Optimising productivity and grape composition (grapevine potential) for a specific wine production goal: adaptation of grapevine reproductive/vegetative balance in modified training systems

by

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DECLARATION

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SUMMARY

Provided the current economic context in South Africa, grape producers are being forced to think outside the box and explore and employ new approaches in order to optimize productivity in a sustainable way. Optimum productivity is only achievable once a balanced vine is capable of producing its maximum yield at optimum quality, while keeping input costs (*i.e.* labour) at a minimum. The perception that only low yielding, small vines are capable of producing quality yields contributes to the general reluctance among producers to consider taking actions such as converting existing trellising or training systems to increase vigour and yield.

Three training systems (Smart-Dyson, vertically shoot positioned system (VSP) and a reduced canopy treatment), executed in a *Vitis vinifera* L. cv. Shiraz vineyard located in Stellenbosch were evaluated over the course of three seasons. The purpose was to investigate whether or not the conversion of an existing training system is indeed a viable option to increase productivity in a sustainable way and without negatively impacting on wine quality. In addition to this, the concepts of grapevine balance and compensation were studied to reach scientifically valid conclusions regarding the vine's compensatory reaction to an alteration in its architecture. This investigation was conducted by converting an existing training system to determine whether it is possible for grapevines to reach maximum productivity (yield) without forfeiting quality. The trial vineyard was characterized by high variability in vigour. After assessing vigour according to historical pruning data, grapevines were divided into high and low vigour categories after which conversion to the altered training systems (treatments) were carried out. The layout of this experiment was a completely randomized block design.

Plant and soil water status was monitored, but soil water monitoring was not measured treatment specific, which meant that the exact water requirement on a per treatment basis could not accurately be determined. Vegetative and reproductive measurements were conducted over all three seasons. Pruning and yield data was collected and the yield:pruning mass ratios were determined and compared between the various treatments. Vegetative measurements included primary shoot growth tempo and length, total lateral shoot length, total primary leaf area, total lateral leaf area and total leaf area per vine. In general, a progressive increase in vegetative growth was observed in all treatments as the trial progressed. All the Smart-Dyson treatments displayed a steady increase in yield over the course of the trial.

Starting before véraison, berry sampling took place weekly and berry composition was analysed in order to determine ripening progression. Wines from each individual treatment of each season's harvest were prepared, and the wines made during the first two seasons evaluated by means of qualitative descriptive analysis (QDA). Results obtained from QDA, indicated that no negative parameters were associated with any treatments, thus the conversion effect and increase in vegetative growth and yield had no substantial influence on composition. Instead, all indications were that wine style rather than wine quality was influenced. It was concluded that seasonal effects played a substantial role in the difference in wine styles between seasons. The conversion effect

itself played a relatively smaller role when considering that no significant differences in wine attributes between treatments and controls were detected.

The decision to modify existing training systems to accommodate larger vigour and increased production is an option that can be seriously considered, since this trial has proven that actions that increase yield do not necessarily mean that quality has to be forfeited.

OPSOMMING

Gegewe die huidige ekonomiese konteks in Suid-Afrika, word druifprodusente daartoe gedwing om buite die boks te dink en nuwe benaderings te verken en toe te pas, ten einde produktiwiteit te optimaliseer op ŉ volhoubare wyse. Optimale produktiwiteit is slegs haalbaar wanneer ŉ gebalanseerde wingerdstok daartoe in staat is om die maksimum opbrengs teen optimale kwaliteit te produseer, terwyl arbeidskostes en -insette tot ŉ minimum beperk word. Die persepsie dat slegs klein wingerdstokke met lae opbrengste kwaliteit druiwe kan lewer, dra by tot die algemene aarseling onder produsente om aksies te neem soos die omskakeling van bestaande prieel- of opleistelsels, wat sal lei tot ŉ toename in groeikrag en opbrengs.

Drie opleistelsels (Smart-Dyson, vertikale lootposisionering sisteem (VSP) en ŉ gereduseerde lower behandeling), uitgevoer in ŉ *Vitis vinifera* L. cv. Shiraz wingerd in Stellenbosch is geevalueer oor die verloop van drie seisoene. Die doelwit was om ondersoek in te stel na of die omskakeling van ŉ bestaande opleistelsel daadwerklik ŉ lewensvatbare opsie is om produktiwiteit te optimaliseer op ŉ volhoubare wyse, sonder om wynkwaliteit negatief te beïnvloed. Hiermee saam, is die konsepte van wingerdbalans en -kompensasie bestudeer om tot wetenskaplik grondige gevolgtrekkings te kom rakende die wingerdstok se kompensasie reaksie op ŉ verandering in argitektuur. Hierdie ondersoek was ingestel deur die omskakeling van ŉ bestaande opleistelsel om te bepaal of dit moontlik is vir druiwestokke om optimale produktiwiteit (opbrengs) te realiseer sonder om kwaliteit in te boet. Die proef wingerd was gekenmerk deur ŉ hoë variasie in groeikrag. Nadat groeikrag geassesseer is volgens historiese data, is druiwestokke verdeel in hoë en lae groeikrag kategorieë, waarna die omskakeling na die alternatiewe opleistelsels (behandelings) uitgevoer is. Die uitleg van hierdie proef was ŉ totale ewekansige blok ontwerp.

Plant- en grondwater status was gemonitor, maar grondwater monitering was nie spesifiek volgens behandelings gemeet nie, wat daartoe gelei het dat die presiese water behoefte op ŉ per-behandeling basis nie akkuraat bepaal kon word nie. Vegetatiewe en reproduktiewe metings was uitgevoer oor al drie seisoene. Snoei- en opbrengsdata was ingesamel en die opbrengs:snoeimassa verhouding was bepaal en vergelyk tussen die verskeie behandelings. Vegetatiewe metings het ingesluit die groeitempo en lengte van hooflote, totale syloot lengte, totale hoofloot blaaroppervlakte, totale syloot blaaroppervlakte en totale blaaroppervlakte per stok. Oor die algemeen was ŉ progressiewe toename in vegetatiewe groei waargeneem in alle behandelings met die verloop van die proef. Alle Smart-Dyson behandelings het ŉ geleidelike toename in opbrengs getoon met die verloop van die proef.

Monsterneming van korrels het reeds begin voor deurslaan en is weekliks uitgevoer, waartydens korrel samestelling geanaliseer is om die verloop van rypwording te bepaal. Tydens elkeen van die seisoene is wyne van elke individuele behandeling voorberei, en die wyne geproduseer tydens die eerste twee seisoene was geëvalueer deur die gebruik van kwalitatiewe beskrywende analise (“qualitative descriptive” analysis of “QDA”). Resultate verkry vanaf QDA het aangedui dat geen negatiewe parameters geassosieer was met enige behandelings nie, dus het die omskakelingseffek

en toename in vegetatiewe groei en opbrengs geen noemenswaardige invloed op wynkwaliteit gehad nie. Inteendeel, alle aanduidings was dat wynstyl eerder as wynkwaliteit beïnvloed was. Daar is tot die gevolgtrekking gekom dat seisoenale effekte ʼn groot rol gespeel het in die verskil in wynstyle tussen seisoene. Die omskakelingseffek self het ʼn relatiewe klein rol gespeel wanneer daar in gedagte gehou word dat geen noemenswaardige verskille in wyneienskappe tussen die behandelings en die kontroles waargeneem is nie.

Die besluit om ʼn bestaande opleistelsel te modifiseer om groter groeikrag en ʼn toename in produksie te akkommodeer, is ʼn opsie wat ernstig oorweeg kan word, aangesien hierdie proef bewys het dat aksies wat lei tot ʼn toename in opbrengs nie noodwendig beteken dat kwaliteit ingeboet moet word nie.

This thesis is dedicated to my family and especially my children

BIOGRAPHICAL SKETCH

Anneli Bosman was born in Cape Town on 3 December 1977. She matriculated at Waterkloof High School in 1995. Anneli enrolled at Stellenbosch University in 1996 and obtained the degree BScAgric in Viticulture and Oenology in December 2000. She then enrolled for the MScAgric in Viticulture degree in 2012 at Stellenbosch University.

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PREFACE

This thesis is presented as a compilation of four chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Enology and Viticulture.

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Chapter 4: General conclusions and recommendations

Chapter 1

GENERAL INTRODUCTION AND PROJECT AIMS

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1.1 Introduction

The current economic context in South Africa forces producers to maximise yield while maintaining optimum quality aimed at a specific production goal and price point. Certain vineyards perform sub-optimally for various reasons. This is to be expected since several long- and short-term practices interact with environmental factors to realise or suppress the genetic potential of the scion-rootstock combination. One of the aspects adding to the problem of sub-optimal grapevine performance is that the perception still exists that "quality" grapes can only be produced from small, low-yielding vines. However, in the current economic climate it is not sustainable to only produce in small quantities. VINPRO's 2017/2018 cost guide indicates that annual total production costs for the viticulture industry (excluding dry land vineyards) increased with 7% from R44 390 per hectare in 2016 to R47 513 per hectare in 2017. If the period from 2008 to 2017 is considered, production costs doubled. The production costs can be divided into two sections, namely cash expenditure and provision for renewal. Tax, entrepreneurial obligations and interest are all omitted in this calculation. Total cash expenditure, including all direct costs such as labour, mechanisation and other general expenses has increased by 7% from R34 047 in 2016, to R36 554 in the 2017 production year. The main reasons for the increase in production costs can partly be attributed to the weak ZAR during that stage, plus the 13% annual increases in the cost of chemical sprays. Provision for renewal showed a 6% increase from 2016 to 2017, amounting to a total of R10 959/ha in 2017. Primary producers have very limited control over the increasing of costs. Furthermore, the larger than predicted harvest in 2017 led to the need for more intense input in order to achieve the wine goal that was aimed for (Van Zyl & Van Niekerk, 2017).

