl., ~40, 75, 150, 250, 350, 500 mSm^{-1} met 4 herhalings van elk. Die waterkwaliteit was beheer vanaf 'n inspuitstelsel gekoppel aan 'n hoë konsentrasie voorraad oplossing. Die voorraad oplossing het bestaan uit NaCl en CaCl_2 gemeng in 'n Na:Ca verhouding.

Beskrywing van die blaredak en blaredakstruktuur van 'n gewas is essensieel t.o.v. formulering en beskrywing van plantreaksie a.g.v. plant-omgewing interaksies. Daar was met hierdie studie gekyk na metingstegnieke om die blaredak deur nie-destruktiwe metodes te beskryf en dus plantreaksie op verskillende brakwaterbehandelings te kwantifiseer. Metingstegnieke het bestaan uit fisiese destruktiwe metings en ligonderskeppings tegnieke waaronder die *Sunfleck Ceptometer* en *Licor C2000 Plant Canopy Analyzer* tel. Destruktiwe metings was slegs gedoen ter kalibrering van die nie-destruktiwe metodes. Die *Dynamax Heat Balance Sapflow Meter* was gebruik vir sapvloeimetings, om die verskille in transpirasie tussen behandelings waar te neem. Die gemete transpirasie was vergelyk met weerstasie afgeleide evapotranspirasie en ook met die natrium absorpsie verhouding van die verskillende gronde.

Daar was gevind dat blaar oppervlakindekse wel duidelik behandelingsverskille uitwys. Daar is ook gevind dat teen die tyd dat verskille sigbaar is, daar reeds onomkeerbare skade aan die blare is. Blaar oppervlakindekse het dus wel gehelp om die behandelingsverskille uit te wys maar dit kan nie gebruik word in 'n produksie omgewing om blaarskade te help voorkom deur dit as 'n bestuurshulpmiddel aan te wend nie. Daarvoor was sapvloeimetings gedoen om aan te toon dat verskille in sapvloeimetings reeds bestaan voor blaarskade sigbaar is. Sapvloeimetings sou dus met groter sukses aangewend kan word as 'n bestuurshulpmiddel en ook as navorsingshulpmiddel. 'n Goeie kalibreringsoefening om blaaroppervlak indekse akkuraat te bepaal m.b.v. nie-destruktiwe metodes, het gehelp om transpirasie en evapotranspirasie baie akkuraat te benader.

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CHAPTER 1

INTRODUCTION

In Soil Science, manipulation of the soil is inevitably tested in the reaction of plants cultivated on that soil. To find out if irrigation with saline water will in any way have an effect on plant or food production, plant reaction to saline irrigation has to be tested.

Since 1991, the Department of Soil and Agricultural Water Science have been testing the salt tolerance of grapevines in the Breede River valley and Stellenbosch. Grapevine is the principle crop under irrigation in the Breede River Valley in the south-western part of South Africa. However, there is concern that increasing irrigation water salinity may affect the sustained production of grapes in this area. In Stellenbosch where only supplementary irrigation is applied, poorer water quality may also in future hamper sustained grape production. Literature reveals little about the sensitivity of the grapevine to salinity and most of what is known seems to have been inferred from studies that were not primarily designed to investigate the salt tolerance of the plants (Moolman *et al.*, 1999). Prior *et al.* (1992 a,b,c) reported a threshold value of 100 mSm^{-1} .

Measurement of salt tolerance can be done by monitoring plant performance regarding growth potential and ability to bear fruit. One alternative option to evaluate the effect of saline water on plants is to study vegetative growth of the plant, of which leaf surface is but one aspect.

Light interception by leaves is of primary importance in transpiration and photosynthesis. Saline water tends to restrict growth and leaf surface and therefore light interception by the plant. Light interception can be quantified by various techniques. Although many articles have been written on methods to quantify leaf surface, none was found that dealt directly with drought and salt stress conditions in the plant.

1.1 The Aims of this study

The main aim of this study was to determine methods for accurately and rapidly determining leaf area index (LAI) and evapotranspiration in vineyards subjected to saline irrigation water.

The leaf surface plays a major role in a plant's water budget and indeed, in the water balance of the surrounding area.

LAI was determined with remote techniques and correlated with destructive techniques. Where the remote techniques were inadequate, destructively measured leaf area was correlated with leaf length. This provided a method to determine LAI non-destructively. For transpiration measurements, the total leaf area measurement per plant cannot be destructive or be done in such a way that the leaf orientation is disturbed. This alters sap flow readings and makes repetitive sap flow measurements on one plant impossible.

This study also attempted to bring saline soil water conditions into relation with leaf area index, transpiration and evaporation. The application of leaf area assessment techniques in plant stress situations are highlighted. The effect of soil water content and sodium absorption ratios (SAR) of the soil on transpiration and evapotranspiration are discussed.

Evapotranspiration determined from sap flow and LAI measurements was compared with weather station derived evapotranspiration.

1.2 Hypothesis

The visible leaf area changes in a vineyard, subjected to saline irrigation do not reflect true stress from the onset thereof but rather at the end when damage is almost irreversible. Transpiration measurements will be more sensitive to drought and salt stress.

1.3 Literature cited

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CHAPTER 2

LITERATURE REVIEW

2.1 Importance of remotely sensed parameters in Soil Science

Supplies of good quality irrigation water are expected to decrease in future because the development of new water supplies will not keep pace with the increasing water needs of industries and municipalities (Oster, 1994). The drainage water from agricultural lands invariably is more saline than the irrigation water supplied to agriculture.

Irrigated agriculture is therefore faced with two daunting challenges, namely that of using less water, in many cases of poorer quality than present, and how to maintain production of food and fibre for an expanding population. Sustainable use of saline water for irrigation depends on the impact of salinity on the soil, the crop and the environment. Several reviews on the impact of salinity on soils and crops were published in this decade, amongst which are Francois & Maas (1993), Oster (1994), Shalhevet (1994) and Walker (1994).

This study will focus primarily on canopies of vines as an indicator of salt stress. In future it might be inavertable to use techniques developed to predict or diagnose salt stress as a means of maintaining production.

Description of canopy structures are thus essential to achieve an understanding of plant processes because of the profound influence that canopy structure has on plant–environment interactions. Studies of the geometric features of canopies are difficult because canopies are spaciouly and temporally variable. The vegetative architecture, not only affects exchanges of mass and energy between the plant and it's environment, but it may also reveal a strategy of the plant for dealing with long-lasting evolutionary processes, such as adaptation to physical, chemical or biotic factors, by reflecting the organism's vital activity or peculiarities in growth and development (Pearcy *et al.*, 1991).

Amongst other factors, wind, radiation and water quality effect canopy structure. Wind and radiation as well as water quality is linked to specific territories. The effect of wind is usually not quantified because of complexities associated with measurements and modelling (Pearcy *et al.*, 1991). The relation between radiation environment and canopy is better quantified as a result of the strong interaction between them. This relationship forms the basis for indirect measurement techniques. Canopy structure in it's turn affects other environmental factors such as air and leaf temperature,

atmospheric moisture, soil evaporation, soil heat storage and soil temperature, precipitation interception and leaf wetness duration (Norman and Campbell 1983). It also affects other organisms that live within or below the canopy (Toole et.al. 1984). Pearcy (1991) defines canopy structure as the amount and organisation of above ground plant material. He also included the size, shape, orientation and positional distributions of various plant organs such as leaves, stems, branches, flowers and fruits.

2.2 Response of fruit trees and vines to salinity

2.2.1 Introduction

Although much is known of the impact of salinity on irrigated crops, most of the studies aimed at understanding and quantifying salinity effects have been done on annual crops that attempted to find answers to questions like which crops to grow under saline conditions and how to use saline water for irrigation. The solution is threefold. It involves criteria for selecting the appropriate crops, guidelines for controlling soil salinity and hydraulic properties. It is important to know the water use pattern of plants throughout the season, the capacity of the soil to retain water for use by these plants, the availability of water and quality of the water throughout the season. It also requires improved knowledge of plant response to salinity. Irrigation management technology will in future include critical measurement systems that will enable the farmer to react to stress symptoms from the soil or plant.

The number of salt tolerance studies conducted on mature yielding fruit trees and vines was very little (Bernstein *et al.*, 1956, Maas & Hoffman 1977, Maas 1990, Hoffman *et al.*, 1989, Prior *et al.*, 1992a Boland *et al.*, 1993 and Moolman *et al.*, 1999). In these studies the high sensitivity of most fruit trees and grapevines was evident and they were classified among the most sensitive crops. The recent increase in number of publications on the response of mature trees to saline conditions, indicates the world wide trend of increased exposure of fruit trees and vines to salinity (Hoffman *et al.*, 1989; Catlin *et al.*, 1992; Boland *et al.*, 1993; Prior *et al.*, 1992a, 1992b, 1992c; Walker 1994). Salt tolerance classification of agricultural crops in almost all cases used growth or yield response to the depth-mean root zone salinity under one dimensional water flow (Maas & Hoffman, 1977; Ayers & Westcot, 1985; Maas, 1990; Francois & Maas, 1994).

Salinity can suppress growth and yield with no specific visual salt damage. This damage correlates with the soil solution osmotic potential, which for convenience of determination is usually replaced by the electrical conductivity of the saturated soil

paste extract (EC_e). Visual damage symptoms, such as leaf burn followed by death of twigs and shoots, are the result of the accumulation of specific ions, mainly chloride (Cl^-) and sodium (Na^+), to toxic levels in plant organs. Most fruit trees are sensitive to both osmotic and specific ion effects with increased importance of the toxic effect as exposure of the tree to salinity increases (Bernstein *et al.*, 1956, Hoffman *et al.*, 1989, Walker 1994, Catlin *et al.*, 1992, Prior *et al.*, 1992a, 1992b, 1992c, Moolman *et al.*, 1999).

2.2.2 Specific ion effects linked to plant stress

The initial symptoms of excess Cl^- accumulation in fruit crops is 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 the vine (Bernstein, 1980). Chloride is absorbed by the roots, transported and deposited in the leaves of fruit and vine crops more rapidly than Na. Therefore chloride toxicity generally shows up earlier, is more severe and is observed on a wider range of species than Na^+ toxicity (Bernstein, 1980; Hoffman *et al.*, 1989; Maas, 1990; Francois & Maas 1994, Walker 1994, Moolman *et al.*, 1999). Chloride content in grape leaves increased more with time of exposure of the plant to salinity than with leaf age. In grapes (Bernstein *et al.*, 1969) and other fruit and nut crops (Bernstein & Hayward, 1958), chloride was higher and increased more than sodium with increased water salinity. There was no correlation between severity of burn and leaf chloride level, the severity apparently being determined more by duration of harmful levels than by actual level at the time of sampling. In some cases non-damaged young leaves had higher chloride content than old damaged ones (Moolman *et al.*, 1999).

Maas (1990) stated that injury by Na^+ could occur at concentrations as low as 5 mmol L^{-1} in the soil solution. Symptoms caused by specific ions may however not appear for a considerable time after exposure to salinity. Time is needed to load the perennial organs with ions like Na^+ or to cause change in the capacity to retard the transport of ions to the leaves. Some of the more sensitive fruit crops may accumulate toxic levels of Na^+ and/or Cl^- over a period of years from soils that would otherwise be classified as non saline and non sodic (Ayers *et al.*, 1951; Bernstein 1980). Initially it was thought that Na^+ was retained in the sapwood of the tree and with the conversion of the sapwood to heartwood is released and then translocated to the leaves causing leaf burn (Bernstein *et al.*, (1956); Francois & Maas, (1993)). With succeeding years, the Cl^- and Na^+ accumulated more rapidly in the leaves, causing leaf burn to develop earlier and with increasing severity (Hoffman *et al.*, 1989). The results of the latter study also showed that Na^+ accumulation in plum leaves did not significantly increase

until the leaves were already severely damaged by chloride accumulation. This suggests that high Cl⁻ levels probably damages leaf cell membranes (Moolman *et al.*, 1999).

In view of published data it can be inferred that osmotic effects influence the salt tolerance of fruit and vine crops, but in many cases the specific ion effects seem to be more damaging than the osmotic effect. Therefore in cases where NaCl is the principal salt in the irrigation water, it will be rather difficult to distinguish between osmotic and specific ion effects (Moolman *et al.*, 1999).

Growth reductions in grapevines are observed at relatively low salinities, often before the appearance of visible symptoms (Downton, 1977, Walker *et al.*, 1981). Grapes grafted on rootstocks with low chloride uptake will primarily respond to the osmotic effect (Bernstein *et al.*, 1980) and, will consequently then (incorrectly) be classified as moderately salt tolerant (Ehlig 1960). Growth inhibition and yield reduction may be the result of both total salinity and specific effects of toxic ions on key processes. In the case of toxic ion effects, visible symptoms of leaf and shoot damage may initially be absent. Stone fruit, citrus, avocado and grapes have shown growth reduction at salt concentrations that do not cause visible leaf damage (Francois & Maas 1994). In the absence of visible toxic symptoms it was assumed that the response is to the soil solution osmotic potential and can be expressed as a function of the total salt concentration. However, once salts have accumulated to toxic levels, the additive effects of osmotic stress and specific ion toxicities suppress growth and yield (Moolman *et al.*, 1999).

According to Walker (1994) a comparison by Kishore *et al.*, (1985) of the effects on grapevine growth of a range of different salts (*viz.* chloride, sulphate and carbonate salts of magnesium, calcium, potassium and sodium) demonstrated that chloride salts caused more leaf damage than sulphate or carbonate salts at the same concentrations. Sodium and potassium caused greater growth reductions than calcium and magnesium.

2.2.3 Possible salt tolerance control mechanisms

2.2.3.1 Irrigation Method

Shalhevet (1994) came to the conclusion that there is a clear relationship between yield reduction due to salinity increase and water consumption. He also reported that the bulk of evidence leads to the conclusion that a single unified function may be applied to both water and salinity stress. This implies that salinity and water stress are additive in their effect on transpiration and yield. However, Shalhevet (1994) showed that the quantitative effects of these two stresses are not identical. Meiri's (1984) analysis of

international literature showed that water stress has a greater weight than salt stress in suppressing growth. From this one can infer that in times of water shortage, it would be better to irrigate with saline water, rather than to let the crop suffer from water stress.

Shalhevet (1994) was of the opinion that actual transpiration and yield are reduced by salinity in accordance with the production function, which relates relative yield to relative evapotranspiration, and the evapotranspiration - salinity response function. However, it is still unresolved whether reduction in water uptake with increasing salinity is the cause or the result of a reduction in growth. Shalhevet (1994) furthermore argued that salinity reduces evapotranspiration (ET), resulting in a slower soil drying than under non-saline conditions. Thus, for the same irrigation interval, the total pre-irrigation soil water potential may be lower under non-saline than under saline conditions, resulting in a greater damage to the crop. Also, as irrigation becomes more frequent, the evaporation component of ET increases, leading to additional water application and an increase in salt load. Shalhevet (1994) concluded that the bulk of evidence in the literature shows no advantage of increasing irrigation frequency when irrigating with saline water. There is evidence that increased irrigation frequency with saline water might even increase salinity damage. However, under excessive leaching this may be reversed.

With transpiration in mind, irrigation method might alter salt tolerance in three principal ways: wetting of foliage, changing salt and water distribution in the soil and applying water at a higher frequency (Shalhevet, 1994). Normally, leaf injury can be reduced by irrigating during the night when saline water does not evaporate from the leaves leaving a deposit on the leaf surface, or by applying non-saline water at the end of each irrigation cycle in order to wash off accumulated salts (Shalhevet, 1994).

The advantage of drip irrigation when using saline water is twofold. Firstly, leaf contact is avoided and for sensitive crops this may mean the difference between success or failure (Shalhevet, 1994). The second advantage of drip irrigation lies in the pattern of salt distribution under the drippers and the maintenance of constantly high matric potentials. The typical pattern is one of low salt accumulation under the drippers due to high leaching and marked accumulation of salt at the wetting front and between the laterals (Yaron *et al.*, 1973, Moolman & De Clercq, 1989). The distribution of water content has a reversed pattern, with a decrease away from the point source. This results in a root pattern in which most of the roots are typically found in the highly leached zone beneath drippers (Moolman & De Clercq, 1989). Shalhevet (1994) concluded that drip irrigation is the best possible way of applying

saline water to crops, avoiding leaf injury and at the same time providing optimum soil water conditions. However, the limited volume of wetted soil might pose problems for fruit and vine crops with larger root systems.