Today, many viticulturists and researchers alike believe that balanced grapevines will produce fruit of high quality. If it is assumed that only small vines with low yields will produce high quality fruit and it is a fact that balanced vines produce the best fruit, the question arises as to whether it can be presumed that only small grapevines are balanced. Balance may very well exist on larger grapevines as well, with similar outcomes in terms of grape composition. The very complicated concept of vine balance has been researched and debated, and many researchers and viticulturists have aimed to define this concept, especially in relation to grapevine size and grape quality. Brase (2004) defined vine balance as an attempt to match the quantity of fruit on a grapevine with the amount of canopy in order to produce grapes that will meet the producer's objective. Others such as Chien (2009) described it as a happy medium where a vine grows comfortably in its assigned space and yield fully matured fruit and wood at harvest. Regarding sources and sinks, Carbonneau (1997) proposed that grapevine growth has three aspects, namely reserves, vegetative growth and fruit growth. Vine balance can therefore probably be summarised as a situation where a vine is comfortably able to produce healthy fruit, suitable for a specific price point and production goal, while still maintaining a healthy reserve status, being able to mature wood and store enough carbohydrate reserves for the following season. Provided that basic viticultural principles are respected in order to achieve and maintain vine balance, local producers will be able to venture away from traditional perceptions to explore sustainable viticultural practices that could maximise productivity and lower input costs.

Varying climatic conditions and general heterogeneous soil conditions in South Africa lead to great variability and non-uniform growth within vineyard blocks. This within-block variability regarding vine vigour can occur even if grapevines are the same scion and rootstock cultivar, the same age and managed with a consistent approach (Steyn & Aleixandre-Tudó, 2016). Although uniformity and balance are per definition not one and the same thing, they interact closely. Since a grapevine reflects the conditions under which it is cultivated, a vast number of complex interacting factors including seasonal conditions, soil nutritional status, grapevine reserve status and cultural practices to name but a few, will affect the grapevine balance. These exact same diverse factors will have an impact on the occurrence of within-block variability. The aim of this study was thus to manipulate the vine architecture by altering training systems to optimise both yield and quality for a specific wine target and in the process, strive towards achieving grapevine balance and minimising variability within a vineyard block. It has to be kept in mind that wine quality is a greatly subjective concept, and that the success of any product is more important than its market price.

Effective canopy surface area was increased in order to not only increase grapevine productivity but also to conserve fruit quality. In many cases in the wine industry, trellis and/or training systems are found to be limiting, and canopy extensions are added with different success rates in accommodating vigour. It is a drastic step to convert existing trellis and/or training systems once it has already been established. The alternative being adapting long term decisions such as trellis and/or training systems from the start (at planting). This study was needed to determine at which point this extreme decision of trellis/training system conversion needs to be taken, seen from a production and quality perspective. It is crucial that this decision needs to be economically justified as the only viable sustainable practice or option.

Current production systems (training and trellising systems) are not always dynamically adapted towards the goal of increasing yield as well as fruit quality. However, there are many success stories in the wine industry with regard to trellis and/or training system conversion, and these systems have been tried and tested. For instance, systems such as the Smart-Dyson and the gable trellis system, have proven successful to name but a few (Bosman, 2010). The question remains as to why so many people are still reluctant to make that big mind shift in the direction of converting to a training system that is alternative to the vertical shoot positioning (VSP) training system. The VSP training system is still the major training system used in the wine industry worldwide as well as in South Africa. It has been seen in some cases where alternative training systems have been used successfully in the industry, that these vineyards break even financially up to ten years earlier than vines trained on VSP systems. Some of these examples have been studied and will be discussed to prove that the practical implementation may reap great rewards. Still, even though these systems are already in widespread use in the industry, some scientific principles underlying their execution are not yet well understood and therefore needs to be investigated.

Within-block information on grapevine performance variability may be used to guide decision making in a vineyard. Using this information, it can be determined which vines are optimally balanced in a block with large variability between vines and their vigour and capacity, and the reasons for and effect of this balance can be further investigated.

This study is significant for the South African wine industry, since it aims to prove that various established training and trellising systems can be adapted in order to create balanced growth and yield for the grapevine. This will in turn ensure optimal ripening conditions for crops of a desired size and on a level that is sustainable for the producer.

1.2 Project aims

The purpose of this study was to explain the association between grapevine size, the yield:pruning mass ratio (Ravaz index) (Ravaz, 1911), grapevine balance and canopy conditions in scenarios where the grapevine training system (and thus grapevine balance) had been modified. The ultimate aim was to optimise vineyard yield and product quality through modified grapevine balance and microclimate, and to study some underlying factors that need to be considered when adapting training/trellising systems under different vigour conditions. The question arises as to whether grapevines that differ with regard to higher or lower vigour as measured by pruning mass, but with similar Ravaz indices, as well as with similar leaf and fruit exposure, can produce grapes of similar composition. If that is the case, the limits to achieve this should be explored. Since modified grapevine architecture necessarily leads to a new grapevine balance, it can be assumed or postulated that the grapevine will display a compensation reaction in response to the human interference. This further leads to an investigation into the level and extent of this compensation.

Taking these aspects into account, this project’s objectives can be summarised as:

- *Objective 1 – to modify grapevine balance in an attempt to optimise yield and production quality in a field trial and, furthermore, study the effects of the modification on yield components as well as grape and wine composition.*
- *Objective 2 – to use the within-block information on grapevine performance variability and yield components to study grapevine balance and develop a guide for decision making in a vineyard based on this.*

- *Objective 3 – to study the effects of initial vigour on the training conversion.*

The significance of this study for viticultural research, grape producers as well as the broader South African wine industry is to demonstrate that lower vigour grapevines with smaller yields do not necessarily produce grapes of higher quality than larger or more vigorous grapevines with higher yields. It can be implied that as long as a grapevine is in balance and the limits for yield:pruning mass are determined, realised and not exceeded, grapes of a similar composition can be produced from grapevines of various sizes. This may have a tremendous impact on the economic viability, sustainability and future existence of many struggling grape producers.

Grape producers are still quite hesitant to convert existing training/trellising systems to systems alternative to the traditional VSP systems. This even though extensive experience has been gained in the last few years proving that increased productivity is possible when adhering to the aforementioned steps regarding maintaining vine balance. The traditional VSP system still plays an important and dominant role in the South African wine industry, but it should not be used as a default without discretion. Since each vineyard is unique in its location, terroir, climatic conditions and the production goal, grapevine architecture and canopy management methods should be revisited and diversified in order to link and compliment the production goal and price point, whether it is for icon wines, or to be used for mass production.

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Chapter 2

LITERATURE REVIEW

AN OVERVIEW OF GRAPEVINE BALANCE MODIFICATION THROUGH TRAINING SYSTEM ADAPTATIONS

CHAPTER 2: AN OVERVIEW OF GRAPEVINE BALANCE MODIFICATION THROUGH TRAINING SYSTEM ADAPTATIONS

2.1 Introduction

In order to secure the sustainability of grapevines and increase their productivity whilst keeping expenditure as low as possible, alternative methods for cultivating grapevines need to be investigated. Vines need to be optimally productive, which means that the maximum quantity of grapes of the highest possible quality must be produced. This can only be achieved if the grapevine's photosynthetic capacity is maximised, meaning that the effective leaf surface must be increased.

By applying suitable short-term practices, such as suckering amongst others, an increased effective leaf surface can be achieved to some extent, but more long-term practices, such as choosing the correct trellising- or training system, or converting an existing trellis system should be examined. Trellising system refers to the structure itself – the poles, wires *etc.*; whereas the training system refers to the shape of the grapevine, or its specific architecture, on the trellising system. Reynolds and Vanden Heuvel (2009) state that training a vine realises many purposes. According to them, the exposed leaf area can be manipulated in such a way that the maximum amount of sunlight can be intercepted, and the permanent parts of the vines can be positioned to avoid direct competition between adjacent vines. Therefore, the efficiency of a grapevine canopy, and consequently its productivity, greatly increases when high light interception, and thus distribution of light within the canopy, interrelates with source sink relations and the partitioning of effective dry matter (Poni *et al.*, 2007).

2.2 Modification of grapevine trellising/training systems

A tremendous number of intertwined factors contribute to a grapevine's response to any modification in its structure. Apart from human interference with short- and long-term practices, all cultivation practices should be adapted to suit specific terroirs and climatic conditions, and also to achieve the required wine style and production goal. Once the balance of a grapevine is altered by for example modifying a trellising/training system, the grapevine's self-regulatory response will strive towards correcting the imbalance. This might take place by means of adaptation and/or changing of the factors determining yield, referred to as yield components (A. Davel, personal communication, 2015). Once one or more of the yield components are changed, for example by means of a training system conversion, the level of other yield components will also change due to the grapevine's self-regulatory response (A. Davel, personal communication, 2015). Yield components include amongst others the bud load per grapevine, budburst percentage, fertility as well as bunch size and mass (Zeeman & Archer, 1981).

These factors are set during the current as well as the previous growing season. The choice of the trellising/training system should thus be done judiciously, considering many factors that correlate with one another in order to create balanced vineyards able to be optimally productive (Hunter & Volschenk, 2001). Once grapevine architecture is altered by means of a training system conversion for example, the grapevine will display a compensatory reaction in an attempt to maintain its above-ground/subterranean growth balance (Archer & Strauss, 1991; Hunter, 1998a; Hunter & Volschenk, 2001; Archer & Hunter, 2004). It must be emphasised that productivity should be viewed objectively and within context of the specific scenario, since vineyards that produce low yields of grapes suitable for icon wines can be viewed as being just as productive as vineyards producing high yields, but at a lower price point (Volschenk & Hunter, 2001).

The chosen training system should be the one that satisfies all the aforementioned objectives adequately within the confines of a specific site, cultivar, and climate. It is therefore not surprising that many different training systems are used in different wine regions of the world. Each of these training systems has their own objectives, creating a specific desired grapevine architecture and thus indirectly influencing the canopy microclimate. The various training systems are usually then linked to specific trellising systems. Examples of the related trellising systems include the Geneva double curtain (Shaulis *et al*., 1966), the Lyre (Carbonneau & Huglin, 1982), the Ruakura Twin Two Tier (RT2T) (Smart *et al*., 1990a) and the Scott Henry system (Henry, 1991).

Extensive research has been done by many authors who aimed to evaluate alternative trellising systems that increase effective leaf surface, optimising sunlight interception and improve grape quality. Much of this research involved the investigation into the division of traditional vertical shoot positioning (VSP) systems into lateral or vertical double cordon systems. Modification involves the configuration of a training system in order to create two or more canopies from the original canopy (Reynolds & Vanden Heuvel, 2009). Higher yields, enhanced fruitfulness, improved fruit composition and thus overall improved productivity and quality could be expected from modified systems (Smart *et al.*, 1985a; Smart *et al.,* 1985b).