2.2.3.2 *Soil properties*

For the same evapotranspiration rate a sandy soil will lose proportionally more water than a clay soil, resulting in a more rapid increase in the soil solution concentration (Shalhevet, 1994). However, if sound irrigation practices are followed, the sandy soil will be irrigated more frequently, thereby reducing the damage caused by increased concentration. The water-holding capacity of a sandy soil is lower than that of a medium textured soil, which in turn is lower than fine textured soils. The studies of Prior *et al.*, (1992c) demonstrate the need to consider soil properties, specifically texture, when predicting the effects of saline water on grapevine productivity. In their study, irrigation with saline-sodic water caused more damage to sultana grapes in heavier than in lighter soils. Root zone depth and root density was lower in the heavier soils. The textural effect on yield was the result of reduced leaching and increased salinity in the more clayey soils with no effect in the yield response to soil salinity (Prior *et al.*, 1992c)

Soil properties that may alter the salt tolerance of plants and therefore total leaf surface, are fertility, texture and structure (Shalhevet, 1994). In a generalised statement Shalhevet (1994) wrote that at high fertility levels, there will be a larger yield reduction per unit increase in salinity than under low fertility, meaning that plants are more sensitive to salinity when conditions are conducive to high absolute yields. At extremely low fertility levels, when yields are low, increase in salinity may have very little additional damaging effect on yield. The effects of soil texture and structure are revealed through influence on the infiltration capacity, water-holding capacity and ratio of saturation water content to field capacity. The combination of high salinity and low soil oxygen for grapevines results in greater uptake and transport of chloride and sodium ions to shoots compared with high salinity and well drained, aerated conditions (West & Taylor, 1984). If applied long enough, these combined factors can have a severe effect on the vine crops.

2.2.3.3 *Climate*

Prior *et al.* (1992b) in Australia found that symptoms of leaf damage that appeared in December or January were related more to climatic stress than to particular chloride or sodium levels. Shalhevet (1994) reported that three elements of climate, namely temperature, humidity and rainfall, may influence salt tolerance and salinity response,

with temperature being the most critical one. High temperatures increase the stress level to which a crop is exposed, either because of increased transpiration rate or because of the effect of temperature on the biochemical transformations in the leaf. High atmospheric humidity tends to decrease the crop stress level to some extent, thus reducing salinity damage as demonstrated for beans (Hoffman *et al.*, 1978). Shalhevet (1994) concluded that under harsh environmental conditions of high temperatures and low humidity, the salt tolerance of plants may change so that the threshold salinity decreases and the slope increases, making the crop more sensitive to salinity.

2.2.3.4 Time

The study of Moolman *et al.* (1999) was conducted over 5 years after which a total reduction in yield was experienced over all treatments. After five years of saline irrigation water Catlin *et al.* (1992) found that a three-year time integration of soil salinity, better describes the effects of salinity on plum trees. The explanation was that two or three years of averaging accounted for the influence of salinity on bud formation and shoot growth in the years prior to the yield year. Five years of saline irrigation and three years of time integrated mean soil salinity did not change the salt tolerance values inferred after three years of study that much. Hoffman *et al.*, (1989) in their study with plum trees showed that three years of saline irrigation, and a two year time integration, excluding the dormant period, is the minimum time scale to correctly quantify the impact of salinity on plum yield. The interpretation may be that no change occurred in the response of plums to total salinity or, to the combined effects of total salinity and specific ion effects and possibly with no visible leaf damage.

Worsening of the salinity effect with time can result from important metabolic processes that are impaired between seasons. One such process is a decrease in carbohydrate reserves in the perennial organs at the end of the growing season, as shown for grapes by Prior *et al.* (1992b). The most severe salinity effect on grapes and plums was leaf damage that almost killed the vines and trees after two, three and four years of irrigation with water of EC_i of 250 - 800 mSm^{-1} (Hoffman *et al.*, 1989, Prior *et al.*, 1992 and Moolman *et al.*, 1999). In all three studies the visual damage was considered a specific ion effect, which showed up when the Cl^- reached toxic levels in the leaves. Limited leaf damage showed up towards the end of the first season in all treatments with EC_i higher than 300 mSm^{-1} . The leaf damage worsened in proportion to the water salinity and was visible earlier in following seasons. Increased disorders in flowers with the increase in salinity and number of seasons of saline irrigation were also considered toxic effects. Since the soil was leached every winter the increased salinity damage over time suggested a salt carry over in the perennial organs of the

tree. It was previously documented that build up of toxic levels of chloride and sodium in plant organs on soils with relatively low salinity and sodicity can take several years (Bernstein *et al.*, 1958, Francois & Maas, 1994). The possibility that winter irrigation lowers the nutrient status of soils was mentioned by Moolman *et al.*, (1999). This results in lower nutrient levels at budbreak.

Initially, sodium was thought to be retained in the sapwood of the tree. With the conversion of sapwood to heartwood, sodium is released and then translocated to the leaves, causing leaf burn. This may partly explain why stone fruits and grapes appear to be more sensitive to salinity as the plants grow older (Francois & Maas, 1994).

2.3 Methods of determining Leaf Area Index

2.3.1 Introduction

The description of position of all plant organs is not possible at the moment. Therefore quantitative descriptions are statistical in character and usually a representative plant is described. The simplest mathematical descriptions assume organs to be randomly distributed. The amount of leaf material is usually described in terms of the leaf area index (LAI). Leaves and branches have however the greatest impact on canopy environment. Therefore methods described later will only elaborate on the derivation of LAI and the application of LAI with evapotranspiration measurements.

Methods can be divided into destructive and non-destructive techniques. Both non-destructive and destructive can be divided into direct and indirect measurements. Destructive measurements usually entail the removal of plant material. Any measurement that causes disturbance of the canopy is therefore classified as destructive. Destructive direct measurements are labour intensive and therefore indirect non-destructive measurements have huge advantages. The advantages are firstly the speed with which measurements can be made and secondly the fact that measurements can be repeated over time. Destructive measurements though are needed for calibration of almost all indirect measurements.

This study concentrates on grapevines and therefore only measurements that have a direct bearing on the outcome of the LAI of grapevines were taken into account. The canopies of grapevines are largely dependent on the trellising system in use, which can vary from a large vertical row structure to a large horizontal structure.

2.3.2 Destructive methods to determine LAI

Leaves are usually sampled destructively and measured with a leaf area meter. The total leaf area is thus determined and LAI is calculated according to Equation 2.01.

$$\text{LAI} = \text{total leaf area} / \text{total soil surface per plant} \quad (2.01)$$

A second approach entails the correlation of leaf length data with leaf surface data.

2.3.3 Non-destructive methods to determine LAI

Non-destructive methods vary widely. This section includes methods that evaluate the shade of the plant and methods that evaluate the transparency of the canopy.

Wilson (1965) reported the method of inserting a probe with a sharp point into the canopy at a known inclination and azimuth angle and counting the number of times the point contacts leaves and stems. Later a motor driven system was devised with a sensitive point and the number of contacts was electronically counted.

Lang 1973 devised a method of using an ultra high precession potentiometer that recorded the angles of three arms to permit the measurement of three Cartesian coordinates that defined the position of any chosen point of a foliage element. By selecting an appropriate array of points on any given leaf, the position, inclination, azimuth and area of any triangle which is enclosed by three of these points, could be measured directly.

Choudhury (1987) has also used spectral methods. He made use of a combination of near infrared (NIR) and photosynthesis active radiation (PAR) measurements. As foliage cover develops over the soil the ratio of near infrared to visible radiation increased. A useful form of this ratio is termed the normalised difference vegetation index (NDVI) and is given by

$$\text{NDVI} = (\text{NIR rad} - \text{PAR rad}) / (\text{NIR rad} + \text{PAR rad}) \quad (2.02)$$

This spectral method has been used extensively in recent years because of applications to remote sensing of satellites.

2.3.3.1 Gap-Fraction Methods

The gap-fraction methods are possibly the most popular methods in use presently and instruments that can measure gap-fraction are relatively cheap and accurate. These

methods originated from making firstly, a cross section through the shade of a plant with a meter stick and counting the sunfleck to shadefleck ratio at an azimuth of 57° . This method was later improved into a system using quantum light-bar sensors. This instrument measures direct and diffuse radiation, includes PAR readings and was first reported on by Lang *et al.*, (1986) and Norman & Cambell, (1983).

Secondly a photographic method whereby a fisheye lens was used to photograph the canopy from below, pioneered the implementation of the reverse point source method (Anderson 1971). From this Campbell (1986) developed the method used by the Licor c2000 Plant Canopy Analyser (LC). This method is a mathematical calculation of a system where in falling light is focused on a sensor with 5 concentric rings. Each of the rings represents different elevation angles.

2.3.3.2 *Sunfleck Ceptometer*

The Sunfleck Ceptometer registers the size of the gaps in the canopy that is penetrated by sunrays passing through the canopy to the plane of measurement. The sun elevation and orientation, canopy width, height and canopy inclination determine the shade boundaries. Ceptometer measurements for a row crop like vines are valid for the time of day when there is no overlapping of shades from neighbouring plants.

Measurements at different times of day, varies according to the zenith angle of the sun and therefore need to be corrected for sun angle. This angle determines the size of the shade and the length of the sunbeam path through the canopy for different times of day. The increase of this length for a given gap between leaves reduces the chances for an open path oriented to the sun that produce sunfleck. Therefore this angle also influences the density of the shade.

The effect of sun angle, row orientation and canopy inclination on the size of the shaded area, are best described by the shade of a theoretical non-translucent body with similar dimension to that of the vine row. Relating the Ceptometer shade data (1-sunfleck) to this theoretical shaded area for the same sun angle, gives an estimate of the shade density. The shaded area is estimated by using the same zenith angle as the time at which Ceptometer readings are taken.

Various models for the leaf extinction coefficient or the resultant gap fraction was proposed by Campbell (1986), Norman & Campbell (1989), Welles & Norman (1991), and Lang (1992). The general approach is to use a spherical model in absence of long day measurements or to use the ellipsoidal model when reliable full day measurements exist.

According to Campbell (1986) and Lang (1992) the LAI can be calculated by

$$L\bar{G} = -\cos\theta \overline{\ln \tau} \quad (2.03)$$

where L is the LAI, G represents the average gap fraction and $\ln \tau$ is the average sunfleck reading when dealing with a range of sun angles, θ , encompassing 1 radian. The gap fraction is analogous to transmittance and depends on the foliage orientation, foliage density and the path length through the canopy. The left side of the equation must be regressed upon θ and then the slope B and constant A must be used as follows to produce L (or LAI):

$$L = 2(A + B) \quad (2.04)$$

This however results in a LAI that is not corrected for either the inclined structure of the vine trellis or the row orientation. Therefore a correction similar to Equation 2.06 must also be introduced here. The proposed gap fraction G for an ellipsoid, can be modelled for a range of zenith angles by the following equation where:

$$G = (x^2 + \tan^2\theta)^{0.5} / (x+1,774(x+1,182)^{-0.733} \quad (2.05)$$

and

$$x = \exp(-B/0,4L) \quad (2.06)$$

A correction for the sunfleck data to remove the effect of the row orientation and sun angle or to normalise the data is however still needed.

2.3.3.3 Licor c2000 Plant Canopy Analyser (LC)

This method is completely non-destructive. The LC measures the probability of seeing the sky looking up through a vegetative canopy in multiple directions (Figure 2.01). It can also be seen as a reverse point source application. The measurements contain both the foliage amount and foliage orientation.

Campbell (1986) pointed out that a beam of radiation passing through a canopy has a certain chance of being intercepted by foliage. The probability of interception is proportional to the path length, foliage density and foliage orientation. The beam of light has both direction and azimuth angle given by (θ, ϕ) . The beam of light also has a probability of non-interception given by T (θ, ϕ) :

$$T(\theta, \emptyset) = \exp(-G(\theta, \emptyset) \mu S(\theta, \emptyset)) \quad (2.07)$$

where $G(\theta, \emptyset)$ is the fraction of foliage projected toward (θ, \emptyset) , μ is foliage density and $S(\theta, \emptyset)$ is the path length through the canopy. Since the LC's optical sensor averages over the azimuth, \emptyset is not taken into account.

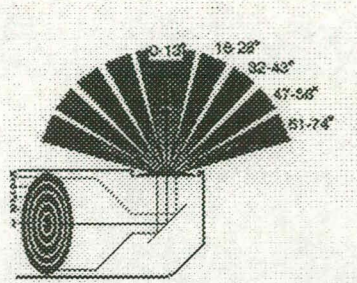


Figure 2.01. A cross section of the lens and view angles of the Licor c2000 Plant Canopy Analyser (From manual).

Now equation 2.3 can be rewritten in terms of foliage amount and orientation, i.e. $G(\theta) \mu$ as follows:

$$G(\theta) \mu = -\ln(T(\theta)) / S(\theta) \quad (2.08)$$

Equation 2.4 also equals the contact frequency as described by Miller (1963) namely $K(\theta)$. Miller also gave an exact solution for μ :

$$\mu = 2 \int_0^{\pi/2} \frac{-\ln(T(\theta))}{S(\theta)} \sin \theta d\theta \quad (2.09)$$

In homogenous canopy conditions, foliage density is related to the LAI for canopy height z and path length S for zenith angle θ :

$$LAI = \mu z \quad (2.10)$$

and

$$S(\theta) = z / \cos \theta \quad (2.11)$$

Substitution in Equation 2.09 gives the equation for LAI:

$$LAI = 2 \int_0^{\pi/2} -\ln(T(\theta)) \cos \theta \sin \theta d\theta \quad (2.12)$$

As a result of the 5 zenith angles of the instrument, the sum of $K(\theta)$ is calculated for

$$i = 1 \text{ to } 5 \quad (2.13)$$

As a result of the tendency of the LC to underestimate LAI, a correlation is done between a destructive LAI measurement technique and the LC LAI to calibrate LC LAI for specific conditions (Grantz & Williams, 1993). The best correlation is chosen by examining different combinations of the five $K(\theta)$ values.

2.4 The response function as a means of predicting Salinity Hazard

Indices of salinity hazard include water salinity, soil salinity and the ionic composition of selected plant organs. Leaf chloride was the most convenient and reliable method of measuring yield response to salinity for peach (Boland *et al.*, 1993, Moolman *et al.*, 1999). For grapes a high chloride content in the petioles (Christensen *et al.*, 1978) and laminae (Walker *et al.*, 1981) indicate whether plants have been subjected to salinity. The petiole chloride predicted the yield response slightly better than the laminal chloride in long-term field studies (Prior *et al.*, 1992b; Moolman *et al.*, 1999).

Fruit trees and vine crops were included in the general model (Maas & Hoffman, 1977) that describes the response to total salinity as a response function where the threshold salinity (EC_t) is the maximum salinity without yield reduction, and S is the slope of the curve determining the fractional decline per unit increase in salinity beyond the threshold. For generality the data is normalised by relating the yield to the non saline treatment yield (RY) and uses the depth mean salinity of the saturated paste extract (EC_e) assuming a stable and one dimensional salt profile.

$$RY = 1 - (EC_e - EC_t) * S \quad (2.14)$$

Hoffman *et al.* (1989) applied the model to the data of their plum experiment with reasonable success. However, the response function correlated better with the mean root zone salinity to a depth of 120 cm for a two year time integration than with the mean salinity of the yield year. In the case of a six year study on salinity effects on grapevine (Prior *et al.*, 1992a), yield was affected by the salinity of current and preceding seasons. The salinity effects were described better by a logistic function than by the Hoffman- response model. The logistic function was of the form:

$$y = D \left[1 + \left(\frac{EC_i}{EC_{ih}} \right)^a \right]^{-1} \quad (2.15)$$

where y is yield, EC_i is salinity of irrigation water, D is the theoretical yield at $EC_i = 0$, EC_{ih} is the half-effect EC_i and α is the shape parameter. This model has no threshold value and shows a reduced marginal effect with increasing salinity. The EC_{ih} value for pruning weight in the Prior model was lower than for yield which suggest that salinity has a larger effect on pruning weight than on yield. Larger salinity effects on shoot growth than on yield were reported also for plum trees (Catlin *et al.*, 1993).

2.5 Transpiration and plant stress

2.5.1 Physiological response to salinity

A drops in CO_2 fixation rate, reduction in stomatal conductance and photosynthesis, increased stomatal resistance and reducing sugar concentrations are among the physiological responses to salinity reported (Downton, 1977, Walker *et al.*, 1981 and Prior *et al.*, 1992b).

Downton (1977) reported that in a glasshouse study, potted Sultana vines treated with NaCl up to 125 molm^{-3} showed decreasing rates of CO_2 fixation with increasing levels of Cl^- in the leaves. Prior *et al.* (1992b) showed that field grown Sultana vines subjected to salinity, experienced similar reductions in stomatal conductance and photosynthesis, with the reduction also strongly correlated with leaf chloride. The leaves of salt-treated plants that show reduced rates of photosynthesis, have lower sucrose and starch concentrations, but increased reduction in sugar concentrations (Downton, 1977a). Salt-stressed Sultana vines in the field showing reduced photosynthetic rates, also have lower starch concentrations in shoots (Prior *et al.*, 1992b). Reduction in photosynthesis was shown to be due to increased stomatal resistance (Walker, 1994) which in turn might be related to internal disturbances at higher leaf chloride levels (Walker *et al.*, 1981).

Similar results were reported by Boland *et al.*, (1993) for peach trees. Photosynthesis of peach trees was reduced at high levels of salinity in the irrigation water with decreased stomatal conductance and likely chloride toxicity in the leaves. He also demonstrated that saline irrigation on peach trees resulted in less negative leaf water potential after two years of salinity exposure.