The aim during a training system conversion by dividing an existing canopy is to extend or double existing cordon space/length whilst restricting root volume. Since a close relationship exists between above-ground and subterranean growth (Archer & Strauss, 1991; Hunter 1998a), the available soil volume will be better utilised by the roots of such converted systems. This is mainly due to an increase in the formation of fine roots (Hunter 1998a). Other authors such as Orlandini *et al*. (2015) compared the VSP trellis system with the Lyre system and concluded that the latter displayed higher whole-plant photosynthesis, and thus more vegetative growth.

Hunter and Volschenk (2001) investigated the response of a Chenin blanc vineyard with a five-strand VSP trellis system to its conversion to two alternative systems – the first converted system involved doubling the original cordon length of vines by removing alternate vines, whereas the other conversion was the Lyre system (Figure 1). These two converted systems were then compared to the five-strand VSP trellis system and each other. In the case where alternate vines where removed, root volume doubled, but with the converted Lyre system, the root volume stayed the same. They reported that converted systems utilised the available soil volume more effectively due to the increase in fine roots. The Lyre system displayed the highest yield:pruning mass ratio when compared to the other treatments. Although the yield on a vertically extended VSP system increased by only 11%, it increased by 65% in the Lyre system (Volschenk & Hunter, 2001). By extending cordon length, the canopy was better accommodated and distributed. This was even more pronounced when the ratio of cordon length to root volume was increased, as was the case with the Lyre system (Hunter & Volschenk, 2001). The Lyre system displayed better canopy efficiency in terms of sunlight utilisation, and therefore also photosynthetic activity (Volschenk & Hunter, 2001). The better utilisation of soil surface area can be ascribed to more balanced growth and improved canopy microclimate. In the case of the Lyre system, balanced growth and improved microclimatic conditions was due to the fact that the growth of the root system compensated by an increase in the development of fine roots, rather than an increase in size (Hunter,1998a).

Figure 1 The Lyre system. By: Tracey L. Kelley Rethinking Trellis Viability in the Age of Mechanization - The Grapevine Magazine

Hunter and Volschenk (2001) concluded that excessive growth can be successfully managed by converting a VSP system to a Lyre system since vegetative growth was diverted to increased reproductive growth leading to a substantial increase in yield. Presumably the increase in effective leaves which serve as sources and provide supporting compounds, as seen in the converted systems, will lead to an increase in root efficiency in order to maintain the root system whilst supporting above-ground growth (Richards, 1983). Therefore, since the canopy microclimate had changed for the better together with an increase in effective leaf area (thus an increase in photosynthetic productivity), it had a positive impact on root efficiency.

However, for the Lyre system to be optimally productive, it must have a uniformly distributed canopy with sufficient sunlight penetration (Volschenk & Hunter, 2001). Adaptation of irrigation scheduling and fertilisation will be necessary to support the enlarged canopy surface, and therefore factors such as soil type and available water must be considered when converting a training system. Another aspect to take into consideration is that the conventional Lyre system is very difficult to mechanise (Matti & Orlandini, 2005).

The Geneva double curtain (GDC) system (Figure 2) is another alternative horizontally-split training system. The shoots are positioned outward and downward to create two distinct canopies and this is crucial to achieving the full potential of the GDC (Shaulis *et al.*, 1966; Zoecklein *et al.*, 2008). Although the GDC was initially developed for Concord (*Vitis labrusca*) and for cultivars with a somewhat more trailing growth habit, the system was later modified worldwide to be implemented on *Vitis vinifera* cultivars (Cargnello, 1982; Cargnello & Lisa, 1982). Extremely high labour inputs are also required in order to curb and control the excessive vegetative growth to achieve optimal sunlight interception - especially in warmer, humid climates where grapevines grow too vigorously (Zoecklein *et al.,* 2008). In such cases, traditional VSP systems may benefit from the division of the canopy since it will reduce the intensity of canopy management practices and may lead to higher yields and improved grape quality.

Similar to the GDC is the vertically and horizontally divided Ruakura Twin Two Tier (RT2T) system which was specifically developed for high soil fertility conditions (Smart *et al.*, 1990a). It differs from the GDC in that its canopy is not only split into two thinner downward positioned canopies, but it is also spread over four cordons - two with shoots positioned upwards and two with shoots positioned downwards. This results in four meters of cordon per meter row spacing (Smart *et al*., 1990b). Research by these authors showed that the RT2T system is able to produce double the yield of standard VSP systems due to its greatly enlarged canopy. It is necessary to avoid any gravimorphic effects where buds positioned higher on a vine tend to grow more vigorously than those nearer to the ground (Smart *et al.*, 1990a; Dry, 2000). The RT2T is able to curb very strong vigour and is therefore recommended on fertile soils with sufficient water.

Figure 2 The Geneva Double Curtain (GDC) system. By: Melissa Hansen Trellis enhances grape quality | Good Fruit Grower

Probably the most well-known vertically divided training system is the Scott-Henry system (SH) (Henry 1991; Smart, 1998; Reynolds & Vanden Heuvel, 2009). In the SH system, all of the shoots of one vine are trained upward, while all of the shoots of the next vine are trained downward. Smart (1998) investigated and evaluated the effectiveness of the SH system and concluded that this system is not only able to produce higher yields without the loss of quality, but that it is also very well suited for mechanical harvesting. Zoecklein *et al.* (2008) also investigated the effectiveness of vertically split-canopy training systems such as the Smart-Dyson (SD) system - a modification of the SH system which has recently became popular in the viticultural areas of the Western Cape. With the SD system, one half of the canopy is positioned upwards, and the other half downwards to one side. Since one thick canopy is divided into two thinner ones, the main aim of the SD system is to improve canopy microclimate and to increase exposed and efficient leaf area. It has also been reported that there can be a slight decrease in canopy temperature in converted grapevines due to an increase in air flow through the canopy (Volschenk & Hunter, 2001). When this system is implemented on vigorous vineyards, it might have a devigorating effect leading to a more balanced grapevine (Coombe & McCarthy, 2000). It is therefore no surprise that the SD system is usually associated with higher productivity – both with regard to quality and quantity (Bosman, 2010).

Figure 3 The Scott-Henry (SH) system. By: Richard Smart & Amaya Atucha The Scott Henry Training System; Easy to Learn, And a Route to Improved Profitability & Wine Quality - The Grapevine Magazine

The Ballerina system is a further modification of the SD system. Whereas the downward positioning of the SD shoots is only to one side, the Ballerina has a combination of both upward and downward pointing shoots to both sides of the cordon to create a vertically divided canopy. The downward positioned shoots of the Ballerina system are trained at an angle of between 45° and 60° to the horizontal, while in the case of the SD system, it is trained strictly vertically (Smart, 1994). This system was initially developed in California where some growers were faced with a dilemma of over vigorous vineyards, but not necessarily possessed the financial means required to convert an existing trellis system (Smart, 1994). The Ballerina system could be easily implemented and was economically worth the while as yield could be increased with minimum capital layout. This system brought about reduced shading in the canopy, promoting fruitfulness and budburst (Smart, 1994).

Although there are many advantages to a divided canopy, as literature has proven, vertical canopy divisions might have a few shortcomings. The upward positioned shoots in the SH system are usually much more vigorous than the downward positioned ones (Henry, 1991). Downward positioned shoots have smaller primary leaves and total leaf area, fewer lateral leaves, a lower number of nodes, shorter shoot length and smaller stem diameter when compared to upward positioned shoots (Kliewer *et al.*, 1989; Henry, 1991; Schubert *et al.*, 1995; Lovisolo & Schubert, 2000; Pisciotta *et al*., 2004; Somkuwar & Ramteke, 2008). In some situations, the ripeness level of grapes in downward orientated shoots may differ to that from upward positioned shoots (Iland *et al.*, 2011). However, in systems such as the SD or Ballerina where the shoots on one vine are positioned both upwards and downwards alternately, these phenomena are not that noticeable (Smart & MacMillan, 2003).

Although the SD system's popularity has increased over the last decade in South Africa, some underlying principles such as an increase in productivity have not yet been studied intensively under local conditions. In industry experiments under South African conditions, Bosman (2010) noted that production can be increased without loss of quality and that this was ascribed to more balanced growth. Even though this system, as with the Scott Henry system, possesses two different fruiting zones exposed to different climatic conditions, he noticed that there is less of a difference in ripening time between these two zones with the SD system.

2.3 Assessment and modification of grapevine training systems

A grapevine can be trained and trellised into a multiple number of forms. Reynolds (2001) stated that a grapevine derives its form and height from the structure (trellising system) on which it grows. By converting or altering existing trellis systems, grapevine architecture (training system) can thus be manipulated in order to reach the intended purpose of the grapes cultivated (Poni *et al.*, 2007). Once grapevine architecture is modified, spatial leaf distribution will inevitably be influenced, which in turn will affect solar radiation interception, light penetration inside the canopy, sun-flecks and overall canopy and vineyard microclimate. It will also affect flower induction, leaf area index, growth of shoots, leaves and clusters, grape maturation and carbohydrate partitioning (Mabrouk *et al*., 1997a; Mabrouk *et al*., 1997b).

The issue, however, is whether any long- or short-term practices, including training, will lead to grapevines reaching their optimal efficiency to intercept and distribute sufficient light throughout the canopy. This is necessary for bud fertility, fruit development and sufficient carbohydrate partitioning between source and sink organs (Roitsch & Ehness, 2000; Vivan *et al.*, 2000). A balance thus needs to be established and maintained between vegetative growth and reproductive growth, and optimal light interception must be achieved since fruitfulness is associated with high light levels in the canopy (Reynolds, 2001).

A thorough assessment of a system requires knowledge of grapevine photosynthesis and grape component metabolism amongst others (Reynolds, 2001; Reynolds & Vanden Heuvel, 2009). Long-term practices such as training systems and plant spacing, as well as short-term practices such as pruning and canopy management, are closely interweaved together affecting canopy architecture and leaf distribution to a great extent. All short- and long-term practices should be adapted to suit specific terroirs and climatic conditions as well as to achieve the required wine style and production goal.

As mentioned before, several factors contribute to a vine's reaction to any modification to its structure as in the case of performing a training system conversion. It is therefore extremely difficult to determine this response ahead of time and there is a risk of ending up with either ineffective or over-dense canopies. Meticulous seasonal viticultural practices are crucial to create conditions favourable to optimal production, but long-term decisions such as converting a training system should be investigated, since this will provide a more sustainable long-term solution (Matii & Orlandini, 2005). The reason for this, according to Carbonneau (1997), is because it plays an important role in the regulation of the equilibrium between vegetative growth and reproductive potential.

2.3.1 Grapevine balance

The source/sink relationship in any grapevine greatly dictates whether it can be regarded as being in balance or not. Organs that produce, store and export carbohydrates are referred to as sources, while the receiving organs are referred to as sinks. The receiving organs utilise these carbohydrates in metabolic reactions, *i.e.* ones that stimulate growth. Organs are not static in their status as either sources or sinks and can serve as either of the two at different phenological stages (Iland *et al.*, 2011).

Grapevine balance can be manipulated and altered in many ways in order to achieve a specific production goal. Whether a grapevine grows vigorously or weakly, the aim must always be to maintain balance and maximise the photosynthetic capacity by increasing the sunlight interception by the canopy. This can only be realised when overshadowing is prevented, as in the case with canopies that are not over dense, and vines that do not compete excessively for space.

Many different authors have attempted to define vine balance and proposed ways in which it can be measured and expressed (Ravaz, 1911). As early as 1911, Ravaz proposed that vine balance can be expressed by the ratio between fruit and wood, or in other words, yield:pruning mass. Partridge (1925) suggested that a balanced vine is one that is able to optimally ripen its crop in time without any detrimental effects on vegetative growth or reserve status. Archer and Strauss (1991) disagreed with this statement to some extent, since the termination of vegetative growth is required during certain stages of fruit development and ripening. Brase (2004) used the context of wine style in his attempt to define grapevine balance when he stated that the yield on a grapevine should match the amount of canopy to produce the desired grape quality for its purpose. The size, structure and management of grapevine destined for premium quality wine may differ vastly when compared to one intended to provide base wine for distilling purposes.

Taking all these definitions into account, grapevine balance can thus basically be defined asthe happy medium where any vine grows without any excessive stress and is able to fully ripen its crop to achieve the desired production goal and in addition still maintaining a healthy reserve status. It has to be emphasised that a grapevine, being a natural creeper, will be predisposed to favour vegetative growth to the detriment of reproductive growth as long as conditions remain favourable (Archer & Hunter, 2004). Therefore, moderate, elastic stress during certain phenological stages can be positive since vegetative growth needs to cease during, for example, the stage of véraison in order for actively growing shoot tips not to compete with fruit ripening (Archer & Strauss, 1991). This remains a challenge for grape producers - managing a vine in order to maintain balance and achieve timely cessation of growth (Archer & Hunter, 2004). Plastic stress refers to a situation where a grapevine is subjected to such severe stress that physiological processes are hampered and it is unable to fully restore its metabolic functions, even once the source of stress is removed. On the other hand, if a grapevine is able to completely reverse the stress applied to it and recover, the stress is referred to as elastic stress (Hunter, 2001).

Since many vineyards in the Western Cape are grown on soils with high potential for viticulture, it is inevitable that excessive vegetative growth might pose a problem in various scenarios. An over-simplistic perception exists that only small-framed, low-yielding grapevines are considered as having the potential to produce icon wines. The question arises: if a vigorously growing grapevine is seen as being "in balance" physiologically, why would it not be able to also produce grapes suitable for producing a wine of a higher price point or even an icon wine? Once a grapevine is in balance, vegetative growth and fruit ripening, together with reserve status, should exist in harmony.

2.3.2 Indices and measurements

Several levels of balance, which could be translated into measurable parameters, are mentioned in literature. Since the majority of authors address vigour, capacity, effective leaf surface, yield and pruning mass in their attempts to define balance, it is necessary to clarify the exact meaning of these concepts. Whereas vigour refers to the ability for a grapevine to initiate and maintain a steady vegetative growth rate, grapevine capacity signifies a grapevine's ability to ripen a certain amount of fruit optimally, while still being able to sustain a healthy reserve status (Jackson, 2008).

The photosynthetic capacity of a grapevine is determined by its effective leaf surface, and this will result in a certain ability of a vine to ripen its wood and produce a given mass of dry material when pruned (Zeeman & Archer, 1981). If the total amount of canes pruned from a specific grapevine during winter is weighed, it then gives an indication of its total pruning mass. Yield refers to the number of grapes per vine that can be fully ripened. Although many parameters have been suggested to define vine balance, there is usually one shortcoming – it has often not been assessed on a per-vine basis.

Various authors differed in their approach to and perception of grapevine balance, resulting in several parameters that can be used to define and measure grapevine balance. Ravaz (1911) suggested that the yield:pruning weight ratio can be used as a means to define balance, whereas Kliewer and Dokoozlian (2005) proposed using a ratio between leaf area and crop mass (yield). It is proposed that another parameter, namely the potential exposed leaf area (SFEp) (Carbonneau, 1995; Carbonneau *et al*., 2000) should also be considered once the focus is on the production of very high-quality grapes (Martinez de Toda *et al*., 2007).

2.3.2.1 Yield:pruning mass

Ravaz (1911) was one of the first authors to attempt defining grapevine balance by suggesting that it could be explained by the ratio between fruit (yield) and wood. Partridge (1925) also suggested that the total mass of pruning canes may serve as an indication of any vine's ability to optimally ripen a certain crop level during the next year. Pruning mass per vine is determined by weighing all the canes per vine at pruning. Since pruning mass is directly related to the reserve status of the vine it will also be a good indicator of the expected growth and capacity in the new season. Consequently, Carbonneau (1997) proposed a complex model incorporating the reserve status of the grapevine to explain vine balance (see section 2.3.1). In order to determine the yield on a per vine basis, the total amount of grapes on a vine can be weighed during harvest. The previous season's pruning mass is then brought into relation with the current season's yield to investigate vine balance as proposed by Ravaz (1911). The larger either of these two components become in relation to the other, the more the balance of the grapevine will be disrupted.

Authors such as Zeeman and Archer (1981) and Zoecklein *et al*. (2008) recommended a yield:pruning mass ratio ranging from 5 to 10 for a grapevine to be balanced, but other authors found that even a range of 4 to 12 might be acceptable (Kliewer & Dokoozlian, 2005). Many factors such as soil potential, the scion/rootstock combination, plant spacing, training systems and climatic factors may actually play a role in determining this range (Bravdo *et al*., 1985a). Usually the higher end of these ratios is preferred in larger vines, but the assumption that a larger vine can ripen a larger crop could be problematic since sunlight exposure levels and interception, and also bud fertility in larger vines may decrease once over shadowing occurs (Pool, 2004).

2.3.2.2 Leaf area/fruit mass ratio (LA/F)

Kliewer and Ough (1970) and Kliewer and Weaver (1971) proposed that the leaf surface to fruit mass (yield) ratio (LA/F) can be used as a parameter to indicate whether a grapevine is balanced. They suggested that 10-14 cm^2 of leaf surface per gram of grapes is optimal and speculated that this ratio is applicable to any grapevine cultivar. In later research done by Kliewer and Dokoozlian (2005) it was established that large discrepancies regarding LA/F values exist with values varying between 7 and 14 cm^2/g grapes produced.

These values may depend on many factors that interact with each other, one of these being bud load. Different levels of bud load could be maintained as long as the maximum bud load per certain leaf area was not exceeded (Kliewer & Ough, 1970). Once this bud load is exceeded, yield components might be disadvantaged (Winkler, 1954), which then inevitably leads to reduced yield and a decrease in fruit quality. However, it cannot be assumed that this is necessarily applicable under all conditions. Cultivars' responses with regard to differences in soil potential, water availability, different pruning and training systems, as well as climatic conditions during the current and previous year, are but some of the many factors that may influence the LA/F values (Iland *et al*., 1993; Kliewer & Dokoozlian, 2005; Jackson, 2008). Sánchez-de-Miguel *et al*. (2010) and Jackson (2008) thus concluded that in order to successfully define grapevine balance, the proportions of exterior, sun exposed leaves must be compared to that of interior, shaded leaves (refer to 2.3.2.3).

Although the LA/F ratio does provide an indication of a grapevine's ability to ripen fruit, it was over simplistically assumed in the past that once leaf area is increased the ability of a grapevine to produce a larger yield increases linearly as well (Winkler, 1958; Jackson, 2008). The grapevine is a complex plant with the ability to compensate, and many other conditions will play a role in ripening fruit, such as conditions in the previous year that may have a significant influence on the current year's crop (Jackson, 2008). Leaf surface as such is not essentially the determining factor of capacity, but that it is rather the amount of leaves that are fully functional and exposed to the sun (Jooste, 1983). So, instead of only focussing on vigour and canopy shape as separate concepts, the focus has shifted to rather studying the interaction between these two components and the influence on the SFEp (Carbonneau, 1995; Carbonneau *et al*., 2000).

2.3.2.3 Potentially exposed leaf area (SFEp)

Although the leaf area index (LAI) can be used effectively in a wide variety of crops to predict crop growth and productivity, its use might be limited when applied to grapevines. This is mainly due to the fact that it provides no information on the exact distribution of a grapevine canopy, thus not keeping in mind its heterogenous spatial distribution (Schultz, 1995; Mabrouk *et al*., 1997a). Therefore, an index was developed specifically for grapevines, namely the SFEp, which can relate the canopy structure to light microclimate (Carbonneau, 1995; Carbonneau, 1997; Carbonneau *et al.*, 2000). The SFEp index estimates the portion of grapevine canopy area which is optimally exposed to sunlight, thus reaching maximum photosynthetic ability, and still contributing largely to the grapevine's ability to build up and store carbohydrate reserves (Carbonneau, 1995; Carbonneau *et al*., 2000). This effective leaf surface can be achieved by altering the canopy structure by positioning and altering the amount of leaves, grapes and shoots in order to manipulate the spatial distribution of the canopy including leaf area, exposure and orientation. However, the SFEp index mainly deals with mean values of a grapevine canopy as a whole (Mabrouk *et al*., 1997a), estimating the average foliage area that is representative of the physiological potential of a canopy but not addressing the microclimatic or morphological potential (Carbonneau *et al*., 2000).