2.5.2 Model and mass balance approach

Scholes & Savage (1989) reported the water balance for a site to be as follows:

$$W = P - R - ET - D \quad (2.16)$$

Where

W is the change in the water content of the rooting zone,

P is the net precipitation,

R is the net runoff,

ET is the total evaporation,

= evapotranspiration

D is the deep drainage from the bottom of the rooting zone.

By convention, however, the units in terms of the water balance equation are equivalent depths of water (mm) rather than volumes of water. This is a generalised approach for any area of unspecified boundaries. Furthermore, 1mm depth of water equals 1 kg m^{-2} .

2.5.3 Evapotranspiration (ET) and Transpiration

2.5.3.1 The Simplified Penman-Monteith Equation

Pearcy *et al.* (1991) recommend a simplified form of the Penman-Monteith Equation (2.17) to determine ET:

$$E_T = [s(R_n - G) + \rho_a c_p g_h \Delta e] / \lambda [s + \gamma g_h / g_w] \quad (2.17)$$

where (s) = vapour pressure deficit of the air, (R_n) the available energy of net radiation with soil heat flux (G), (ρ_a) is the density of the air, (c_p) the specific heat of the air, (g_h) the total thermal conductance, (Δe) the vapor pressure deficit, (λ) the latent heat of vaporisation, (γ) the psychrometric constant and (g_w) is the total pathway conductance.

2.5.3.2 Discussion of Penman-Monteith Equation

The Equation (2.17) applies to single leaves, plants or whole canopies. The model can be applied successfully over periods of weeks, days, hours or minutes, provided that reliable values of variables are available. The inputs required depend on the time scale associated with the models and can range from hourly means to daily values.

Van Zyl & De Jager (1989) developed the PUTU model that used atmospheric evaporative demand (AED) as the evaporation upper limit for natural vegetation. This was defined as the water vapour transfer to the atmosphere required to sustain the energy balance of a given vegetative surface (crop) in a given growth stage, when its roots are supplied with adequate soil water to permit unhindered transpiration and the surface soil has a given water content. AED can then be measured with a lysimeter or

weather elements generated by a modern weather station. An appropriate formula will then be:

$$\text{AED} = E_p F \quad (2.20)$$

where F is the normalised crop factor for a specific crop and a specific region. Potential evapotranspiration (E_p) is quoted in mm day^{-1} or mm h^{-1} . E_p is usually calculated from meteorological data and the reference method is based on the Penman-Monteith equation. It requires knowledge of net irradiance, soil heat flux density, air temperature, water vapour pressure, water vapour deficit and wind speed. Very few weather stations record all the data necessary for this calculation. Where less detailed data is available empirical models have been developed. Many of these empirical models are reasonably accurate within the geographical region for which they were developed (Scholes & Savage 1989).

2.5.3.3 Stomatal conductance and transpiration

Because of the differences amongst the physiological properties of leaves in a canopy, the latter should be considered as consisting of a number of classes of leaves. The conductance of a particular hierarchy of leaves is the sum of the conductance of all leaves in that category within an imaginary vertical column, standing on unit ground area and passing through the canopy. Then, if the average stomatal conductance of individual leaves in a class is expressed per unit leaf area, the class conductance is the product of the average stomatal conductance and the area of that class of leaves in the column. Since the conductance of the canopy is the sum of conductances of all individual leaves in a canopy,

$$g_c = \sum_1^n (\bar{g}_{si} L_i) \quad (2.21)$$

where \bar{g}_{si} is the average stomatal conductance (or leaf) conductance per unit leaf area of the i th class of leaves of the leaf area index L_i and there are n classes referring to plant, level of development, shoot category, or age. Canopy conductance can, therefore be found from stratified sampling of the canopy for \bar{g}_{si} using a diffusion porometer and measurements of the partial leaf area indices (Jarvis *et al.*, 1981). However, measurements of \bar{g}_{si} with a porometer and estimation of L_i is labour-intensive and subject to error (Roberts *et al.*, 1980; Leverenz *et al.*, 1981). The need to acquire regularly measured values of g_c therefore, severely restricts the use of Equation (2.18) (Jarvis *et al.*, 1981).

2.5.4 Transpiration and the Heat Balance Method

Savage *et al.* (1993) reported the testing of the stem steady state heat energy balance technique in order to determine transpiration in situ. The technique make use of steady state conditions, i.e. a known amount of energy applied and a highly effective insulating shield that cover the area of testing around the stem. Also around the stem is the heater that makes contact with the stem and a set of 4 copper-constantan thermocouples that is placed in contact with the stem rather than imbedded in the stem. The amount of energy loss from this system is then measured and calculated as $g\ h^{-1}$ water movement through the stem. An accurate total leaf surface area measurement of the plant is then needed to calculate mm per hour or mm per day transpiration.

Savage *et al.* (1993) made use of the heat energy flux terms E_{radial} , E_{upper} , E_{lower} , E_{heater} and E_{sap} to formulate the balance equation:

$$E_{\text{sap}} = E_{\text{heater}} - E_{\text{radial}} - E_{\text{upper}} - E_{\text{lower}} \quad (2.22)$$

Where E_{sap} is the convective component due to sap flow, E_{heater} is the known amount of energy applied, E_{radial} is the radial heat loss, E_{upper} is the downstream stem temperature and E_{lower} is the upstream temperature. The apparatus used for these measurements is the Dynamax sap flow meter

The use of the Dynamax system does not go without problems as was shown by Savage *et al.* (1993), Smith & Allen (1996) and Shackel *et al.* (1992) amongst others. It is also believed that there is a miss understanding with most writers toward the use of the system. Savage (1997) devised methods whereby all energy surrounding this measuring point can be accounted for. These methods were never reported by other writers in the field and are not mentioned in the manual for the Dynamax sap flow meter. Savage (1997) used double-sided mirror tape to insulate all electrical connections. He also used extra tinfoil, which was mounted, over large sections of the stem and the sensor. The tinfoil acts as a shield that cuts out all sunlight but with little holes made in it that allows wind flow. The shield also protects the base of the stem, below the sensor, to be heated by direct sunlight throughout the day.

2.6 Concluding Remarks

From this review it is clear that the total leaf surface of any vine plays a major role in the plant in terms of the water budget of that vine as well as of the immediate surrounding area. There seems to be consensus among authors that visible stress

symptoms appear rather late in the leaves, with the result that when it occurs, the condition is irreversible within that season. LAI measurements can thus be used as indicator with which to compare treatment effects, but not as an early warning indicator of plant response in a commercial vineyard. Since soil salinity cause a decrease in soil water potential and consequently reduce water uptake, measurement of transpiration could provide an early indicator of salinity stress.

It will show from this study that transpiration measurements have this sensitivity. It is also possible that near infra red (NIR) optical readings integrated over the whole canopy will have this capability.

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CHAPTER 3

THE USE OF A SUNFLECK CEPTOMETER IN A PLANT STRESS EXPERIMENT TO MONITOR PLANT REACTION.

Light intercept by the leaves is the primary factor that determines transpiration (T) and photosynthesis. Salinity that reduces the leaf area will consequently reduce the light intercept. In a salt water irrigation experiment, conducted near Robertson RSA, a *Decagon Sunfleck Ceptometer* was used to measure the light intercepted by the plants of the different salinity treatments. This data was also used to estimate a leaf area index (LAI) for each plot. Estimated LAI was then compared with the LAI derived from physical measurements of leaf area by using destructive as well as non destructive methods on a few shoots per plot. The correlation proved that the ceptometer offers a convenient and rapid method for determining LAI and monitoring treatment effects on leaf area.

3.1 Introduction

Light interception by leaves is the primary factor that determines transpiration and photosynthesis. Salinity that reduces the growth rate of leaf area, maximal leaf area per plant and accelerates leaf defoliation, will reduce light interception. The salinity effects may change over time. Therefore, seasonal integration and time differentiation of salinity effects require closer studies of the changes in light intercept and leaf area. The *Decagon Sunfleck Ceptometer* provided the data of light intercepted by the plants in the different saline treatments. This data can provide good estimates of LAI after appropriate adjustment for the canopy characteristics of the plants. Models that estimate the LAI from ceptometer data is available for cover crops and single trees (Lang *et al*, 1992). A suitable model for a canopy with characteristics similar to that of the Colombar grapevine used in the Robertson salinity experiment does not exist. The unique features of the canopy are the 3m spacing between vine rows with orientation of 303° and a factory roof type trellising system with a south-westward dip. Adjustments to existing models consequently had to be made. To be able to relate the LAI to various other plant physiological parameters that were measured over the same period, one must, however, be sure about the validity of sunfleck ceptometer derived LAI. If a good correlation was to be found, the use of the ceptometer is a less destructive and less time consuming method for monitoring the impact of saline irrigation water on the phenology of the plant. Verification of the ceptometer estimated LAI values, could be made by comparing them with the LAI calculated from leaf area measurements on a few shoots per plot, using non-destructive or destructive methods.

3.2 Theory

The ceptometer registers the size of the gaps in the canopy that is penetrated by sun rays passing through the canopy to the plane of measurement. Figure 3.01 present a schematic cross-section perpendicular to one vine row with 270° orientation, showing the position of the sun at about 11h00.

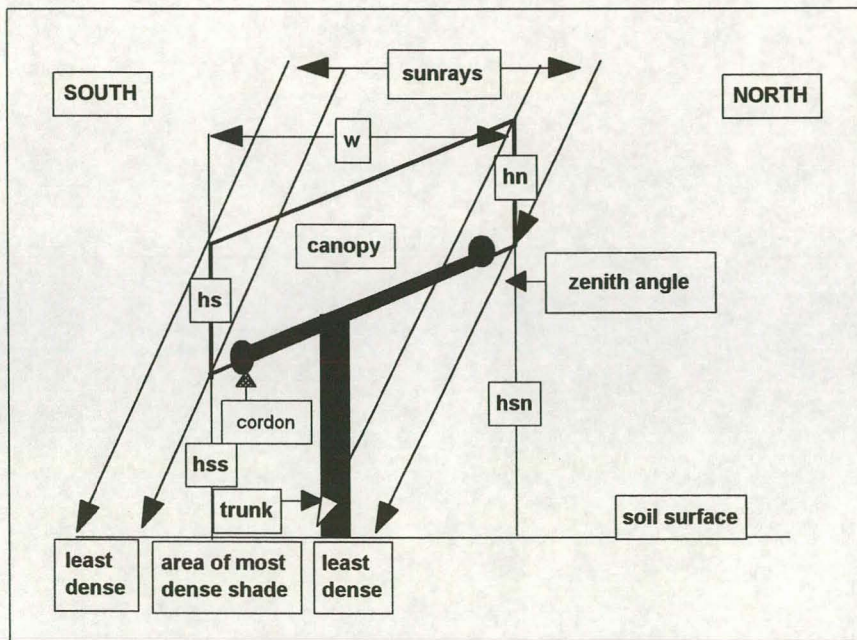


Figure 3.01. Diagram of a cross-sectional view of the vine row indicating the measured parameters on the vines. The parallelogram is a cross section of the monoclinic body used to determine non-translucent body shade. With respect to Fig. 3.01 the following dimensions can be defined: h_s = height of vine above south cordon, h_{ss} = height of south cordon above soil (which was taken as a horizontal surface), h_{sn} = height of north cordon above soil, h_n = height of vine above north cordon and w = width of the vine.

As can be seen, the shade boundaries are determined by the sun elevation and orientation, canopy width, height and canopy inclination. Ceptometer measurements for a row crop like vines are valid for the time of day when there is no overlapping of shadows from neighbouring rows.

Measurements at different times of the day vary according to the zenith angle of the sun and therefore need to be corrected for sun angle. This angle determines the size of the shade and the length of the sunbeam path through the canopy at different times of

the day. The increase of this length for a given gap between leaves, reduces the chances for an open path oriented to the sun that produce sunfleck. Therefore this angle also influences the density of the shade.

The effect of sun angle, row orientation and canopy inclination's on the size of the shaded area, are best described by the shade of a theoretical non-translucent body with similar dimension to that of the vine row. Relating the ceptometer shade data (1-sunfleck) to this theoretical shaded area for the same sun angle, gave an estimate of the shade density. The shaded area was estimated by using the same zenith angle as for the time at which ceptometer readings were taken.

Some of the existing formulae to determine the elevation angle of the sun from the zenith, θ , had to be adjusted for the southern hemisphere and were calculated from (all angles in radians):

$$\theta = \arccos(\sin L \sin D + \cos L \cos D \cos(0,2618(t-t_0))) \quad (3.01)$$

where L is the latitude for the place in question, D the solar declination, t the time and t_0 is the time of solar noon. The declination (D) can be calculated from

$$D = \arcsin(0,39785 \sin(4,869 + (\pi/180)J) + 0,03345 \sin(6,224 + (\pi/180)J)) \quad (3.02)$$

where J is the Julian day.

The time of solar noon is calculated from:

$$t_0 = 12 - LC - ET \quad (3.03)$$

where LC is the longitude correction and ET the equation of time. The Robertson experimental farm is situated at 19 degrees and 54 minutes east and therefore:

$$LC = (19,9-30)/15 \quad (3.04)$$

(Data of the temporal statistics of the sun's position relative to the Robertson vineyard, were obtained from List (1966)).

The equation of time represents a 15 to 20 minute correction depending on the time of year and is given by:

$$ET = (-104,7 \sin \phi + 596,2 \sin 2\phi + 4,3 \sin 3\phi - 12,7 \sin 4\phi - 429,3 \cos \phi - 2 \cos 2\phi + 19,3 \cos 3\phi) / 3600 \quad (3.05)$$

where:

$$\phi = (279,575 + 0,986J)\pi/180 \quad (3.06)$$

To be able to correct the sunfleck data for row orientation and for the varying sun angle, the canopy dimensions of the plants at the point of sunfleck measurements were used to calculate the maximum or total possible shaded area. The cross-sectional surface of a plant through the row (perpendicular) was taken as a parallelogram and a correction equation, X, was determined where:

$$X = ((h_s + h_{ss} - h_{sn}) \zeta \tan \theta + w) \quad (3.07)$$

and

$$\zeta = |\sin \lambda - (-\cos D \sin(\pi/12(t-t_0))/\sin \theta)| \quad (3.08)$$

where λ is the row orientation measured from north.

When ζ is 0, i.e. when the azimuth of the sun is equal to the azimuth of the row, X becomes

$$X = w \quad (3.09)$$

In the last instance where the azimuth of the row is smaller negative than the azimuth of the sun, i.e. when the sun has crossed the row, X becomes

$$X = ((h_n + h_{sn} - h_{ss}) \zeta \tan \theta + w) \quad (3.10)$$

Canopies with similar size and leaf area will produce varying size shade at different times of day and seasons due to changes in the sun position with respect to the row. Figure 3.02 illustrates the effects of row orientation and canopy inclination on the size of a shaded area of a non-translucent body (Equations 3.07-3.10) on day of season (DOS) 113 (December 21) the day with the smallest sun angle from zenith at noon. Figure 3.02 shows the effect on the shade of the row orientation alone, as well as the effect of both row orientation and canopy inclination. It also compares the shade of two rows where the cordons are on the same, as well as different heights from the soil (horizontal). One row orientation is 270° and the sun never crosses it and the other is

303°. The latter produces the largest shade over the entire day. In the first instance $w=18$ dm, h_n and $h_s=9$ dm. For the last, $h_n=95$, $h_{ns}=15,7$ dm and h_{ss} 13,5 dm was used.

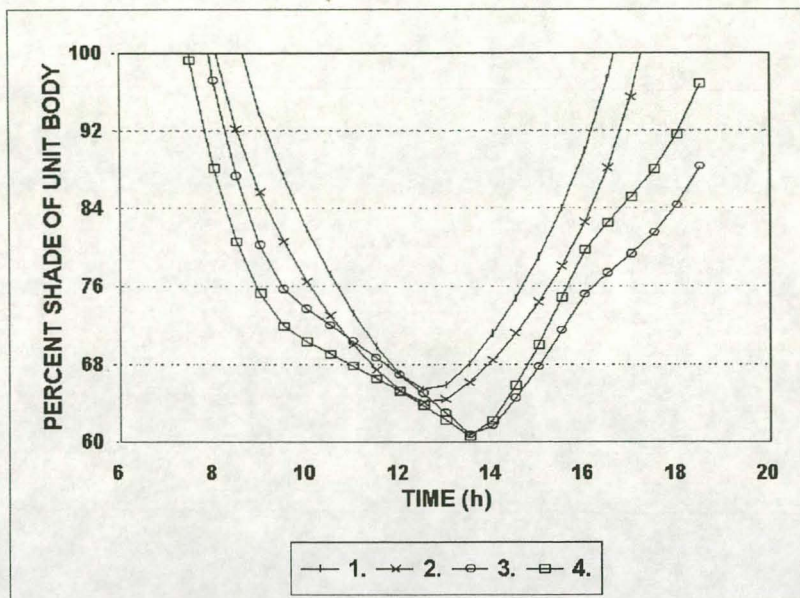


Figure 3.02. Shade correction for a non-translucent body on DOS 113: 1) row at 270° from north and horizontal canopy, 2) row at 270° and inclined canopy, 3) row at 303° and horizontal canopy and 4) row at 303° and inclined canopy.

The non-translucent body produces the maximum shade (X in Equations 3.07, 3.09 and 3.10) that can possibly be measured for a certain θ . The measured shade from the ceptometer divided by the result X now gives a shade density per area (d_1). This shade density per area d_1 , has a certain relation with the shade density per area for conditions where the zenith angle of the sun is zero. The relation between the two, or for any other zenith angle, can be modelled for a whole day. This was approached by Campbell (1986) as an ellipsoidal gap fraction model (Equation 2.05).

Various models for the leaf extinction coefficient or the resultant gap fraction were proposed by Campbell (1986), Norman & Campbell (1989), Welles & Norman (1991), and Lang (1992). The general approach is to use a spherical model in absence of long day measurements or to use the ellipsoidal model when reliable full day measurements exists.

The approach of Campbell (1986) and Lang (1992) as described on page 15 was used in this section to determine the gap fractions.

The density per area of the shade (d_2) can also be calculated from the sunfleck data by determining the shaded area as the area where a sunfleck reading was encountered smaller than 100%. The shade fraction of the sunfleck data divided by the area, gives the density per area. A correction for the sunfleck data to remove the effect of the row orientation and sun angle or to normalize the data was done by determining C from

$$C/(w/300) = d \quad (3.11)$$

where C is the adjusted average measured shade, $w/300$ is the width of the plant as a fraction of the row spacing and d is the density of the measured shade per area. This, however, does not adjust for gap fraction in all cases, but presents an easy solution to determining LAI when the gap fraction need not be taken into account.

3.3 Materials and Methods

This study was conducted on two vineyards in two regions namely the Robertson experimental farm just outside of Robertson (33° 48.5' South and 19°52.5' East) and the Nietvoorbij experimental farm just outside of Stellenbosch (33° 51.75' South and 18° 51.49' East). Between December 1990 and June 1998, six salinity treatments, ranging in electrical conductivities (EC_i) from *ca.* 30 mSm^{-1} (fresh water), 75, 150, 250, 350 and 500 mSm^{-1} were used to investigate the long-term effect of salinity on *Vitis vinifera* L. cv Colombar and Weisser Riesling. The control treatment ($\sim 30 mSm^{-1}$) was the local fresh water. The other five EC_i levels were obtained by preparing a $\sim 30\%$ stock solution of 1:1 molar ratio NaCl and $CaCl_2$. During irrigation, the five levels of EC_i were controlled by a fully automated computerised salt injection system (Moolman *et al.*, 1999). The 1.2 ha experimental vineyard with a 3 m x 1.5 m row and plant spacing was established on the Robertson experimental farm in 1974. Colombar grafted on 99 Richter rootstock was planted. The vines were trained on a factory roof trellis system (Saayman, 1988). Each plot consisted of an experimental row and two border rows on either side. Ten vines in the centre row of each plot were used as experimental plants. The vineyard at the Stellenbosch Nietvoorbij experimental site was established in 1990 and the first saline irrigation event was in 1995. The same treatments were applied as in Robertson. Each plot had 6 rows with 10 vines in each row. The 8 experimental vines were the 4 vines in the middle of the two inner rows.

The soil at Robertson is classified as a Trawal 2210 fine sandy loam (Typic Durochrepts) with a duripan at approximately 1.2 m (Soil Classification Working Group, 1991). The clay content ranges from 18 to 25%, the cation exchange capacity from 11 to 14 $\text{cmol}_c(+)\text{kg}^{-1}$ and bulk density from 1.49 to 1.63 Mgm^{-3} . The soil at Stellenbosch is classified as a Glenrosa soil form and is underlain by bedrock of Malmesbury shale (Soil Classification Working Group, 1991). The clay content varies between 15 to 23% and consists partly of swelling clay. The bulk density of the soil varies between 1.25 and 1.48 Mgm^{-3} .

During summer, soil water content was measured in each plot twice per week with a neutron probe at depths of 0.15, 0.3, 0.6, 0.9 and 1.2 m. Water was applied according to the measured soil water deficit of the four control plots. All treatments received the same amount of water and no special provision was made for leaching during summer. In order to leach the excess salt during winter (May to August), natural rainfall was supplemented with irrigation using the low salt content water of the control plots (30 mSm^{-1}).

Pruning was done on all sites according to the spur-pruning method (Saayman 1988). A whole range of other plant related parameters and plant chemical analysis was done but did not have a direct bearing on the outcome of this study.

During summer the soil was covered with a straw mulch. This resulted in a much cooler upper soil and much less evaporation from the soil.

For the sake of this study and to fully investigate plant reaction to irrigation water with a high salt content, LAI was approached using treatments ~ 30 (fresh), 150 and 350 mSm^{-1} at Robertson and ~ 40 (fresh) and 500 mSm^{-1} at Stellenbosch. Transpiration measurements were only conducted in Stellenbosch on the two mentioned treatments.

The experimental site near Robertson consisted of 24 plots, each having 5 rows with 22 vines per row. The 10 experimental vines in the centre of the middle row were used to monitor all non-destructive parameters. Destructive measurements were done on plants similar in size and growth vigour from rows adjacent to the experimental row on each plot.

Data were collected with a *Decagon Sunfleck Ceptometer* which consists of an 0,8 m long probe and a recording unit. The instrument records the PAR, sunfleck percentage

and time of measurement simultaneously. A 3 m long measuring rod was prepared with 0,15 m spaced markings. It was placed across the interrow space with the 0 and 3 m marks of the measuring rod, in two adjacent rows and in the centre of 2 x 1,5 m spaced vines (Figure 3.03). The instrument was then moved perpendicularly over the rod, parallel to the vine rows, to each mark where a reading was taken. Forty measurements were taken over this area in a 2 x 20 configuration between four fixed plants. The plants were similar in size and representative of the mean of the plot. Measurements were only taken when clear and stable sky conditions prevailed and the same procedure was followed at all measuring sites at all times and dates.

Several sets of data were taken over all treatments together with shoot samples for destructive measurements. The canopy dimensions were also determined, i.e. the height of the cordons from the soil, the height of the canopy above the cordons and the width of the plant across the row. Each vine has an effective soil surface area of 1,5 x 3 m. Since one plant canopy occupied more or less a third of this space at midday, care was taken not to sample data when the shade of two plants was overlapping later or earlier in the day.

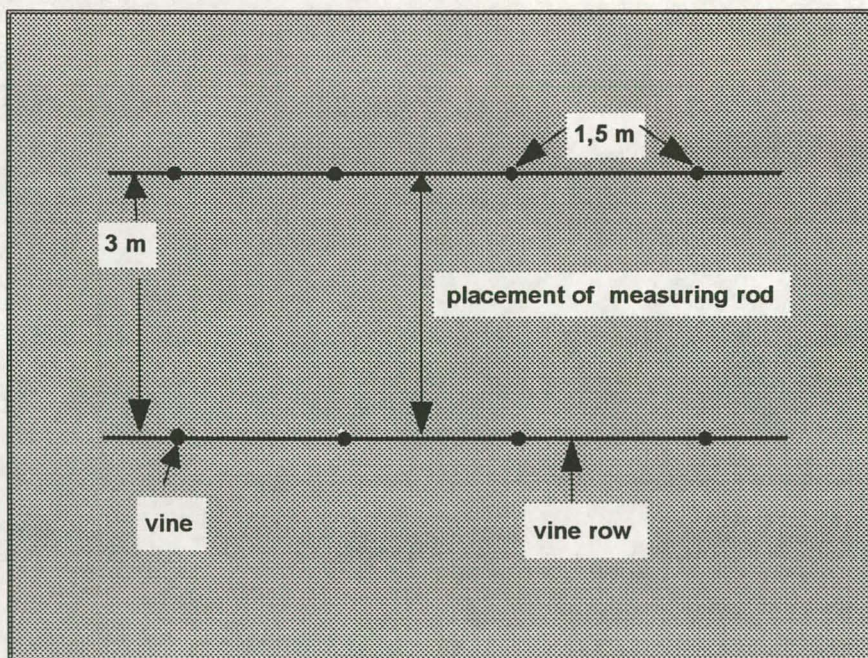


Figure 3.03. Schematic site diagram showing the position where the 3m measure was put to take readings at accurate intervals

Destructive measurements of leaf area were also conducted at the same time as the Ceptometer readings, but on different plants in the same treatment. Shoots were

sampled and the area of the leaves measured with a Licor leaf area meter. The number of shoots per vine were counted and multiplied by the average leaf area per shoot. A total leaf area per plant was thus approached. The LAI was therefore calculated as:

$$\text{LAI} = \text{LA}_s * \text{N}_{sp} / \text{SA}_p \quad (3.12)$$

with LA_s the leaf area per shoot, N_{sp} the number of shoots per plant and SA_p the soil surface area per plant (4.5m²).

3.4 Results and discussion

Figure 3.04 shows the sunfleck data measured at plot 1 in the Robertson vineyard. The two areas around the cordons, which are the most dense part and accordingly produce the most dense shade, can clearly be seen. Since these measurements were taken on the morning of April 20, 1993 (DOS 232) at 10h05, the results represent only the shade of the northern row. The inclination of the sun does have an effect on the shade density. The graph can therefore be divided into three segments namely, a top line which is 100 percent sun, parallel to this a baseline which represents the most dense shade and the rest of the graph which represents the transition between these two lines. To be able to determine density, one has to determine the area that the averaged or totalled sunfleck value must be related to. The first problem here is to decide where the cut-off point or the perimeter of the shaded surface should be.

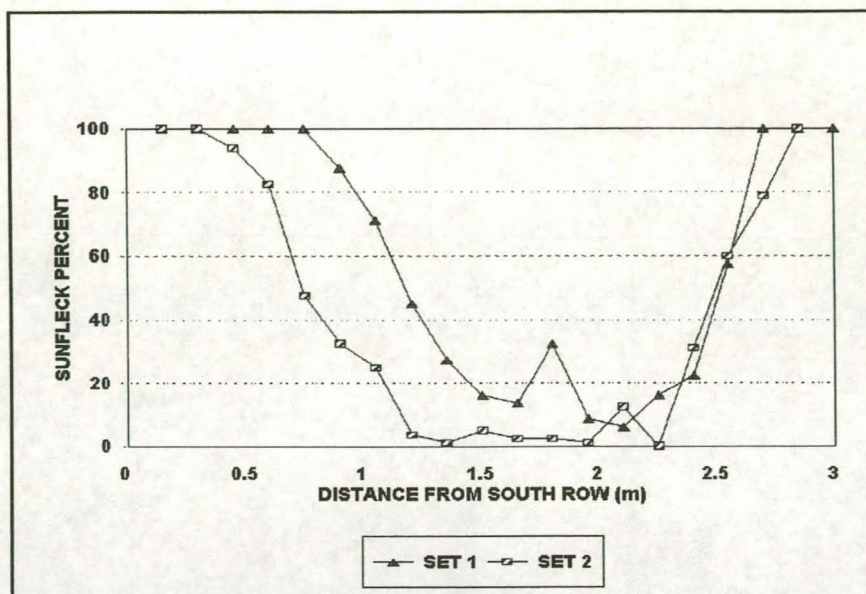


Figure 3.04. The raw sunfleck data of plot 1 in Robertson showing two transects from the south to the north row, set 1 measured west of the trunk and set 2 measured east of the trunk on DOS 232 between 10h00 and 11h00.

There can be three scenarios.

- i) The first is to decide to include the maximum surface area, thus the drip line surface.
- ii) The second is to decide to use only the area of the most dense shade.
- iii) The third is to use 50 percent sunfleck as the cut-off point or to determine the point where the surfaces of the area above and below the line will be equal (which will be in the vicinity of 50 percent).

The last seems to produce the best estimate but since the results had to be related to the measured canopy results (solid body shade), the first approach was used as this best represented the canopy measurements taken by hand.

The means of the four replicates of treatments 1(35 mSm⁻¹), 4(250mSm⁻¹), 6(500mSm⁻¹) and the field mean of all 24 plots of one day's measurements, are shown in Figure 3.05. The mean values for all treatments are presented in Table 3.01. It is clear that treatment 6 represented the area with least shade and treatment 1, the area with the widest but not the most dense shade. From the baseline data shown in Figure 3.05 it can be inferred that salinity effected the leaves and shoots of treatment 4 in such

a way that it produced a very dense, but not necessarily large shade. To a certain extent this was substantiated by measurements of shoot and leaf elongation rates. Also evident from the Figure 3.05 is that the higher the salt content, the narrower and higher the V-shape of the graph. The low sunfleck values of treatment 3 shown in Table 3.01, which suggest a large and dense leaf area, correlates with the observation that it had the lowest soil water status throughout the 1992/93 season. The larger leaf area will lead to higher transpiration rates and a greater rate of soil water depletion. However, this analogy between sunfleck data, leaf area and soil water status does not hold for the other treatments.

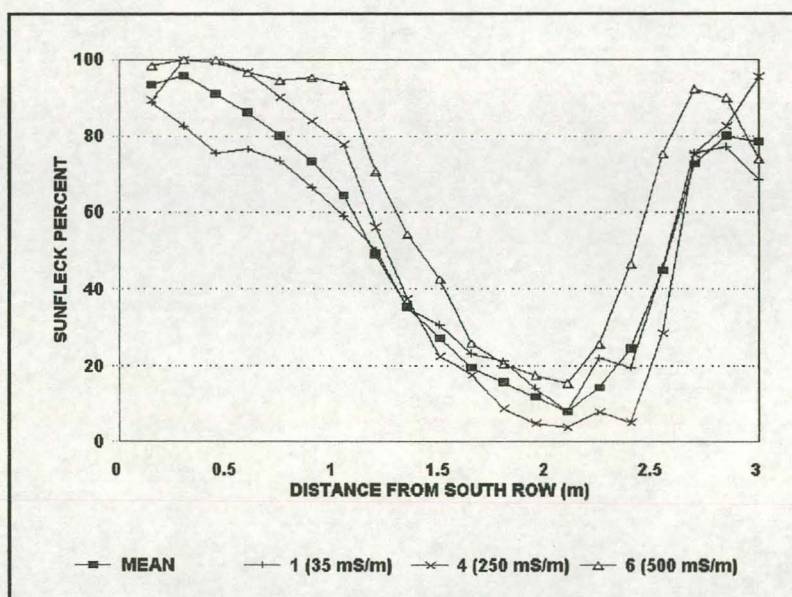


Figure 3.05. The mean sunfleck data at Robertson for treatments 1, 4 and 6 together with the overall mean of all six treatments measured on DOS232 between 10h00 and 11h00.

Table 3.01 Treatment mean sunfleck data measured on 20/04/93 (DOS 241)

Treatment	EC _i	Sunfleck (%)
1	30	50,6
2	75	44,2
3	150	42,2
4	250	54,2
5	350	61,6
6	500	66,4

100%=full sun, no shade

In Figure 3.06 the calculated shade (Equations 3.07 to 3.10) of the vineyard as a non-translucent body, is compared with the averaged shade (1 - sunfleck) measurements made at the same zenith angle of the sun. When the sunfleck readings are divided by

the calculated values, the shade density of the plants in the vineyard, which is in a certain relation to their leaf density, is obtained. Therefore the difference between the two sets of data account for the leaf density. This difference increased with an increase in soil salinity. These calculations were made for a day, late in the season, when salinity-induced leaf drop was significant. When the sunfleck readings are divided by the corrected values, the shade density of the plants (which is in a certain relationship to their leaf density) is obtained. The correlation between the measured shade and the solid body shade, calculated according to the procedure described above, i.e. for the same time of day when the measurements were made (Equation 3.07), is presented in Figure 3.07. The regression equation,

$$\text{SHADE}_{\text{ceptometer}} = 0,69 * \text{SHADE}_{\text{theoretical}} + 32 \quad (3.13)$$

is also presented in Figure 3.07. The offset is the point of minimum true (ceptometer measured) shade. This linear relationship has a R^2 of 0,90. The offset can be interpreted as the cordon and shoot skeleton dimensions with no leaves. The slope >1 indicate higher leaf density in larger plants. This can be the result of initial higher density or less leaf drop at lower salinities. Calculations of these ratios during the growing season can illuminate this point and provide information on shoot and leaf growth. The results presented in Figure 3.07 are very significant in that either one of the two sets of data can be predicted by the other.

In the next step, averaged seasonal leaf area index (LAI) data per plot, obtained from measuring leaf area per shoot and the LAI derived from shadefleck data, were compared. The following four approaches were used to compare between the measured and ceptometer derived data:

- i) The ceptometer data was converted to LAI using Equation 2.03 with $G=1$ and compared with destructive LAI.
- ii) The same as i) but assuming a spherical model with $G=0,5$.
- iii) The same as i) but assuming an ellipsoidal model with G varying between 0,42 and 0,919 for the different treatments.
- iv) Predicting ceptometer LAI from the ceptometer data using the regression statistics of the comparison of i) with destructive data.