2.3.3 Modifying balance

Archer and Hunter (2004) described five levels of balance, namely balance i) between the left and right cordons, ii) between fine and thick roots, iii) between subterranean and above-ground growth, iv) between shoot growth and yield, and v) between young and old leaves in the canopy. Various long- and short-term viticultural practices may contribute to modifying any of the above-mentioned levels of grapevine balance. Grapevine establishment methods, starting at soil preparation and including the crucial choices of planting method, plant spacing, scion/rootstock combination and training system are all crucial in order to establish a root system of a certain volume. Once any of these practices are altered or modified, it will affect root growth in a specific soil. It is a well-known fact that a concrete relationship exists between above-ground and subterranean growth (Archer & Strauss, 1991; Hunter, 1998a; Archer & Hunter, 2004). Consequently, once there is a change in the root system, it is inevitable that there will be a compensation reaction in above-ground growth. Furthermore, modification of any short-term practices, such as canopy management, pruning, fertilisation and irrigation, will lead to a similar reaction. It is therefore of utmost importance to keep the root:shoot ratio in mind when considering modifying an existing situation, since it will determine whether the long-term effects of a conversion is negative or positive.

In the case of, for example, converting a traditional VSP system to a Lyre system, above-ground growth is doubled, but since the volume of soil available to the roots does not increase, the subterranean growth will undergo a compensatory reaction by increasing its efficiency and density through the formation of more fine roots (Hunter, 1998a; Hunter & Volschenk, 2001).

2.3.3.1 Grapevine establishment, soil preparation and soil management practices

In order to minimise input, and therefore financial expenditures, all long-term practices, including the all-important soil preparation and grapevine establishment, should be planned judiciously. Long-term practices should be complimented by the natural environment (macro- and mesoclimate, terroir, soil type *etc*.) and not be limited by it.

Any practices altering soil environmental conditions should not be approached lightly. Soil manipulation may be able to improve a certain restriction in the soil, but due to the intricate association between the many soil properties (physical, chemical and/or nutritional), the alleviation of one constraint might highlight another (Lanyon *et al*., 2004). It is thus an immensely challenging task to manage soil potential whilst still bearing in mind its interaction with climatic conditions when intending to change grapevine balance. Much research has been done regarding soil preparation and soil properties in the last few decades, especially in South Africa (Saayman & Van Huyssteen, 1980; Van Huyssteen & Weber, 1980; Saayman, 1982). In particular soil depth and method of soil preparation, soil moisture conservation and the influence of organic matter on soil properties are some of the aspects on which the innovative and revolutionary work of South African researchers has focussed.

Since the growth balance between subterranean and above-ground growth is largely determined by the size of the root system, soil preparation is a decisive, crucial practice during which no compromises should be made (Archer & Hunter, 2004). By doing thorough soil preparation, full advantage can be taken of the natural soil depth in order to accommodate, and not limit, root growth and development. Furthermore, the aim of all planting practices should be to create the most favourable conditions for root development and building a strong buffer capacity for the grapevine. A vine with a high buffer capacity created by favourable soil conditions will be able to withstand greater water deficiencies and fluctuations in temperature.

Raath and Saayman (1995) also suggested that practices such as ridging of waterlogged soils may increase soil potential due to better drainage and therefore increased soil volume available to the roots, more favourable mineralisation conditions and thus increased nitrogen (N) release during winter. In addition to this, mulch as a short-term soil management practice has been investigated by authors such as Chan *et al*. (2010). They reported that sites where mulch was added to the soil surface produced higher yields with grapes exhibiting increased berry potassium (K^+) and pH. This can mainly be ascribed to more optimal soil conditions including reduced soil temperatures, less fluctuation in soil temperature, less evaporative water loss and increased water retention ability being brought about by the addition of the mulch (Van Huyssteen & Weber, 1980; Lanyon *et al*., 2004; Chan *et al*., 2010). However, it was recommended by Lanyon *et al*. (2004) that this practice should be applied with care on mainly low yielding vineyards.

2.3.3.2 Vine spacing and trellising/training systems

Vine spacing and trellising systems are closely related in the sense that vine spacing affects subterranean and above-ground growth, and the trellising system support and accommodates this above-ground growth. This in turns then provides the grapevine with the capacity to ripen a certain crop load. Ineffective trellising systems that are not able to accommodate the grapevine's natural growth will lead to an imbalance in the above-ground and subterranean growth since the ratio between fine and thick roots are disturbed (Archer & Strauss, 1991; Hunter, 1998a; Archer & Hunter, 2004). In order to improve production and quality and for a grapevine to adapt to progressive cultural practices and climate change, new training and trellising systems (or the modification of existing systems) need to be examined constantly (Pisciotta *et al*., 2004). Consequently, there is a constant aim towards developing and/or implementing the trellising system most suitable for the scenario as a whole. The system must complement the natural growth of a specific scion/rootstock combination with the chosen spacing in any given environment and not limit it.

Training systems on existing trellising systems can be modified to increase photosynthetic efficiency. By dividing one thick (and sometimes over dense) canopy into two thinner canopies, sunlight exposure, photosynthetic activity and efficiency, bud fertility and flower differentiation can all be increased (Smart *et al.*, 1985a; Smart *et al.,* 1985b; Smart & Robinson, 1991). Examples of such trellising and training systems are mentioned in section 2.2.

The choice of vine spacing is greatly determined by soil potential, which is dictated by the intricate interaction between the soil chemical and physical properties (Richards, 1983; Lanyon *et al*., 2004). Keeping the intended purpose of the grapes in mind, as well as the fact that soil potential will interact closely with climatic conditions, it can be ascertained that an ideal vine spacing exists for each unique situation. Mild competition between adjacent vines (brought about through a specific spacing) may aid in enhancing grape quality, but once a certain threshold is exceeded the effect on productivity may become negative (Casteran *et al.*, 1980). Also, maximum productivity (dry mass per unit area of soil) can only be achieved if a vine is able to intercept the maximum amount of sunlight, leading to optimal photosynthetic capacity (Champagnol, 1982). Only when the ideal plant spacing for a specific situation is applied can a vine intercept the maximum amount of sunlight. Vine establishment is a holistic approach and all the many environmental factors affecting the choice in vine spacing should be considered before making a decision regarding this crucial matter.

In the research done by Hedberg and Raison (1982), the question is asked whether vine training systems can be altered and/or manipulated in order to produce yields of similar size and quality. In asking this question, the authors focused on whether a higher amount of less productive shoots achieved in closer vine spacing might be more productive than fewer, but more fruitful shoots, at lower vine densities.

Much research has been done in the past and various authors came to the same conclusion: that closer vine spacing may increase yield per hectare, in other words the number of fruitful shoots per hectare, if the basic rules of vine balance are adhered to (Winkler *et al.,* 1974; Turkington *et al.*, 1980). In theory, in scenarios with low potential soils, vines may benefit from narrower between-vine spacing in terms of yield, productivity and quality, and an increase in root depth can be observed. Archer and Strauss (1991) researched this hypothesis and further proved that not only did such vines benefit in terms of production, but it also resulted in improved root penetration and cessation of shoot growth at the required phenological stages. If within-canopy shade is at a minimum, narrower spaced grapevines may produce optimal yields of high quality. In more fertile, higher potential soils, contrasting observations have been made in more dense plantings where shaded conditions due to increased vegetative growth lead to a decrease in both yield and quality (Archer & Strauss, 1991; A. Strever, personal communication, 2016). However, it is possible to implement narrower spacing with success on higher potential soils, provided that the training system is able to accommodate and not limit the increased vigour and spatially arrange the canopy for maximum sunlight interception. If, under higher potential soils, the canopy of a vigorous growing grapevine can be divided and in so doing create an enlarged effective foliage surface, positive effects with regard to yield and quality can still be achieved (A. Strever, personal communication, 2016).

2.3.3.3 Rootstock/Scion combination

Ever since the cultivation of grapevines with rootstocks was initiated in the 1860's due to the spreading of the phylloxera aphid from North America to Europe, breeding evolved and resulted in a large variety of hybrid rootstocks suitable and adapted to specific, sometimes even challenging, environments. Ungrafted grapevines might not otherwise have been able to survive under such circumstances due to the presence of other soil borne pathogens, physical and/or chemical soil conditions, or other unfavourable environmental conditions (Alleweldt & Possingham, 1988).

The soil potential mainly dictates the choice of a suitable rootstock. The genetically determined growth potential of a rootstock in combination with a specific scion cultivar will, to a great extent, determine the vigour of the grapevine. Therefore, the choice of this combination can be altered to fulfil the specific production goal. On soils with lower potential, more vigorous rootstocks can be used.

The size of a grapevine's root system determines its efficiency in water uptake and drought resistance, which has in recent years become of increasing importance in the current context of global climate warming. Even though the extent of root development may have a genetic component (Pongrácz, 1983), it has been suggested that environmental factors and soil properties may play a conclusive role (Van Zyl, 1988). Thus, physical soil properties such as impermeable stone or clay layers, or the presence of chemical limitations such as acidity, appear to have a greater influence on root development and distribution than the inherent genetic predisposition of the rootstock (Smart *et al*., 2006). In research carried out on a great variety of rootstocks, all of which colonised the same volume of soil with their root systems, Swanepoel & Southey (1989) concluded that any rootstock's water extracting capability contributes more to its drought resistance than the ability of a rootstock to enlarge its root volume in order to utilise a larger volume of soil. In addition to this, factors influencing the vigour and vine form above-ground, including an adaptation or modification in training system, will also impact greatly on root characteristics such as root development and water uptake ability (Van Zyl & Van Huyssteen, 1980; Archer & Strauss, 1985).

2.3.3.4 Pruning

Winter pruning is a seasonal practice that is crucial to create and maintain grapevine balance. It involves the selective removal of unnecessary wood in order to maintain a good grapevine shape, create a favourable balance between vigour and yield, and to position spurs in order to contribute to a spatially well balance canopy in the following growing season (Zeeman & Archer, 1981; Jackson, 2008). Bud load is also determined during pruning and contributes towards determining the next season's yield. A balanced bud load is therefore an all-important decision that will contribute towards creating a balanced yield:pruning mass ratio.