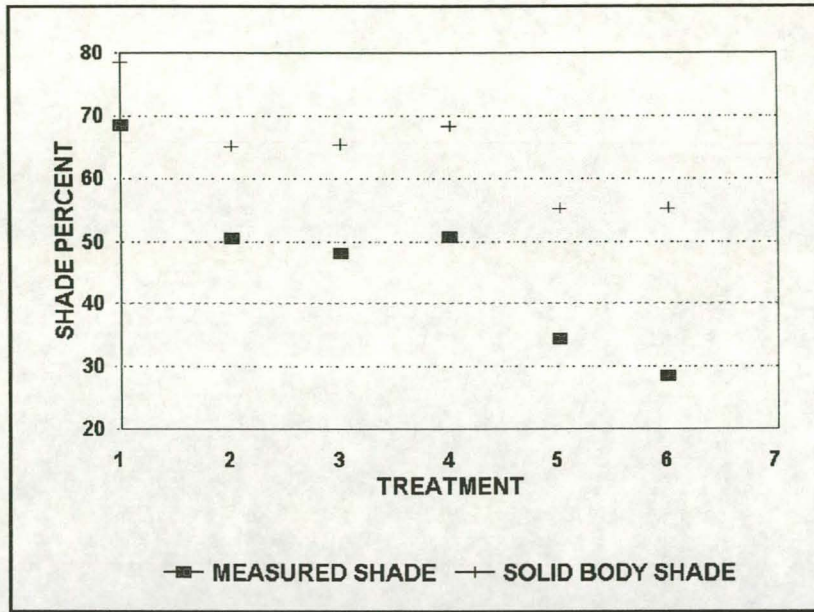


Figure 3.06. The calculated shade per treatment for the X (Equations 3.07-3.10) corrected non-transparent body, and the measured shade percent per treatment for day of season 232 and time between 10h00 and 11h00.

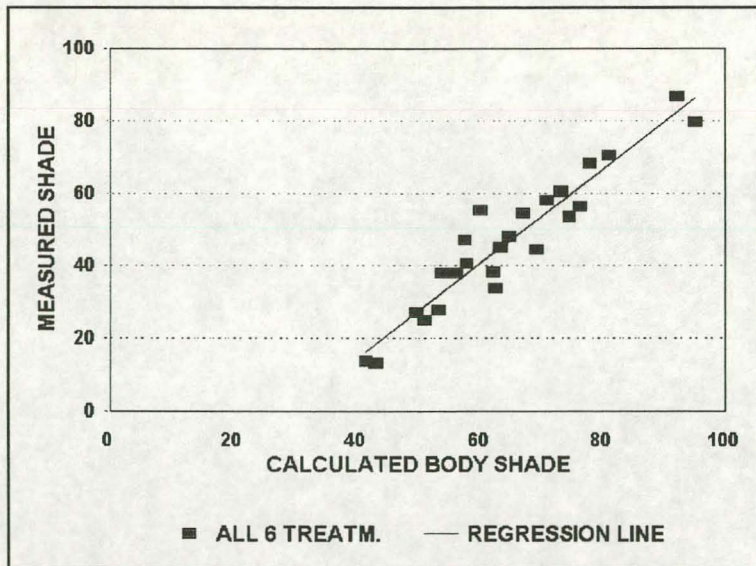


Figure 3.07. Relationship between measured and theoretical body shade at Robertson on day of season 232, and time between 10h00 and 11h00.

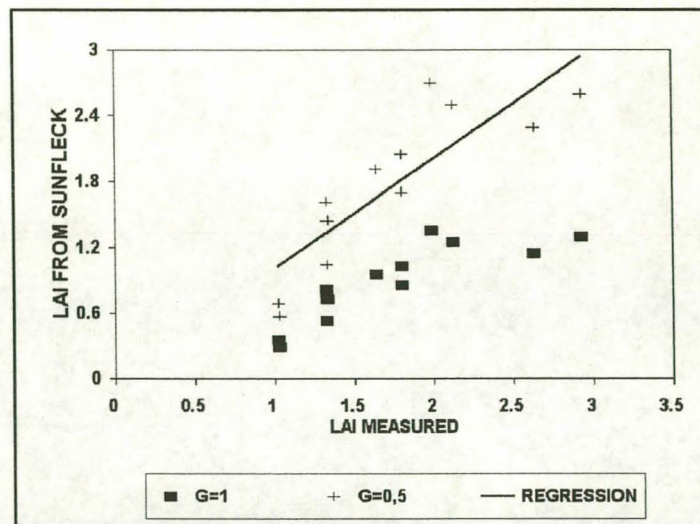


Figure 3.08. Comparison between the leaf area index (LAI) measured from destructive plant analysis and the LAI derived from sunfleck ceptometer data using different values for G in Equation 2.03 at Robertson on day of season 232.

The approach of using $G=1$ (no leaf extinction model) agreed well with the measured $LAI_{\text{ceptometer}}$ and the regression results can therefore be used to predict the true (destructive) leaf area index. In the second approach the correlation between these two sets of data presented a useful result with a correction equation of:

$$LAI_{\text{predicted}} = 0,92 * LAI_{\text{ceptometer}} + 0,57 \quad (3.14)$$

With a slope of almost one, the need to correct for the gap fraction diminishes.

The ellipsoidal model in the third approach presented a result not worth discussing. With the fourth approach, which is similar to the first approach, one uses the best regression equation by using all available data and formalises it to be used for future calculation of LAI.

With a $LAI_{\text{ceptometer}}$ above 2,5 the increase in LAI did not affect the sunfleck readings, as this is the value where 100 percent shade exists. The interpretation of this curve is that at $LAI_{\text{ceptometer}}$ of 2,5 the canopy approaches characteristics of a non-translucent body. Also as the shoots become longer, they tend to fall over and rest on the support system. For cover crops this point is at about $LAI=4$ (Welles *et al.*, 1991). Using the ratio of maximal canopy width of 1,8 m to row spacing, as a conversion factor to find this point for the vineyard:

$$1.8\text{m}/3\text{m} * 4LAI = 2.4LAI \quad (3.19)$$

resulted in similar LAI values. The slightly larger threshold in the vineyard may be the result of sunflecks at the canopy sides where path length is shorter.

Bearing in mind that the foregoing discussion was based on readings that were taken during the same time of day, for different days over the season, thus minimising the effect of sun position, a model was developed after the analysis of full day measurements on specific plants. Therefore, because of full day measurements on single plants, it was found that measurements taken in the afternoon are subjected to very rapid and large change not only over the afternoon but also over the season. Instead it was proposed to model $LAI_{\text{ceptometer}}$ at or around the time when the sun angle with the row is perpendicular and represents the smallest seasonal effect (Figure 3.09).

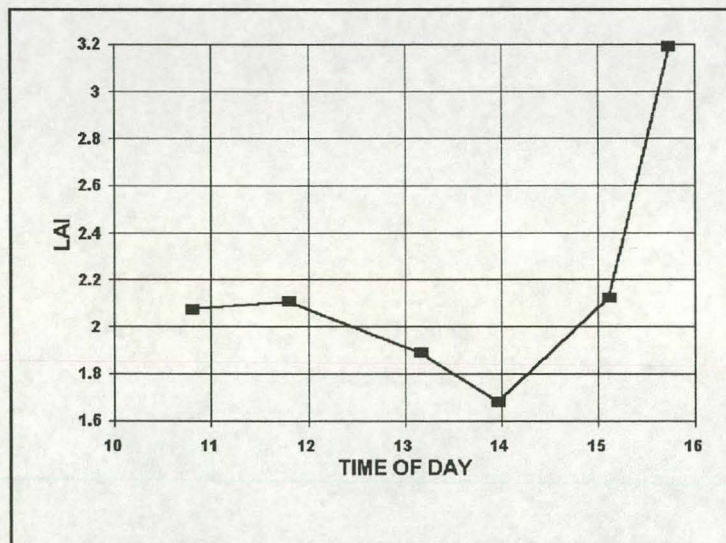


Figure 3.09. Full day measurements of one plant to demonstrate the rapid change after 12h00.

Calculation of LAI can be simplified if a good relationship between shade fraction of ceptometer readings and LG (Equation. 2.03) exists. If this is true, LAI can be obtained from the measurements of the shade fraction, using an empirical G value that was not derived from an spherical or ellipsoidal model. Using all the sunfleck ceptometer data of the 1992/93 season, LG (Equation 2.03) was determined and compared with corrected shade (Equation 3.11). In both cases the gap fraction and/or leaf extinction coefficient were ignored. The results are presented as Figure 3.10 and the regression was:

$$LG = -0,008 + 2,54(\text{shade fraction}), R^2 = 0,76. \quad (3.16)$$

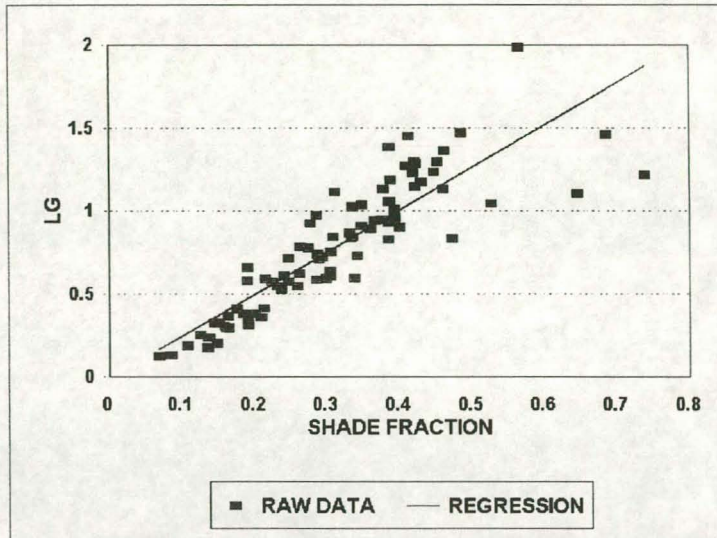


Figure 3.10. Relationship between LG (Equation 2.03, with $G=1$) and corrected shade data (Equation 2.04) based on all the sunfleck ceptometer data of 1992/93

With the exception of a few points at the upper end of the curve (i.e. shade fraction $> 0,6$), the relationship is very good.

The seasonal trend of the treatment mean sunfleck data are shown in Figure 3.11. It is clear that treatments 1 and 4 showed an upward trend over the season. Treatment 6 was more or less stable during the middle part of the season followed by a downward trend towards the last part of the season, which is the result of salinity-induced defoliation. It is important to note that the LAI results in Figure 3.11 were calculated with G -value = 1.

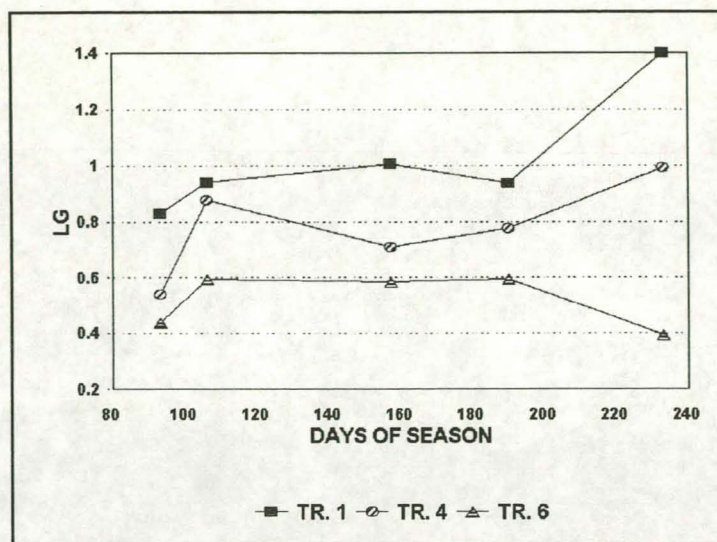


Figure 3.11. Seasonal changes in average LG for treatments 1(35mSm⁻¹), 4(250mSm⁻¹) and 6(500mSm⁻¹) at Robertson.

To summarise, the dimensions of the plants were measured and a potential maximum shade was calculated. The specific time of day and year was taken into account to calculate the zenith angle of the sun. Then Equation 2.03 according to Campbell (1986) was determined for each plant. The gap fraction (G) was calculated by means of a regression analysis for data taken at the same sun time of day. Since the path of the sun over the plant did not follow a symmetrical shape, a good model could not be defined for the gap fraction of the whole day. It was, however, possible to derive a model for the morning to noon period (Figure 3.11) but this also proved to be a long procedure with no real gain. It proved that the initial approach, to take readings during the late morning, was indeed the right one as changes during this period were minimal. This correlation proved to be extremely successful.

3.5 Conclusions

Experience gained during the 1992/93 and 1993/94 seasons confirmed the usefulness of the sunfleck ceptometer as an instrument to measure LAI of row crops such as grapevines. A sound theoretical basis for correcting the ceptometer data according to row orientation, canopy and trellising structure, time of day and year, has been established. A good correlation between the adjusted ceptometer data and LAI

measured destructively and non-destructively from the leaves of individual shoots, was found. The instrument could be used in the present study to monitor the effect of salinity on canopy development and leaf area non-destructively. It also allowed a great number of measurements to be taken in a very short time span.

Based on the experience gained by using the ceptometer in a vineyard, the following recommendations can be made:

- i) For row structures in an east-west orientation, readings must be taken when the sunrays are perpendicular to the row. For rows in a north-south orientation, a time of day must be secured that were to minimise the effect of neighbouring plants on the readings. The best time to take readings is when the sun angle is at 57 degrees from the horizontal (Campbell 1986).
- ii) Readings must be taken parallel to the row direction at a constant interval (10-15 cm), so that the whole canopy can be described. This approach has two advantages, namely to be able to successfully interpret point readings and to get an average of a full cross section of the plant row.
- iii) From the time of day that readings were taken, theta values (the zenith angle of the sun) could be determined for use in Equation 2.03.
- iv) LG and $LAI_{\text{destructive}}$ could be correlated and the regression equation used to calculate $LAI_{\text{ceptometer}}$.

The greater the symmetry of the plant measured, the easier the solution. In the Robertson vineyard, when measuring the vine in a row where neighbouring vines inter grow, the strike of the row presents a problem as to the time of day best suited to take readings. Furthermore, the inclined trellising system in use adds to the problem as it accounts for a rapid enlargement of the shade, as well as the longer path length of the suns rays through the canopy during part of the day.

The results are presented in Figure 3.11 and it is clear that the LAI calculated from only one reading per day without some compensation for the time of day will be of no use. A general formula to correct the LAI for any time of day was attempted. The idea was abandoned, as it is quite clear that readings in the afternoon are very sensitive to changes in the sun position (Figure 3.09).

3.6 References

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CHAPTER 4

THE ESTIMATION OF LEAF AREA INDEX WITH A LICOR C2000 PLANT CANOPY ANALYZER IN A COLOMBAR VINEYARD THAT WAS SUBJECTED TO SALINE IRRIGATION

Light intercept by the leaves is the primary factor that determines transpiration (T) and photosynthesis. Salinity that reduces the leaf area will consequently reduce the light intercept. In a salt water irrigation experiment, conducted with the support of the Water Research Commission near Robertson RSA, a *Licor c2000 Plant Canopy Analyser* was used to measure the light intercepted by the plants in the different salinity treatments. This data were also used to estimate a leaf area index (LAI) for each plot. Estimated LAI was then compared with the LAI derived from physical measurements of leaf area by using destructive as well as non destructive methods on a few shoots per plot. A correlation was found which proved a *Licor c2000 Plant Canopy Analyser* as a convenient and fast means to determine LAI and monitor treatment effects on leaf area.

4.1 Introduction

Light interception by leaves is the primary factor that determines transpiration and photosynthesis (Percy, 1989). Salinity that reduces the growth rate of leaf area, maximum leaf area per plant, and accelerates early defoliation, will reduce light interception. The salinity effects may change over time. Therefore, seasonal integration and time differentiation of salinity effects requires closer studies of the changes in light intercept and leaf area. The *Licor 2000 Canopy Analyser* (LC) provided the data of light intercepted by vines in the different saline treatments. This data can provide good estimates of LAI after appropriate adjustment for the canopy characteristics of the plants.

Shalis *et al.*, (1996) were among the first workers to recognise the profound influence of vine training and trellising on the light environment within grapevine canopies and the effect of canopy architecture on productivity and berry composition. Very little work was done on the relationship between leaf area density and canopy environment for grapevines and relatively little information is available. A visual assessment to describe the grapevine vigor was used in the form of scoring (Dokoozlian & Kliewer, 1995). Vines with large dense canopies and low interior sunlight were referred to as "high vigor" vines. Those with low leaf area density and high interior sunlight exposure were designated as "low vigor" vines.

The unique features of the canopies under investigation are a 3m spacing between vine rows with orientation of 303° and a factory roof type trellising structure with a south-

westward dip. Adjustments to existing models for the LC consequently had to be made. To be able to relate the LAI to various other plant physiological parameters that were measured over the same period, one must, however, be sure about the validity of LC derived LAI. If a good correlation was to be found, the use of the LC implies a less destructive and less time consuming method for monitoring the impact of saline irrigation water on the phenology of the plant. LAI is also an important parameter in the measurement of transpiration and therefore, needs to be non-destructive in nature. Verification of the LC estimates of LAI, could be made by comparing them with the LAI calculated from measurements of the leaf area on a few shoots per plot, using non-destructive or destructive methods (Grantz & Williams, 1993).

4.2 Theory

The amount of foliage in a vegetative canopy can be deduced from measurements of how quickly radiation is attenuated as it passes through the canopy. By measuring this attenuation at several angles from the zenith, foliage orientation information can also be obtained. The LC measures the attenuation of diffuse sky radiation at five zenith angles simultaneously. The LC projects the image of its nearly hemispheric view onto five detectors arranged in concentric rings (Figure 4.01). Thus if the sensor level is viewing the sky, detector 1 will measure the brightness straight overhead, while detector 5 will measure the brightness of ring centred at 68° zenith angle (22° above the horizon), subtending 13° (LC operating manual, 1992). This method is completely non-destructive. The LC measures the probability of seeing the sky looking up through a vegetative canopy in multiple directions (Figure 4.01). It can also be seen as a reverse point source application. The measurements contain both the foliage amount and foliage orientation.

The method of Campbell (1986), Lang (1992) and Miller (1963) as described on pages 15 and 16 was used to approach LAI with the LC. As a result of the tendency of the LC to underestimate LAI, a correlation was done between a destructive LAI measurement technique and the LC LAI to calibrate LC LAI for specific conditions (Grantz & Williams, 1993). The best correlation was chosen by examining different combinations of the five $K(\theta)$ values.

4.3 Materials and Methods

Materials and methods were discussed fully in section 3.3. Measurements were done on *Vitis vinifera*, L.cv. Colombar grapevines, which are the most common grapevines under irrigation in the Breede River Valley. The experimental site near Robertson consisted of 24 plots, each having 5 rows with 22 vines per row. The 24 plots were randomly divided into 6 treatments with 4 replicates of each treatment. The 10 vines in the centre of the middle row were used to monitor all non-destructive parameters. Destructive measurements were done on plants similar in size and growth vigour from rows adjacent to the experimental row on each plot.

The 6 treatments were (1) canal water $\sim 35 \text{ mSm}^{-1}$ (2) 75 mSm^{-1} , (3) 150 mSm^{-1} , (4) 250 mSm^{-1} , (5) 350 mSm^{-1} and (6) 500 mSm^{-1} . All vines received the same amount of water. Irrigation was scheduled on a weekly basis with a neutron probe and the soil water deficit was replaced (plus a percentage for leaching), as measured on treatment 1. The salinity levels were controlled by a computerised control system that was built locally. The salt stock solution consisted of a mixture of NaCl and CaCl_2 in a 1:1 molar ratio.

A 180° lens cap was used with the LC and measurements were done on the north side of the row, so that the person taking the readings faced south. The sensor therefore was always in the shade of the person taking the readings (Figure 4.02). Setting for a row structure was used in the calculation of the leaf area index.

Since the Robertson region has a low average annual rainfall and is predominantly of a winter rainfall nature, it was decided that measurements had to be made in the morning between 8h30 and 10h30. At this time of day the sunlight falls on the back of the person taking the readings. In the mornings there was less wind and the sky was normally clear. The above-canopy readings or background readings of sky brightness was taken and thereafter the under canopy readings, one at each of the 10 experimental vines. The 10 readings were averaged for each plot. Care was taken to ensure that all readings were taken from the shade of the operator and that the instrument faced the same direction for above and below canopy readings.

Grantz & Williams (1993) found that only the two inner circles of the LC must be used when measuring trellised grapevines (Figure 4.01). This was done by using the

supplied software for the instrument that allows the exclusion of any one or any combination of rings in the calculation of LAI. This method was unsuccessful, as the LCLAI correlation with the destructive measurements were poor. A testing of ring combinations revealed that the three outer rings distinguished best between treatments. This was primarily resulting from the difference in the factory roof-type trellising systems used at the Robertson vineyard and the Perold-type trellising system used by Grantz & Williams (1993) (Burger & Deist, 1981).

To be able to compare the LC readings, destructive measurements of leaf area were also conducted, though not always on the same day as the LC and never on the same plants. Shoots were sampled and the area of the leaves measured with a Licor leaf area meter. The number of shoots per vine were counted and a total leaf area was calculated as

$$\text{LAI} = \text{LA}_s * \text{N}_{\text{sp}} / \text{SA}_p \quad (4.01)$$

with LA_s the leaf area per shoot, N_{sp} the number of shoots per plant and SA_p the soil surface area per plant (4.5m^2). Calculated LAI was then correlated with LC LAI values to establish a model to predict LAI values from LC readings (Pearcy, 1989).

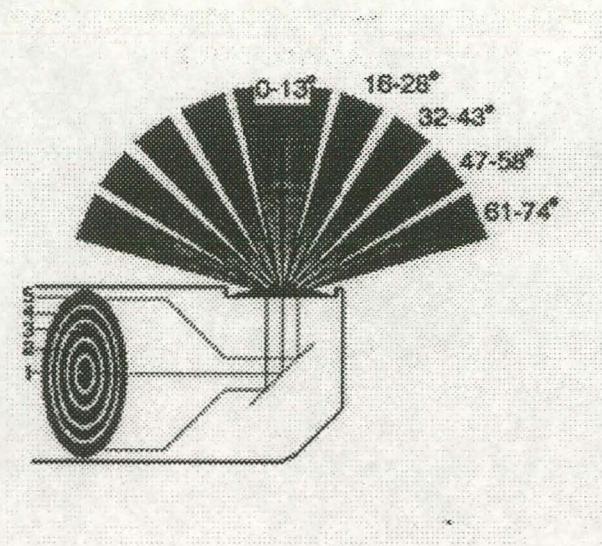


Figure 4.01. Cross section of the Licor C2000 Canopy Analyser's sensor to show the view angles and the projection onto the five concentric light sensitive detectors.

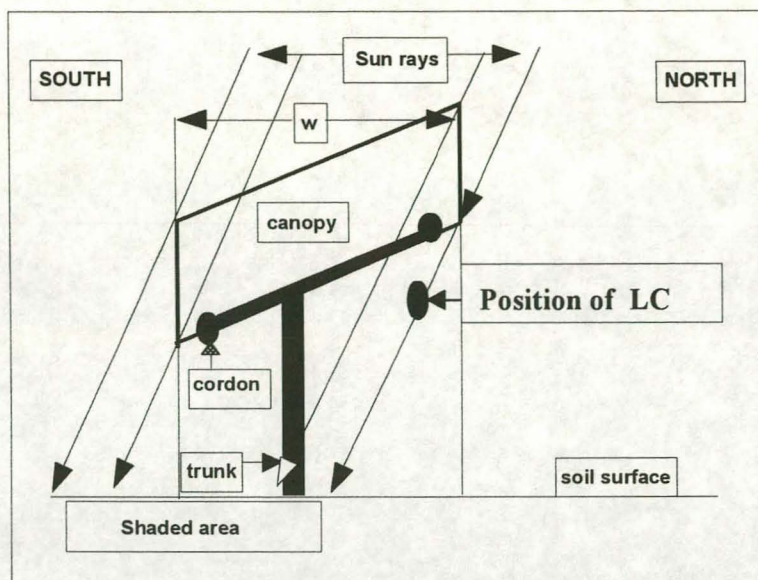


Figure 4.02. Diagram of a cross-sectional view of the vine row indicating the position of measurement.

Leaf area was first correlated with leaf length, which had the added benefit that the same plants could be used to measure both LC derived LAI (LCLAI) and destructively measured LAI (DLAI). Secondly leaf surface of destructively sampled shoots was correlated with shoot length (Figure 4.04).

4.4 Results

In the search for the best possible results from the LC data, various combinations of rings were tested (Figure 4.03). In order to interpret the data correctly, the different development stages of the shoots and leaves is of importance. Special mentioning must be made of the fact that during shoot development, shoots may reach a stage along the season when they become too long and heavy, then fall over, and hang from the cordon. This changes the interpretation of LC derived LAI dramatically. This time of falling over was never reached in the higher saline treatments as the shoot growth was inhibited more with increased salinity. As shoots fell over and started climbing it resulted in a flat canopy structure with a larger gap fraction to the vertical than the situation where shoots remained upright. Therefore to take the vertical, or the inner circles of the LC into account will not at all represent the truth. It was therefore better to concentrate on the outer circles of the LC as this represented vigour better in the more horizontal trellising systems (Figure 4.01 & 4.03). The results in Figure 4.03 showed that when rings 1 and 2 were used, the lower EC_i treatments also had lower

LAI. When rings 3, 4 and 5 were combined the treatment effects showed the best result.

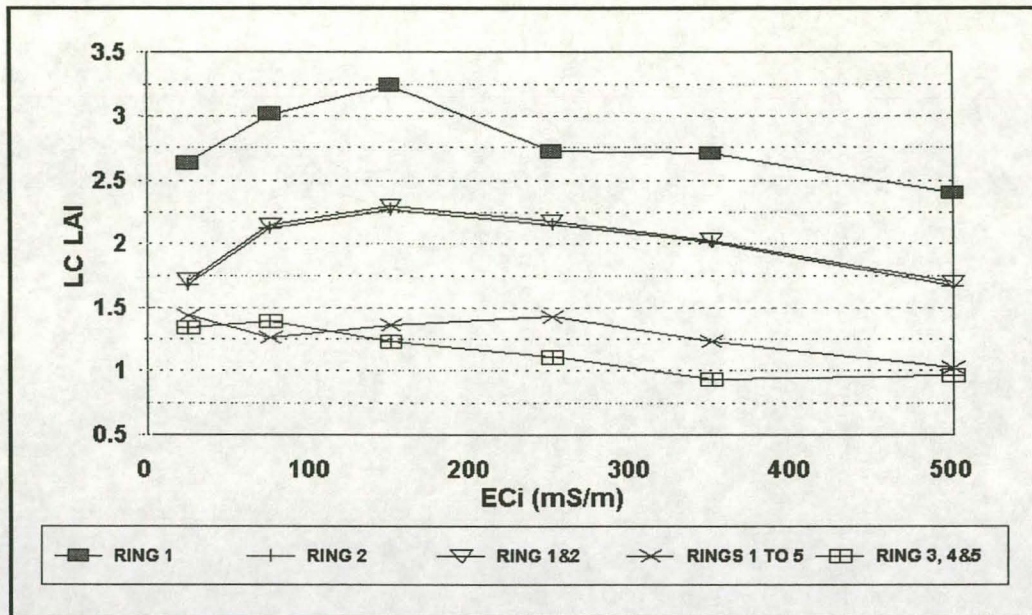


Figure 4.03. A comparison between LAI derived from different ring combinations of the LC.

A correlation between shoot length and leaf area was done (Figure 4.04). This result had the largest effect on the LCLAI of the higher mSm^{-1} treatments (Figure 4.03 & 4.05). The regression between shoot length and leaf area produced the following result:

$$\text{Leaf Area (cm}^2\text{)} = 2.1276 \times \text{Shoot length (mm)} \quad R^2 = 94,4\% \quad (4.02)$$

From Figure 4.06 it is evident that during the initial growth stage up to day 50, it was not worth trying to measure LAI to compare them for treatment effects. During this initial stage shoots of the higher saline treatments develop slightly faster up to day of season 50, a phenomenon that is still not clear. In most cases after day 50, the higher the treatment, the shorter the shoots and the smaller the leaves become, and the higher the incidences of leaf drop later in the season (Figure 4.06). Figure 4.06 therefore combined the trend of the raw data of D LAI and LC LAI after day 50.

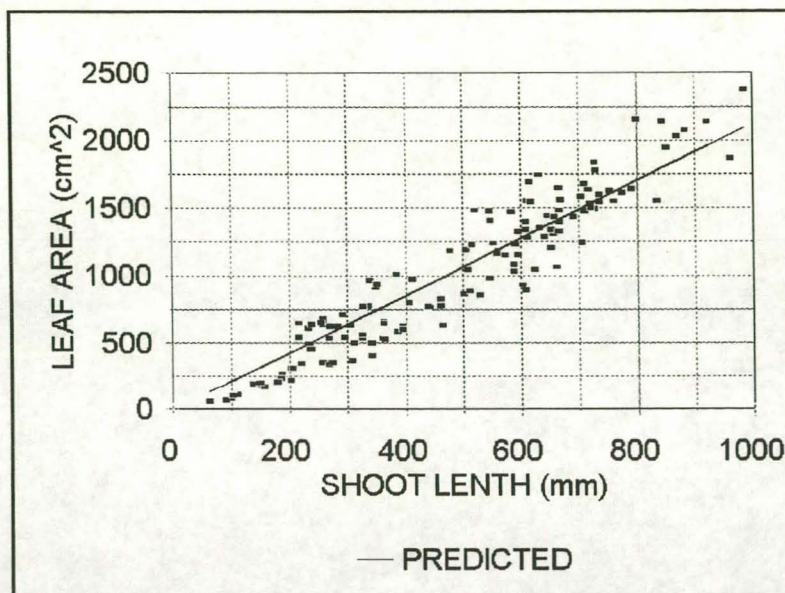


Figure 4.04. A correlation between shoot length and leaf area of samples taken over the 6 treatments.

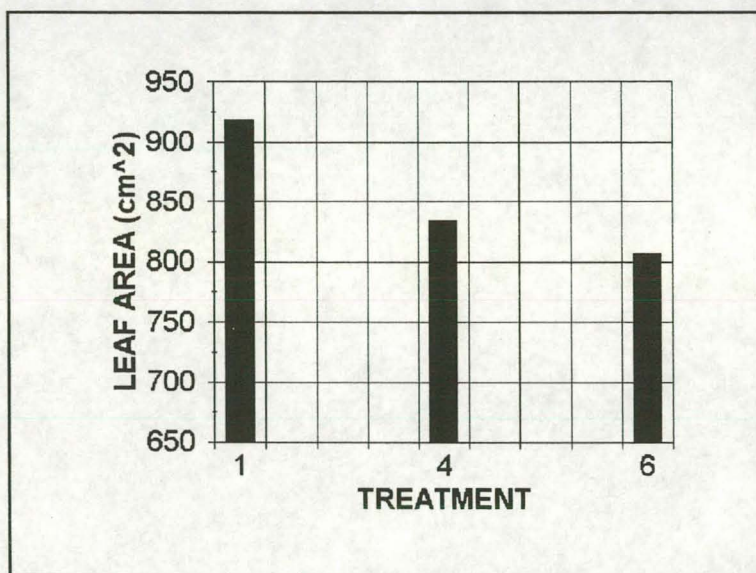


Figure 4.05. Averaged leaf area per shoot of the three treatments used to calibrate the LC.

Lastly D LAI of the 3 treatments combined was correlated with the similar LC LAI. The distribution over all the treatments was not that good, mainly because of the two time series that did not correspond. The regression was therefore poor. Regressions were done between individual treatments and produced a far better result. This was done by linear smoothing of the data (Figure 4.06). Regressions of the smoothed data produced the following equations:

$$\text{TRM 1: D LAI} = 2,7986 * \text{LC LAI} + 9,5 \quad (4.03)$$

$$\text{TRM 4: D LAI} = -0,86387 * \text{LC LAI} + 11,342 \quad (4.04)$$

$$\text{TRM 6: D LAI} = -0,06924 * \text{LC LAI} + 9,6847 \quad (4.05)$$

These equations proved to be adequate for interpretation of all LC data and provided an easy way of interpreting LC data for this irrigation project very accurately.