Carbonneau (1997) described three main aspects by which vine growth and vine balance can be assessed, namely the vine's vegetative growth, its reproductive growth, as well as its reserve status. The value of these three variables and their ratio to each other is supposed to fluctuate very little from year to year should a vine be in balance (Carbonneau, 1997). Therefore, the comparison of cane mass from year to year can serve as an indication of a vine's balance status based on whether or not a variation is observed and, if so, to what degree. Balanced pruning as a concept developed by Partridge (1925) suggests that a grapevine's growth capacity can be determined by weighing cane prunings. This can then be used to calculate the correct bud load that should be allocated to a grapevine to ensure that the vine is able to sustain its capacity by means of building up and storing reserves and maintaining its vegetative growth whilst being able to ripen its crop optimally as well.

In high potential situations conducive to vigorous growth and the development of dense, shaded canopies, conventional or balanced pruning might not be ideal to develop optimal balance (Pool, 2004). Apart from dividing cordons, as in the case with the Smart Dyson, Lyre or Geneva Double Curtain systems (to name but a few), pruning practices also need to be modified by changing bud load, in order to adapt to the increased vegetation. For weaker growing vines bud load can be reduced by pruning to shorter spurs (one bud per spur). Such grapevines may also be spaced closer together leading to shorter cordons, less spurs and a lower bud load on a per vine basis. On the other hand, vigorous growth can be curbed by pruning lightly (leaving more buds per spur) and spacing the spurs further apart so as to ensure lower shoot density and thus a decrease in within-canopy shade (Smart *et al*., 1990b; Smart & Robinson, 1991). Bearer spacing also affects the amount of bearing spurs and shoots per running meter cordon and is normally adjusted to the combination of cultivar, climate and wine style goals. For instance, for a red cultivar where greenness may be problematic in a specific climate, bearers can be spaced further apart (*i.e.* 14 cm apart) to allow more light penetration (A. Strever, personal communication, 2016).

It has been accepted previously that lower crop levels generally produce grapes and wines of higher quality (Winkler, 1954; Bravdo *et al*., 1985a; Bravdo *et al*., 1985b). However, some research indicates that an increase in bud load would not necessarily lead to a decrease in wine quality although a decrease in colour intensity may occur in red wines (Hunter & de La Harpe, 1987) Another consideration is that crop levels which are too low are not feasible in current conditions of an ever-increasing focus on economic sustainability. It also became evident that the effect of bud load is strongly influenced by its interaction with factors such as the scion/rootstock combination, training system and climatic conditions (Jooste, 1983; Hunter & de La Harpe, 1987). Other authors also confirmed this complex interaction, and therefore concluded that generalised recommendations regarding the severity of pruning cannot be made (Archer & Fouché, 1987).

Where the combined effect of a rootstock and the bud load was investigated, it was observed that rootstocks react differently to an increase in bud load. In general, an increase in bud load may lead to a decrease in bud fertility, bunch mass and budding percentage. Therefore, due to the compensatory reaction of the vine, an increase in yield is not necessarily proportional to an increase in bud load (Archer & Fouché, 1987; Archer & Hunter, 2003). This effect was especially pronounced in rootstocks with a genetic predisposition to induce weaker growth. Thus, rootstocks differ with regard to their ideal bud loads, and other interrelated factors should also be considered (Archer & Fouché, 1987). These authors also reported that alternative pruning methods leading to a change in budload lead to higher yield with no significant effect on grape composition. However, lower phenolic extraction levels in wines prepared from vineyards where alternative pruning methods were applied indicates a lower maturation potential in such wines (Archer & Hunter, 2003).

In South Africa, mechanical pruning has gained tremendous popularity in the higher producing, warmer areas with high fertility soils and readily available water for irrigation. Research conducted in such areas showed that in mechanically pruned vineyards not only was there a reduction in labour costs, but also an increase in yields when compared to hand-pruned vines, with no significant difference in grape composition. As a matter of fact, in some cases there was even an improved flavour profile in the case of mechanically pruned vines, since better light interception occurred in the bunch zone due to an open hanging canopy (Archer & Van Schalkwyk, 2007; Van Schalkwyk & Archer 2008). However, for mechanically pruned vineyards to remain sustainable, fertilisation and irrigation regimes must be revised to adapt to the increase in yield (Schultz *et al*., 1999). It is advisable to only apply mechanical pruning on vines with high vigour, and which are established on trellising systems which can accommodate the expanded growth. In the case where one- or two strand hedge trellising systems are used, the material used in construction of the trellis system should be strong enough to accommodate the vigour.

2.3.3.5 Summer canopy management

Canopy management is viewed as positioning and maintaining bearing shoots and their fruit in a microclimate optimal for grape quality, inflorescence initiation, and cane maturation (Smart, 1985; Smart *et al*., 1985a; Jackson, 2008). This includes all techniques applied to a grapevine aimed at altering the distribution and amount of foliage and fruit (Smart *et al*., 1990; Reynolds & Vanden Heuvel, 2009). Canopy microclimate depends on the density and the distribution of leaves, shoots and grapes, which influences light interception and carbon assimilation (Smart, 1985; Schultz, 1995). Homogenous grapevine canopies with higher light interception abilities generally favour yield and fruit quality (Smart, 1985; Dokoozlian & Kliewer, 1995a; Dokoozlian & Kliewer, 1995b) and any alteration of the canopy architecture as in the case with modified training systems will result in altered productivity of a grapevine.

Canopy management alters canopy microclimate as a whole, influencing levels of sunlight interception, canopy temperature, humidity, wind speed and evaporation rate (Smart, 1985). However, the effect of an altered canopy microclimate is noted most prominently with regard to the quantity as well as quality of sunlight interception (Champagnol, 1984; Smart, 1985). In cases where a training system is modified, it will have a large impact on canopy microclimate and if not managed correctly, a decrease in light penetration may occur (Smart *et al*., 1985b). In order to manipulate the canopy microclimate to optimise light interception, Smart (1985) proposed three principals, namely controlling the vine’s vigour, controlling the number of shoots, and adaptation and/or modification of a training system.

The size of the optimally exposed leaf surface will be affected by the height and size of a trellis system, as well as the training and pruning systems applied, and should be taken into consideration when choosing the correct trellising system (Reynolds & Vanden Heuvel, 2009). Canopy surface area can be increased, and shoot density decreased simultaneously in cases where canopies are divided, using for example the GDC (Shaulis *et al*., 1966), the Lyre

(Carbonneau & Huglin, 1982) or the RT2T systems (Smart *et al*., 1990a). Hereby, a favourable microclimate can be created in order to sustain high yields without the negative effects of overcrowding of shoots and excessive shade.

The number of shoots, which determines shoot density, can be controlled by shoot thinning (suckering), by adapting the pruning system (Smart, 1985) or by altering the bearer spacing. Shoot positioning, topping and leaf removal in the period right after budburst up to pea size will also greatly contribute to an increase in sunlight penetration, and thus grape and wine quality (Smart & Robinson, 1991; Hunter, 2000). Leaf removal can increase sugar accumulation whilst decreasing titratable acidity (TA), malic acid (MA), pH and K^+ levels in fruit (Kliewer & Bledsoe, 1986; Hunter, 2000). However, the removal of lateral shoots is discouraged. Not only is this practice not economically viable, but it promotes compensatory growth which contributes to densification of the canopy and thus counteracts the desired outcome - namely to increase sunlight penetration and improve the grapevine microclimate (Hunter, 2000).

2.3.3.6 Irrigation and fertilisation

Climate change in combination with a decreased amount of available agricultural water has forced researchers and grapevine producers alike to be innovative in the approach for efficient water management to maintain production levels without a loss in quality. Once any training system is modified and the canopy surface subsequently increased or doubled, irrigation and fertilization may need to be adapted to suit the needs of the larger canopy (Smart & Robinson, 1991).

Available soil water typically varies with soil depth and throughout the growing season, increasing with depth and decreasing towards the end of the season. Most of the water supplied to a crop is lost to the atmosphere through evapotranspiration (ET), which refers to evaporated water from the soil surface plus water lost from the plant due to transpiration (Netzer *et al*., 2009). Climatic conditions such as temperature and wind speed may affect ET rate. Grapevine growth and yield components are all very sensitive to water stress (Smart & Coombe, 1983) and once the ET demand exceeds the water available in the soil, reduced yields of lesser quality can be expected (Netzer *et al*., 2009). Severe water stress and excessive vegetative growth may both have extremely undesirable effects on yield and/or grape composition. Excessive canopy growth may increase the need for intensive canopy management and other corrective actions in an attempt to restore balance (Netzer *et al*., 2009). It is therefore crucial that an appropriate balance between vegetative and reproductive development is maintained in a grapevine.

Viticultural practices influencing grapevine architecture, and thus spatial leaf distribution, will also contribute to influencing the rate of ET. Canopy architecture influences stomatal conductance, and therefore indirectly influences transpiration rate. Since grapevine water usage is linearly related to the LAI (Williams & Ayers, 2005), any canopy modification leading to an inevitable change in LAI will therefore have a great influence on the transpiration rate and water use efficiency of the grapevine. In cases of trellising systems such as the open-gable trellis system resulting in a high LAI, ET will also increase linearly (Netzer *et al*., 2009). Regarding shoot positioning, photosynthetic activity, stomatal conductance and transpiration rate of upward positioned (phototropic) shoots was higher compared to downward positioned (gravitropic) shoots (Lovisolo & Schubert, 2000; Pisciotta *et al*., 2004).

Irrigation scheduling should not be based primarily on weather and/or soil measurements, but rather according to vine water demand. Taking this into consideration, Acevedo-Opazo *et al*. (2010) proposed that midday stem water potential should be used as a vine physiological indicator.

Irrigation strategies such as partial root zone drying (PRD) and regulated deficit irrigation (RDI) have been proposed and promoted as being effective in regulating and maintaining grapevine water stress levels. In the case of RDI, controlled water stress is applied at various phenological stages to control berry size, which in turn may results in improved red wine quality (McCarthy *et al*., 2002). With this practice, water stress can be minimised while vegetative growth is still being controlled (McCarthy *et al*., 2002; Cifre *et al*., 2005). However, varying results may be obtained when water stress is applied at different phenological stages, and care should therefore be taken when applying RDI (Acevedo-Opazo *et al*., 2010). Similar positive results can be obtained by applying PRD during which biochemical responses of a grapevine in response to water stress can aid in achieving a balance between reproductive and vegetative growth (McCarthy *et al*., 2002; Cifre *et al*., 2005; Dry *et al*., 2015).