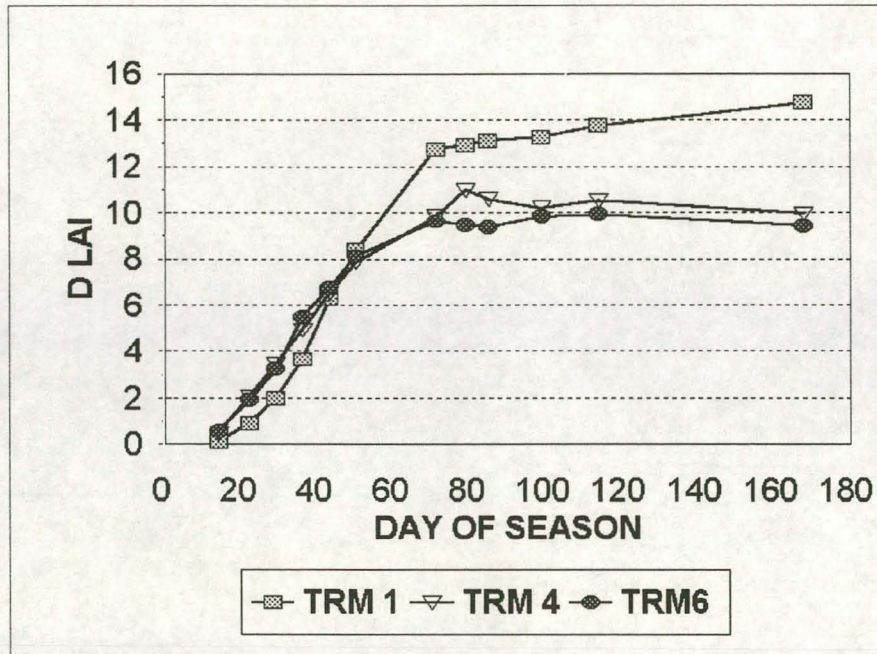
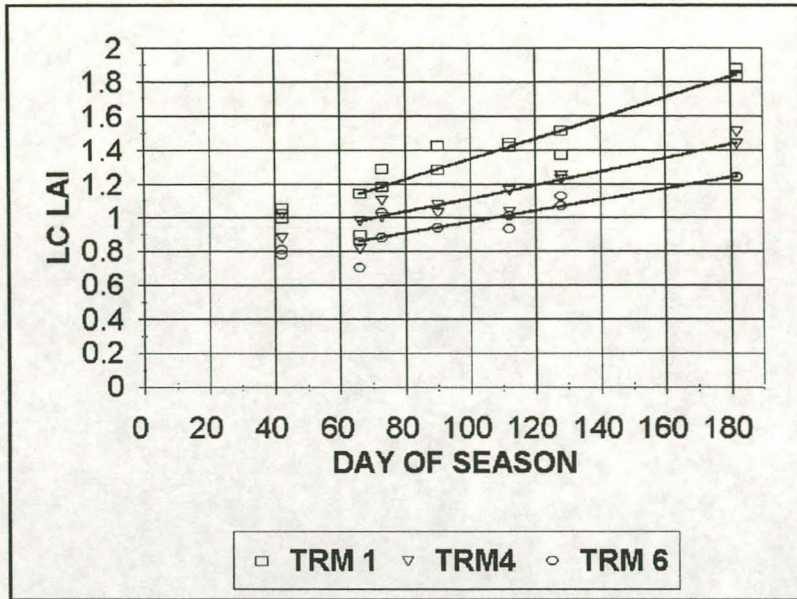
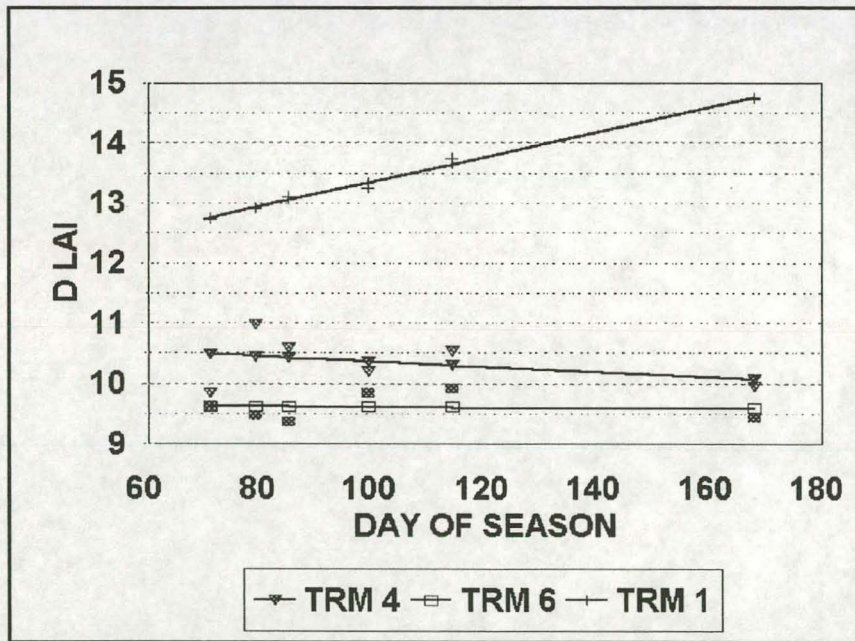


Figure 4.06. LAI calculated from destructive measurements for treatments 1, 4 and 6 over the whole season.



(a)



(b)

Figure 4.07. (a) LCLAI predicted from DLAI and (b) DLAI predicted from LCLAI, for treatments 1, 4 and 6.

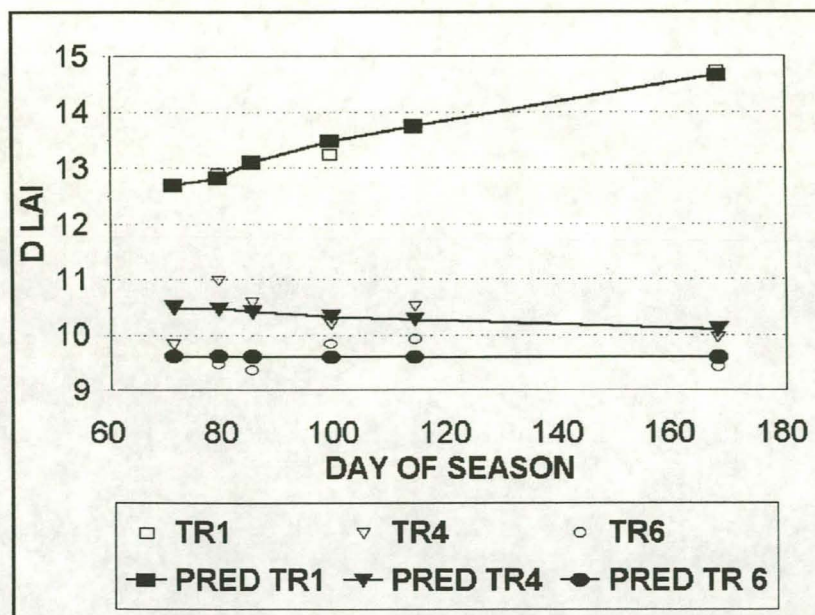


Figure 4.08. DLAI was predicted from LCLAI and is given by the lines

4.5 Conclusion

Three of the treatments namely 35mSm^{-1} , 250mSm^{-1} and 500mSm^{-1} were used to test the applicability of the LC as an instrument to determine LAI. The LAI was used to compare differences in plant reaction amongst treatments.

From Figure 4.08 it is evident that DLAI could be accurately predicted for all three treatments tested. It is only in the lower treatments that constant growth was experienced over the season. This is in accordance with Figure 4.03, rings 3 to 5. It is also in accordance with the averaged shoot length data presented in Figure 4.04 & 4.05.

The LC, therefore, proved to be of no value up to day of season 50 to distinguish between treatments. Secondly the LC initially with all 5 rings taken into account disguised the true trend in the data. Thirdly the LC constantly underestimated LAI.

The good relationship between leaf area per shoot and shoot length of all data over the season implied that leaf drop as a result of saline irrigation did not play a large roll in these measurements. The main effect of saline irrigation is that it caused the shoots to be shorter and leaves to be smaller. It therefore also had an effect on bunches in the same way.

4.6 References

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CHAPTER 5

INITIAL RESULTS OF THE EFFECT OF LEAF AREA ON TRANSPIRATION IN A SALT STRESS EXPERIMENT ON RIESLING.

The transpiration rate of Weisser Riesling grapevines was determined by using a heat balance technique. The aim of the study was to test the differences in transpiration rate between vines that received only rain and fresh water as opposed to those that received rain and irrigation water with an EC of 500 mSm^{-1} . The study was repeated by using 4 different vines, two in each treatment. The study was also done to test the effect of canopy size on transpiration rate as well as soil moisture conditions and soil EC_e .

5.1 Introduction

Due to the increased deterioration of the irrigation water quality in the Western Cape, farmers will increasingly have to rely on poorer quality water. An experiment was therefore started in 1995 at the Nietvoorbij Experimental farm near Stellenbosch where *Vitis vinifera* Weisser Riesling grapevines were subjected to saline irrigation water. The main aim of the experiment was to test and describe plant reaction to saline irrigation water in a region where only supplementary irrigation was needed. Six different treatments were applied namely, fresh water, 75, 150, 250, 350 and 500 mSm^{-1} . However, the heat energy balance technique to determine transpiration rates, was tested in treatment one and six only, i.e. fresh water and 500 mSm^{-1} .

5.2 Theory

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

The apparatus used for these measurements was a Dynamax sap flow meter. The use of the Dynamax system does not go without problems as was shown by Savagé *et al.*, (1993), Smith & Allen (1996), Shackel *et al.*, (1992) and Khan *et al.*, (1995) amongst others. The method was first described by Vieweg & Ziegler, (1960) and later Sakuratani, (1984). Savage (1993) gave a good description of the theory and the

method used on *Eucalyptus grandis*. The Dynamax system consists mainly of a data logger, an advanced power supply unit, cables, sensors and software. The sensors consist of a heater embedded in a thin sheet of cork with a pair of copper-constantan thermocouples placed above and below the heater.

Savage *et al.*, (1993) used of the heat energy flux terms E_{radial} , E_{upper} , E_{lower} , E_{heater} and E_{sap} to formulate the balance equation:

$$E_{\text{sap}} = E_{\text{heater}} - E_{\text{radial}} - E_{\text{upper}} - E_{\text{lower}} \quad (5.01)$$

where E_{sap} is the convective component due to sap flow, E_{heater} is the known amount of energy applied, E_{radial} is the radial heat loss E_{upper} is the downstream stem temperature and E_{lower} is the upstream temperature.

Each of these terms can be calculated, except for E_{sap} that has to be calculated *in situ*. E_{heater} is calculated from electrical resistance of the heater and the voltage supplied to the heater. E_{radial} is measured by a thermopile around the heater and corresponds to the integrated temperature around the heater. E_{upper} the vertical upward conductive heat is calculated in terms of Fick's Law which takes the thermal conductance of the stem into account as well as the cross sectional area of the stem. E_{lower} is the vertically downward stem surface temperature gradients just below the heater and is also calculated in terms of Fick's Law, where the stem thermal conductivity as well as the cross sectional area of the stem is taken into account.

The gauge thermal conductance, K_{gauge} , was determined in two ways. Firstly the gauge was mounted on a wooden dowel rod and secondly, the gauge was mounted on the stem of the vine and determined under low evaporative conditions. Incorrect K_{gauge} values may result in non-zero E_{sap} values. The supplied software can correct this, once the gauge is installed.

Certain technique assumptions were made:

1. Steady state conditions had to prevail. Thermal insulation of the sensors and the heater is therefore a necessary requirement.
2. K_{gauge} had to be calculated under conditions of zero mass flow rate.

The technique is based upon the fact that all energy fluxes account for E_{heater} . Therefore heat energy flux not part of E_{upper} or E_{lower} or E_{radial} must automatically contribute to

E_{sap} . These energy fluxes could possibly be undetected or were already included in the temperature differentials used to calculate E-values. Another disadvantage of the technique was that different diameter vines required different diameter gauges.

Savage (1997) devised additional methods whereby all energy surrounding these measuring point could be accounted for. These methods were not reported by other writers in the field and are not mentioned in the Dynamax sap flow meter manual. Savage (1997) used double-sided mirror tape to insulate all electrical connections. He also used extra tinfoil, which was mounted, over large sections of the stem and the sensor. The tinfoil acted as a shield that cuts out all sunlight and irrigation water as both could potentially interfered with the energy balance. Little holes made in the outer tin foil shield allowed for wind flow. The shield also protected the base of the stem, below the sensor, from direct sunlight throughout the day, therefore, minimising differential temperature effects.

5.3 Materials and Methods

Materials and methods were discussed in full in section 3.3 and 4.3. Specific materials and methods that have direct bearing on this part of the study were included here. This section must therefore be read together with sections 3.3 and 4.3.

The location for the research was at the Nietvoorbij Experimental farm near Stellenbosch. The 0.6 ha site consisted of 24 plots which were divided into 6 treatments with 4 replicates. Each plot consisted of 6 rows with 10 vines per row. The 8 vines in the middle of the plot were used as the experimental plants. The vines were trained to a Lengthened Perold system (Zeeman, 1981). No destructive measurements were conducted on experimental plants. For this paper, however, only two sites were used and of that only 4 vines, two per treatment. One plot was of treatment 1, i.e. ~ 40 mSm^{-1} and the other of treatment 6, i.e. 500 mSm^{-1} . All plots received the same amount of water during the season. Irrigation events were only supplementary irrigation and amounted to 3 events per season.

The main parameters measured in this study were soil water content, electrical conductivity of the saturation extract (EC_e), transpiration, weather and canopy parameters. Transpiration was measured by using the Dynamax heat energy balance system and the software supplied was used to calculate transpiration. Soil moisture

was measured using a CPN neutron probe. A MCS weather station was used to monitor wet and dry bulb temperature, radiation, rainfall, wind speed and wind direction. The canopy characteristics were measured by determining average leaf size per shoot, number of leaves per shoot, number of shoots per plant. The LAI was also determined with a LICOR C2000 Canopy Analyser (LC) (Dokoozlian *et al.*, 1995; Reynolds *et al.*, 1994).

The weather data from a MCS-weather station was used to approach the hourly and daily evapotranspiration according to the Penman-Monteith equation. The logger recorded the data every minute and then averaged and logged every hour. The weather station was situated at the edge of the vineyard, about 50m away from the site where transpiration measurements were done.

Soil samples were taken using a Thompson auger at depths 0-0,15m, 0,15-0,3m, 0,3-0,6m, 0,6-0,9m and 0,9-1,2m. The saturated water extracts of the soil samples were tested for EC_e and the concentration of Na, Ca, Mg and Cl. The sodium absorption ratio (SAR) was calculated with the following Equation (5.02) in mmol_ckg⁻¹:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{(\text{Ca} + \text{Mg})}{2}}} \quad (5.02)$$

Transpiration measurements were done on woody stems under field conditions. The method as first described by Sakuratani (1984) and later by amongst other, Savage *et al.*, (1993) was applied. The Dynamax heat energy balance system made use of a CR10X data logger. Standard sensors were used for measurements of which the stem diameter could vary between 24mm and 32mm. The sensors were installed in the middle of the stem, as this is the only section that had minimal deformities. The heater and the thermocouples were placed in contact with the stem. To ensure the best possible contact, the stem was stripped of all loose bark and sanded to get a smooth surface close to the cambrium. A heat conductive paste was first applied to the stem and then covered with thin plastic film. The heater and thermocouples were insulated with white closed cell rubber foam as supplied by the manufacturer. This in turn was covered with a thick reflective aluminium sheet. A second aluminium foil layer was applied over the whole sensor to further minimise the effect of radiation and wind. The aluminium shield was large enough to shade the lower part of the stem from direct sun.

All connections in the wiring were insulated with double-sided mirror tape. A 12V rechargeable battery was used on site and was charged from a 12V-transformer charger, which was situated at the closest power point 50m away. The battery was connected to the charger *via* a 50m lead.

The logger was programmed to sample every 15 seconds and then logged the averaged value every 30 minutes. The memory capacity of the logger was sufficient to log for a week. The accumulated data on the logger was downloaded to a portable computer via the supplied optically isolated serial interface (Campbell Scientific SC32A). The portable computer was also used in the field and laboratory to determine K_{gauge} values, and in the field to set the correct heater voltage levels.

Every possible precaution was taken to prevent any environmental impact on the transpiration measurements. Shackel *et al.*, (1992) recorded that environmental temperature changes may be large enough to cause temperature differentials in the stem. In this study where two vines from different treatments were tested simultaneously differential temperature effects, if present, would have effected both vines in an equal way. The aim of this study was to measure differences in transpiration rates between the two vines of different treatment, but under similar conditions.

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

Because of the good correlation between shoot length and leaf area as well as shoot length and the LC derived LAI, shoot length data gave the best approximation of the LAI. It was also possible to model the leaf area very accurately by making use of the 2nd order equation derived from the variation of leaf length/size from the base of the shoot to the apex. This resulted in a statistical method whereby the leaf surface of a shoot could be very accurately determined. To predict the leaf surface, all that was required was the leaf length/area of the base leaf, the leaf length/area of the largest leaf with its serial number as a (x,y) pair (is also the turning point) and lastly the number of leaves on the shoot. Side shoots were treated in exactly the same manner. The advantage of this method was that minimal disturbance was done to the canopy.

5.4 Results and discussion.

5.4.1 LAI determined with the LC.

The LC was used at first to determine the LAI of the vines used to determine transpiration. This instrument constantly underestimated the LAI when directly compared with the destructively determined LAI, and the data had to be corrected. It was then decided to find a way of measuring LAI of the plants that were going to be monitored directly. It was then decided to model leaf area from physical measurements like leaf length.

The LCLAI was therefore found to be too insensitive for vines trained to this specific type of trellising system. LAI measurements correlated very well with the width measurements of the vines (over the row), which suggested that the canopies was too dense for any light to fall through and the only dimensional parameter measured with the LC was in fact only the width of the plant. It is standard practice with this type of trellising system to bundle the shoots together between the side wires of the trellising system. A very dense canopy and a artificial width is therefore created that cannot be modelled with the LC.

5.4.2 Leaf length to surface conversion and leaf area modelling.

Though every effort was made to calibrate the LC for use under the above-mentioned circumstances where accurate leaf area measurements are needed, it failed to produce a result within the 95% confidence limits. Such a poor result had the possibility of totally covering the treatment effect on transpiration. For this reason leaf lengths were measured and converted into leaf area. Leaves were sampled over the whole experiment and both leaf length and leaf surface was determined. The following regression equation was determined:

$$\text{Leaf surface (cm}^2\text{)} = 1,36 \times \text{leaf length}^{1,962} \text{ (cm)} \quad R^2 = 0,76 \quad (5.03)$$

Equations for the prediction of leaf length per shoot were also determined from the above. Leaf length, a leaf position from the base of the shoot was modelled into a prediction model where the leaf length of any leaf on the shoot could be predicted. It thus became possible to predict total leaf area per shoot by just measuring the length of the shoot, by counting the number of leaf positions on the shoot and the length of the largest leaf on the shoot. For side shoots the same procedure was followed. This

produced the equations 5.04 and 5.05 for treatments 1 and 6 respectively with P being the serial number of the leaf, counted from the base of the shoot..

$$\text{Tr 1: Leaf length} = 62,0 + 6,9196P - 0,3407P^2 \quad R^2=0,9622 \quad (5.04)$$

$$\text{Tr 6: Leaf length} = 26,3 - 0,21P + P^2 \quad R^2=0,56 \quad (5.05)$$

The poorer R^2 -value of treatment 6 in Equation 5.05, was due to missing leaves and leaves that was necrotic. This data was compared with the direct measurement of total leaf length data that was converted to leaf area, and compared quite well (Figure 5.01).

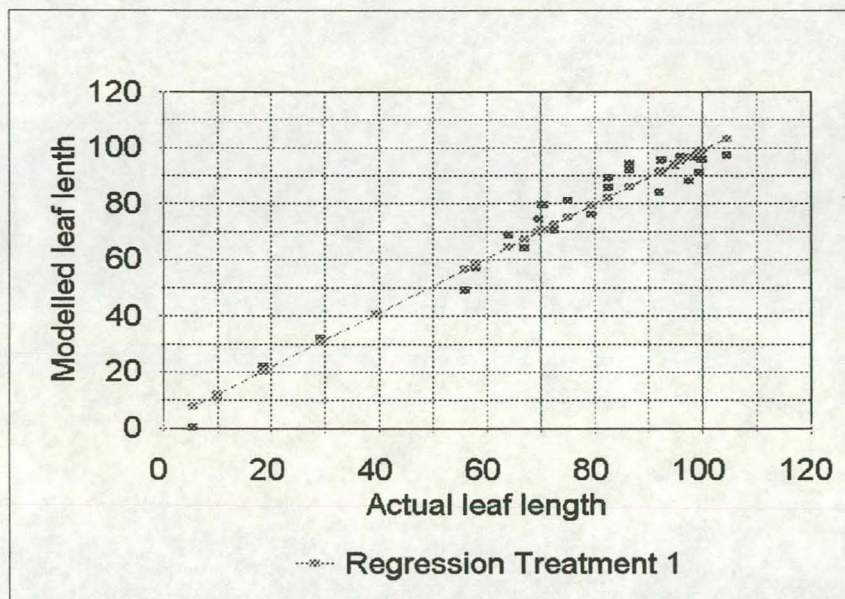


Figure 5.01. The relationship between actual leaf area and modelled leaf area to show the 1:1 relationship of the model that was used to predict total leaf area.

5.4.3 Transpiration measurements.

Transpiration measurements were done on five consecutive days during which there was very little change in the daily weather pattern. Transpiration measurements were first calculated using only total leaf area and not LAI. At first, measurements were done when the soils were very dry. This was followed by an irrigation event during and after which transpiration measurements were done. The topsoil was very dry during the pre-irrigation measurements and its contribution to the evapotranspiration (ET) was very small. Though the soil was wetter after irrigation, the transpiration rate

declined (Figure 5.01) but so also did ET. The data presented here is the averaged data of five days prior to irrigation and five days after irrigation.

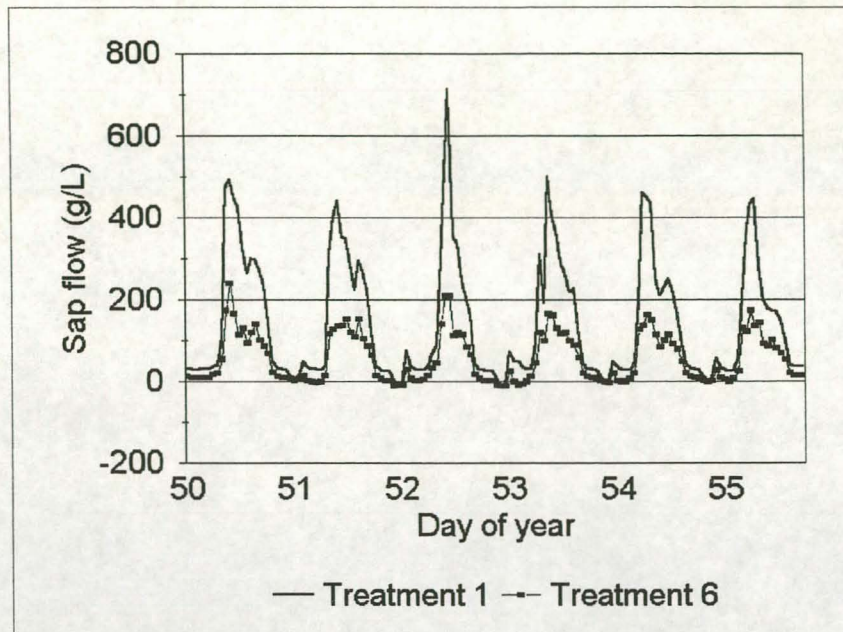


Figure 5.02. Simultaneous measured sap flow rates over 5 days of one vine in the fresh water (Treatment 1) and one in the 500 mSm^{-1} (Treatment 6) irrigation water treatment at Nietvoorbij, Stellenbosch, prior to an irrigation event.

5.4.4 Transpiration and evapotranspiration.

Potential evapotranspiration (ET) was calculated using the Penman-Monteith equation. The data from the logger of the on site weather station was used to calculate hourly ET values (mmh^{-1}). ET was calculated and averaged for the same 5 days before irrigation and after irrigation as the transpiration measurements. These averaged results are presented in Figure 5.03.

It is quite clear from Figure 5.03 that although both ET and T (Dynamax sap flow - transpiration) declined after irrigation, T as percentage of ET increased after irrigation. The relative and absolute values in this respect is given in Table 5.01.

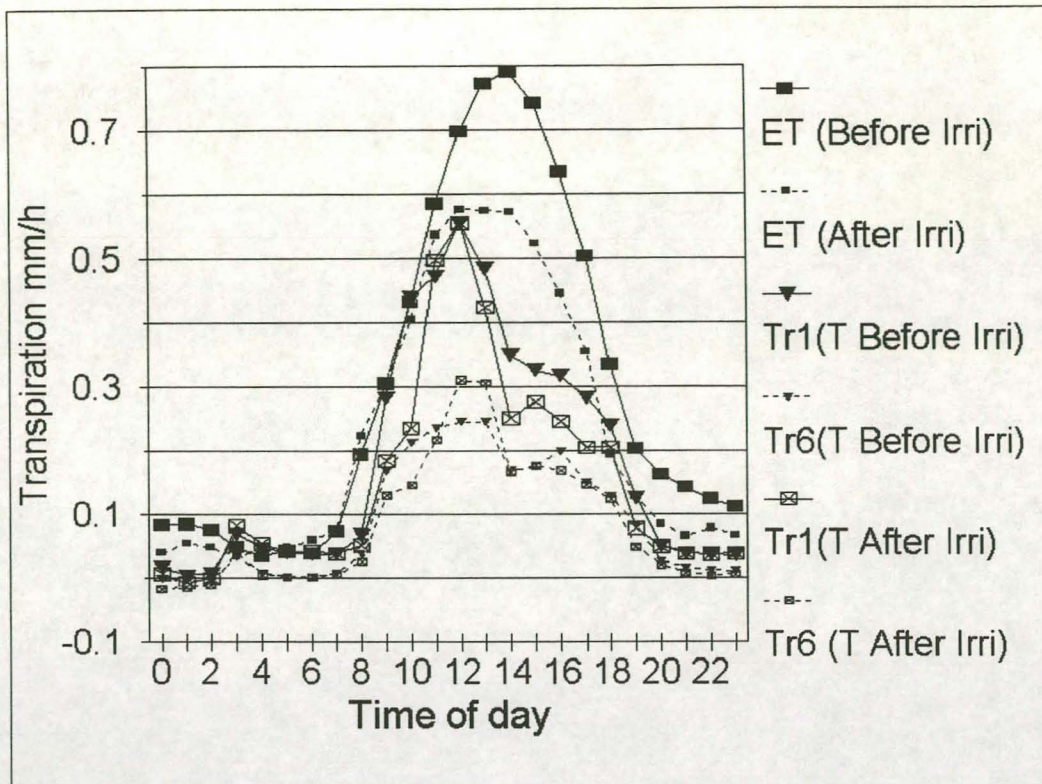


Figure 5.03. Simultaneous ET (weather station) and T (Dynamax sap flow) of two vines, one vine in the fresh water (Tr1) and one in the 500 mSm^{-1} (Tr6) irrigation water treatment at Nietvoorbij, Stellenbosch.

Table 5.01. The relative change in T, ET and soil moisture values of treatments 1 and 6 after irrigation.

		Before irri.	After irri.
T (mm per day)	Treatment 1	4,36	3,62
	Treatment 6	2,16	2,01
ET (mm per day)		7,2	5,5
T as % of ET	Treatment 1	60,4	65,5
	Treatment 6	29,9	36,4
Soil water cont. (mm.m^{-1})	Treatment 1	186,8	238,1
	Treatment 6	170,1	235,8

5.5 Transpiration, SAR and soil moisture conditions.

It was found that the change in soil moisture conditions over the five days before irrigation was too small for the neutron probe to measure correctly. The soil moisture increases after irrigation were however significant and just confirmed that both plants received the same amount of water. Soil samples of the two sites also confirmed the difference in electrical conductivity of the soils water extract (EC_e) and chemical composition of the extract (Table 5.02).

Table 5.02. The EC_e and SAR of the two sites in the Stellenbosch experiment.

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

5.6 Conclusion

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

With transpiration measurements there was no other field method to calibrate or compare transpiration with, other than the weather station and soil moisture depletion data. The transpiration method, if applied correctly, does not need calibration. The method as applied by Savage *et al.*, (1993) is based on the accountability of the total heat flux in the area of measurement. As maximum precautions were taken to account only for energy lost through sap flow, the sap flow rates was accepted to be accurate. The published crop factor for vines during this time of season is 0,4. The estimates of this study from T and ET were 0,42.

The fact that the same method was applied between the fresh water treatment and the 500 mSm⁻¹ treatment makes these findings very relevant. The response of grapevines to salinity and the different water consumption figures over the duration of one day is very clear from this study. The plant reaction after an irrigation event is also very clear. Transpiration rates came down while evaporation rates went up. This means that evaporation from the wet soil surface caused a higher relative humidity and resulted in less transpiration.

Since vines similar in size, leaf colour, overall leaf condition, LAI and soil moisture state were chosen for these measurements, it is quite clear that transpiration measurements are more sensitive to salt stress than what can be deducted from visible

differences in the vine canopies. Leaf area measurements alone can thus not be used as indicators of stress in plants in a management sense. Leaf damage, because of saline irrigation water, is in most cases the cumulative result over the whole season and can not be rectified once it is visible, but can be recorded.

5.7 References

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CHAPTER 6

SUMMARY AND CONCLUSION

From this review presented in chapter 2 it is clear that the total leaf surface of any vine plays a major role in the plant in terms of the water budget of that vine as well as of the immediate surrounding area. There seems to be consensus among writers that stress symptoms shows up visibly in the leaves rather late, with the result that the condition is irreversible within that season. Therefore to simply monitor plant reaction by measuring LAI and to compare LAI among treatments is appropriate but, to use this as an indicator of plant response in a commercial orchard or vineyard, is not. Another approach must therefore be devised and this study showed that transpiration measurements have this sensitivity. It is also possible that near infra red (NIR) optical readings integrated over the whole canopy will have this capability.

From chapter 3, experience gained during the 1992/93 and 1993/94 seasons confirmed the usefulness of the *Sunfleck Ceptometer* as an instrument to measure LAI of row crops such as grapevines. A sound theoretical basis for correcting the Ceptometer data according to row orientation, canopy and trellising structure, time of day and year, was established. A good correlation was found between the adjusted Ceptometer data and LAI measured destructively and non-destructively from the leaves of individual shoots. The instrument was used in the present study to monitor the effect of salinity on canopy development and leaf area. It allowed a great number of measurements to be taken very rapidly.

Based on the experience gained by using the Ceptometer in a vineyard, the following recommendations can be made:

- i) For row structures in an east-west orientation, readings must be taken when the sunrays are perpendicular to the row. For rows in a north-south orientation, a time of day must be secured that were to minimise the effect of neighbouring plants on the readings. The best time to take readings is when the sun angle is at 57 degrees from the horizontal.
- ii) Readings must be taken parallel to the row direction at a constant interval (10-15 cm), so that the whole canopy can be described. This approach has two advantages, namely to be able to successfully interpret point readings and to get an average of a full cross section of the plant row.

- iii) From the time of day readings that were taken, theta values (the zenith angle of the sun) could be determined for use in Equation 2.03. It is therefore important to always log the time and date of all readings.
- iv) The correlation behaviour LG and $LAI_{\text{destructive}}$ must be determined and the regression equation used to calculate $LAI_{\text{ceptometer}}$.

The greater the symmetry of the plant measured, the easier the solution. In the Robertson vineyard, when measuring a vine in a row where neighbouring vines inter grow, the strike of the row presents a problem as to the time of day best suited to take readings. Furthermore, the inclined trellising system in use adds to the problem as it accounts for a rapid enlargement of the shade, as well as the longer path length of the sunrays through the canopy during part of the day. The results are presented in Figure 3.11 and it is clear that the LAI calculated from only one reading per day without some compensation for the time of day will be of no use. A general formula to correct the LAI for any time of day was attempted. The idea was abandoned, as it is quite clear that readings in the afternoon are very sensitive to changes in the sun position (Figure 3.09).

Three of the treatments namely 35mSm^{-1} , 250mSm^{-1} and 500mSm^{-1} were used to test the applicability of the *Licor C2000 canopy Analyser* (LC) as an instrument to determine LAI. The LAI was used to compare differences in plant reaction amongst treatments. From Figure 4.08 it is evident that DLAI could be accurately predicted for all three treatments tested. It is only in the lower treatments that constant growth was experienced over the season. This is in accordance with Figure 4.03, where the results from rings 3 to 5 were used to predict LAI. It is also in accordance with the averaged shoot length data presented in Figure 4.04 & 4.05.

The LC, therefore, proved to be of no value up to day of season 50 to distinguish between treatments. Secondly the LC initially with all 5 rings taken into account disguised the true trend in the data. Thirdly the LC constantly underestimated LAI.

The good relationship between leaf area per shoot and shoot length of all data over the season implied that leaf drop as a result of saline irrigation did not play a large roll in these measurements. The main effect of saline irrigation is that it caused the shoots to be shorter and leaves to be smaller. It therefore also had an effect on bunches in the same way.

In an effort to get a better LAI for the vines that were measured for transpiration, it was necessary to model the leaf area of the vines, since other methods failed to be exact and any change in the canopy dimensions would possibly alter the outcome of transpiration measurements. The reason for the poor LC results was related to the very dense artificial canopy structure that was created. The leaf length-area correlation method worked well; it is more time consuming than remote methods but easier than stripping the plant of all its leaves. It had the benefit that any of the transpiration measurements could be repeated through the season.

With transpiration measurements there was no other field method to calibrate or compare transpiration with, other than the weather station and soil moisture depletion data. The transpiration method, if applied correctly, does not need calibration. The method as applied by Savage *et al.*, (1993) is based on the accountability of the total heat flux in the area of measurement. As maximum precautions were taken into account for possible energy loss at the time of sap flow measurement, the sap flow rates was accepted to be accurate. The published crop factor for vines during this time of season is 0,4. The estimates of this study from T and ET were 0,42.

The fact that the same method was applied between the fresh water treatment and the 500 mSm⁻¹ treatment makes these findings very relevant. The response of grapevines to salinity and the different water consumption figures over the duration of one day is very clear from this study. The plant reaction after an irrigation event is also very clear. Transpiration rates came down while evaporation rates went up. This means that evaporation from the wet soil surface caused a higher relative humidity and resulted in less transpiration.

Since vines similar in size, leaf colour, overall leaf condition, LAI and soil moisture state were chosen for these measurements, it is quite clear that transpiration measurements are more sensitive to salt stress than what can be deducted from visible differences in the vine canopies. Leaf area measurements alone can thus not be used as indicators of stress in plants in a management sense. Leaf damage, because of saline irrigation water, is in most cases the cumulative result over the whole season and can not be rectified once it is visible, but can be recorded.