Even if a suitable irrigation and fertilization regime has been established for a vineyard under specific conditions, a new approach should be considered once any conversion in training system takes place. Such a conversion will have a profound impact on the grapevine in terms of balance as well as water and nutritional requirement.

2.3.4 Physiological aspects of grapevine balance

2.3.4.1 Canopy microclimate

The characteristics of any canopy determine the microclimate which in turn dictates the physiological functioning of that canopy, and eventually determines fruit composition and thus wine quality.

Many long-term factors, such as soil type, climate, rootstock/scion combination, plant spacing, choice of training system as well as numerous short-term viticultural practices, may contribute to the stimulation or suppression of vigour whereby creating a canopy with specific characteristics (Archer & Strauss, 1985; Smart *et al*., 1985a; Hunter *et al*., 1995; Hunter, 1998a, Hunter, 1998b; Hunter & Volschenk, 2001). All these above-mentioned factors might contribute to an increase in early-season growth and therefore an increased leaf area, as well as prolonged growth into the ripening period. It must be stressed that an increase in leaf area might not necessarily mean that a canopy is efficient in its sunlight interception and photosynthetic efficiency (Smart *et al.*, 1985a; Smart, 1988). Once the vine balance is modified, for example by effectively dividing an existing canopy or adapting the trellising system, the microclimate will improve by means of an increase in sunlight interception and wind movement through the canopy (Champagnol, 1984; Smart, 1985; Volschenk & Hunter, 2001; Reynolds & Vanden Heuvel, 2009).

2.3.4.2 Grapevine water status

As previously mentioned, canopy characteristics, and thus microclimate, are influenced by many factors, amongst others the training system. A modified system which alters the total number of leaves, leaf size and/or distribution of leaves will have big implications for the physiological functioning of the vine. Included in this is its photosynthetic capacity, tempo of transpiration and the physiological ratio between the two – referred to as the photosynthetic water use efficiency, or WUE (De Palma & Novello, 2003). An enlarged canopy surface area that is optimally exposed to the sun will usually lead to higher water use in a vineyard. This is not only due to an increased exposure of such leaves to sunlight, but also since they are exposed to greater wind speeds when compared to shaded, interior leaves This leads to a higher transpiration rate in such well exposed leaves (Smart & Robinson, 1991; Schmid & Schultz, 1999; Netzer *et al*., 2009). It is therefore crucial that any modification in foliage surface, and thus the change in physiological functioning, should be accompanied by a revised approach to an irrigation or fertilisation strategy.

In research comparing a minimal pruning (MP) system to a vertically shoot positioned (VSP) system it was found that although the leaf area of MP vines was more than double that of the VSP vines, the water consumption of the former was a third less than that of VSP vines when expressed on a per leaf area basis (Schmid & Schultz, 1999). Since the leaf area density in the MP vines was higher, more shaded leaves may have resulted and this in turn might have led to a reduced transpiration rate per unit leaf area – especially in the middle to upper part of the canopy. Under natural field conditions, the transpiration rate of the VSP vines kept on increasing, but the maximum transpiration rate of MP vines was nearly unaffected. Shaded leaves situated deep within a canopy also display a decrease in photosynthetic efficiency when compared to outer, well exposed leaves. It can therefore also be deduced that the positioning of leaves within a canopy plays a great role in the leaf gas exchange rate (De Palma & Novello, 2003; De Palma *et al*., 2003).

Certain modified training system also involves divided canopies, with some shoots positioned downwards. Examples of these, as previously mentioned, includes the GDC (Shaulis *et al*., 1966), the Ruakura Twin Two Tier (RT2T) (Smart *et al*., 1990a) and the Smart Dyson systems. Apart from the fact that the exposed leaf surface is enlarged and optimised by implementing such a system, there is also the matter of phototropic (upward) versus geotropic (downward) shoot positioning. Geotropically positioned shoots tend to be shorter with smaller leaf areas (Kliewer *et al*., 1989; Schubert *et al*., 1995; Lovisolo & Schubert, 2000; Pisciotta *et al*., 2004;

Somkuwar & Ramteke, 2008) and exhibit lower stem and leaf water potential when compared to phototropic shoots (Pisciotta *et al*., 2004).

Geotropically positioned shoots also display reduced hydraulic conductivity, stomatal conductance and transpiration rate when compared to that of phototropically positioned shoots (Schubert *et al*., 1995; Schubert *et al*., 1999; Lovisolo & Schubert, 2000; Pisciotta *et al*., 2004). The decreased hydraulic conductivity can be ascribed to a reduction in the development of xylem vessel diameter (Schubert *et al*., 1999), but the mechanism responsible for this observation is not clear.

2.4 Effect of modification on grape and wine composition

There is a perception that high yielding vineyards produce grapes and wines of inferior quality. The main reason for decreased quality in higher yielding vineyards might be ascribed to higher vigour and increased leaf area, associated with a decrease in light penetration inside the canopy (Smart *et al*., 1985a). Shaded conditions cause a decrease in sugar content, an increase in must and wine pH (Smart *et al*., 1985b; Reynolds *et al*., 1994) as well as K^+ content. A reduction in wine colour intensity as well as anthocyanin and phenol content can also be observed (Smart *et al*., 1985b). Since shaded conditions cause an accumulation of K^+ in shoots before véraison, the high K^+ content in fruit, as well as the increase in wine pH, can be explained (Smart *et al*., 1990a; Smart *et al*., 1985a).

Sufficient light interception favours both yield and fruit quality (Smart, 1985; Reynolds *et al*., 1994; Dokoozlian & Kliewer, 1995a). Thus in situations where dense, overcrowded canopies may lead to a decrease in quality, a conversion of a training system might be considered in order to optimise a vine’s photosynthetic efficiency and light microclimate. This is achieved by the increased exposed leaf area brought about by such modified systems (Reynolds & Vanden Heuvel, 2009). Modified training systems involving divided canopies with geotropically as well as phototropically positioned shoots may produce berries of different compositions in the distinctive bunch zones. The photosynthetic activity in the leaves of phototropically orientated shoots tends to be higher, producing grapes with higher contents of glucose and tartaric acid (Pisciotta *et al*., 2004). It is of crucial importance to keep the potential difference in berry composition between these two bunch zones in mind when making decisions regarding a training system conversion or deciding on suitable short-term cultural practices.

2.5 Conclusions

In the current economic situation in South Africa, wine farmers have been forced to reconsider existing cultural practices and perceptions in order to remain sustainable and increase productivity of grapevines without compromising on quality. In the past, it was assumed that only low yielding, small vines were able to produce grapes suitable for high-quality wines, and that large, vigorous vines could not achieve this. However, this might only be the case in situations where a grapevine is out of balance leading to dense canopies characterised by high levels of shade. Such conditions will reduce the photosynthetic efficiency of a grapevine, inevitably leading to a decrease in the sugar content of the grapes, and ultimately wines with reduced colour intensity and increased pH. Out of control vigour with the associated risk of shaded, dense conditions require intense interference in order to improve microclimate. Short-term practices, such as summer canopy management, can improve microclimate and are most certainly necessary, but once it is applied as a drastic corrective measure the intensity thereof is not economically justifiable and/or sustainable anymore. In such situations the modification of an existing but ineffective training system that is not able to accommodate a grapevine's vigour provides a more suitable long-term solution. This is achieved through increasing the effective leaf area, which will bring about and maintain vine balance and improved canopy microclimate.

Choosing a suitable training system, or altering an existing one, should be done judiciously keeping in mind that the grapevine will exhibit self-regulatory responses in reaction to any modification in its architecture. These self-regulatory responses will usually result in a change in productivity of the grapevine. Numerous factors contribute to this response making it very difficult to determine the exact nature of the response beforehand. Since there is a tangible relationship between above-ground and subterranean growth any change in the grapevine architecture, as achieved with altering an existing training system, will have a direct influence on the development of the root system. On the other hand, long-term establishment practices such as choice of rootstock/scion combination, plant spacing and trellising system will also have a profound impact on the development of the root system, and therefore the expression of above-ground growth, eventually manifesting in an alteration in canopy architecture and thus microclimate.

If implemented correctly, a modified training system can increase photosynthetic efficiency as well as bud fertility and flower differentiation thereby producing higher yields of enhanced quality. However, these changes force a revised approach in short-term practices such as canopy management, pruning, irrigation and fertilisation.

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Chapter 3

RESEARCH RESULTS

ADAPTATION OF GRAPEVINE REPRODUCTIVE/VEGETATIVE BALANCE IN CONVENTIONAL AND MODIFIED TRAINING SYSTEMS

CHAPTER 3: ADAPTATION OF GRAPEVINE REPRODUCTIVE/VEGETATIVE BALANCE IN CONVENTIONAL AND MODIFIED TRAINING SYSTEMS

3.1 Introduction

It is not viable in the current economic climate in the South African wine industry to only produce very high quality grapes in small quantities. Increased production costs have forced wine grape producers to increase production without a loss in quality. From 2013 to 2014, total cash expenditures showed an increase of 10% (Van Zyl, 2015). Production costs doubled when the period from 2008 until 2017 is considered, increasing from R23 578 per ha to R47 513 per ha. This can be partly attributed to the increase in minimum wage of workers, which in turn set off a chain reaction where producers tended to move increasingly towards mechanical farming practices in an attempt to counteract the increased labour costs Another consideration is record harvests in past years that lead to costlier, more intense input to produce grapes suitable for a specific wine style and cost point (Van Zyl, 2015).

It was incorrectly assumed in the past that only small vines with low yields are able to produce quality fruit. As long as grapevines are in balance, a larger vine might also be able to produce fruit of the highest quality. Grapevine balance remains a complicated concept and many authors have attempted to define it (Carbonneau, 1997; Brase 2004).

Ravaz (1911) proposed that the ratio between fruit and wood, or the yield:pruning mass can serve as an indication of vine balance. Partridge (1925) defined a balanced vine as one that can optimally ripen its crop in time, and Kliewer and Dokoozlian (2005) proposed using a ratio between leaf area and crop mass (yield). Apart from trying to describe this very complex concept of vine balance, this study will also prove that vine balance is a relative, qualitative term, where it is a matter of producing grapes for different wine- and production goals rather than rigidly constricting this concept in terms of the time of ripening or the calculation of different vegetative ratios.

Since soil conditions in South Africa tend to be very heterogeneous, large variability in vigour and non-uniform growth might occur in the same vineyard block. Even though uniformity and grapevine balance interact closely they are not one and the same thing. A great challenge is thus created in establishing and maintaining grapevine balance to produce optimal yields of the highest possible quality.

In situations where training systems are found to be limiting, the result may be over vigorous, unbalanced growth (Smart, 1985). In such cases one consideration may be the conversion of the existing trellising/training system in order to create balance. The conversion(s) can increase the effective canopy surface thus conserving grape quality and increasing grapevine productivity (Volschenk & Hunter, 2001). Grapevine architecture can therefore be altered through training systems to optimise both yield and quality for a specific wine target.

Even though systems like the Smart-Dyson system, the Gable system and the lyre system amongst others have proven the conversion of a training system to be an effective measure to improve microclimate and grapevine balance (Gladstone & Dokoozlian, 2003) and thus produce optimal yields of high quality, there still seems to be a reluctance among grape producers to take this step.

The objectives of the study were to determine the relationship between grapevine size, grape quality, the yield:pruning mass ratio (Ravaz index) and canopy conditions in scenarios where grapevine balance had been modified by means of training system conversions. Historical within-block information was used to determine whether grapevines that differ vastly in size and pruning mass, but with similar Ravaz indices, are capable of producing fruit of similar quality and composition. Furthermore, if this was found to be the case the question of to what extent modification which alters grapevine balance can be applied without negatively impacting grape quality and composition would be investigated. Once grapevine balance is altered by means of the modification of the vine's architecture, it will lead to compensation reaction in the vine. This reaction can be by means of either an adaptation in yield components or a change in vegetative growth. Historical vigour of the vine might also influence the extent to which the conversion of a training system will be successful or not. It can thus be hypothesized that once the "ideal" Ravaz index for a specific grapevine is realised, and the grapevine is in balance, grapes of similar quality can be produced from a variety of grapevine sizes. The future existence and sustainability of grapevine producers greatly depends on whether the above-mentioned theory can be proved and executed with success.

3.2 Materials and methods

3.2.1 Vineyard characteristics

The field trial was carried out in a *Vitis vinifera* L. cv. Shiraz vineyard situated at the Welgevallen experiment farm of Stellenbosch University, South Africa. Measurements were conducted during the 2011/12, 2012/13 and 2013/14 growing seasons. The Stellenbosch wine producing region is situated within a Mediterranean climate and based on the growing degree days (GDD) from September until March, the specific locality falls within a class V climatic region (Le Roux, 1974). The sandy soil belongs to the Longlands form (Soil Classification Working Group, 1991). The soil was deep delved to 1.0 m before planting. Grapevines were planted 2.7 m × 1.5 m and trained onto a 7-wire hedge trellis system with three sets of moveable canopy wires and vertically positioned shoots (VSP). Full details of the Shiraz vineyard are given in Table 1.

Table 1 Vineyard characteristics of the site in Stellenbosch.

Descriptor	**Stellenbosch**
Cultivar	Shiraz
Clone	SH9C
Rootstock	101-14 Mgt (*Vitis riparia* x *Vitis rupestris*)
Year established	2000
Row orientation	North-South
Terrain	Flat
Grapevine spacing	2.7m × 1.5 m
Trellis/training system	7-wire hedge trellis system with three sets of moveable canopy wires (trellis) and vertically positioned shoots (VSP) Modified systems as indicated in next section.
Irrigation system	Pressure compensated drip system

3.2.2 Experiment layout and treatments

Within the Shiraz vineyard, 18 rows of 36 vines each were selected for the experiment. Each row was divided equally into six plots of six grapevines each. Within these six plots, three vines received a reduced canopy treatment (explained below). The remaining vines that formed part of the experiment were randomly chosen, and some vines in between did not receive any treatment at all. The experiment consisted of three different training system/canopy treatments, namely a VSP with moveable canopy wires on 2.4 m poles, a modified Smart Dyson/Ballerina (hereafter referred to as SD) system and a reduced canopy treatment (R). The SD is a training system modification to the established trellis system. The R also utilizes the established trellis system and, in this case, entails a canopy modification. In the case of the SD, no spur spacing was applied, and all shoots were retained during pruning. Two shoots per bearer were positioned upwards whilst four shoots per bearer were selected and bent downwards – two to the left of the cordon and two to the right of the cordon (when looking down the row).

The R treatment vines were chosen according to randomly designed plots, and this treatment was already implemented in the 2008/09 season. The treatment involved removing the apical shoot on each two-bud spur before flowering leaving behind a single shoot per bearer. In the following seasons, the R treatment was applied at 55-60 days after budburst (DAB). It should be noted that this treatment was not applied in the 2013/14 season. For both the VSP system and the SD system, the vines selected for the experiment were chosen according to mean cane mass, resulting in a randomised split-plot design. By comparing the mean pruning mass per cane as recorded the season prior to the trial (2010/11), two different classes of mean pruning mass (high and low) were identified (Figure 4). Out of a total of 648 vines in the whole block, 120 vines with the highest pruning mass, and 120 vines with the lowest pruning mass were identified. Figure 4 indicates how grapevines were grouped to the left of the normal distribution, *i.e.* low mean mass per cane with values between 17 g and 89 g, and to the right, *i.e.* higher mean mass per cane with values between 111 g and 308 g per cane in order to study the effects of initial vigour on the training conversion.

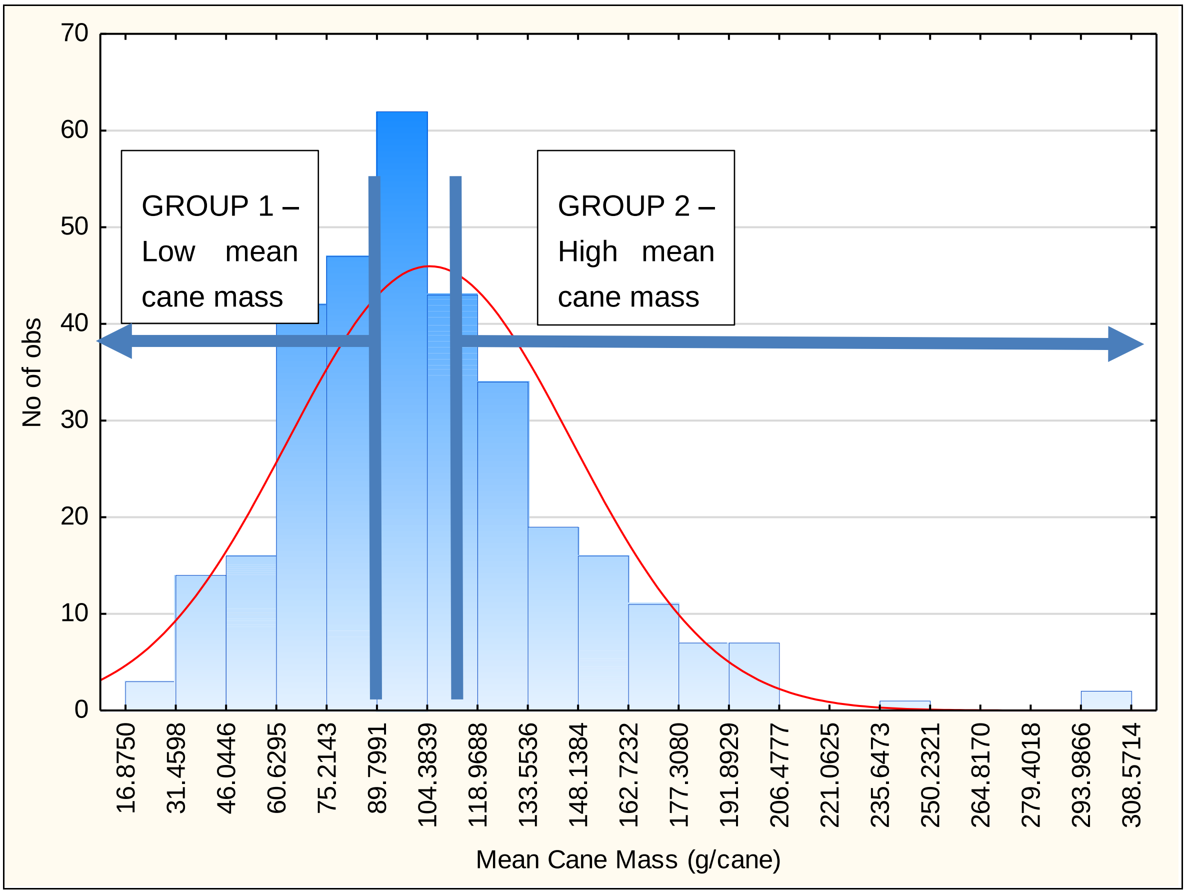

Figure 4 Distribution of values of mass per cane according to which two classes of mean cane mass were identified.

There was great variability in the grapevines' yield to pruning mass ratios, with ratios varying from 1:1 to 12:1 (Figure 5), and also great variability on a yield per vine basis (Figure 6). A completely random layout of vigour classes resulted across the experimental unit due to the classes being assigned to grapevines classified as mentioned before. Of the 120 vines identified for both the high and low mean cane mass classes, 60 randomly chosen vines were converted to a SD system, whilst the remaining 60 vines served as the controls being left as a 7 wire-hedge VSP system. Each of these treatments were further divided in field replicates, namely replicates 1, 2 and 3. The full layout of the trial is depicted in Figure 7.

Pruning and suckering methods for all three seasons are given in Table 2 and (1) Vertical shoot positioning.
(2) Smart Dyson/Ballerina.
(3) Reduced canopy treatment

Table 3. Visual representations of the suckering methods are indicated in Figure 8 and Figure 9.

Season	Treatment	Method
2011/12, 2012/13, 2013/14	VSP[1] (both low and high vigour classes for all three seasons)	Standard. Suckered to two shoots per spur position (control) (Figure 8)
2011/12, 2012/13, 2013/14	SD[2]	Shoots removed, apart from six shoots per bearer.
		Of these remaining six shoots, two are meant to stay upright. Four will, at 15 cm shoot length, be left to grow unhindered outside the foliage wire. Of these four, two will be positioned downwards to the left of the cordon wire, and two downwards to the right (Figure 9).
2011/12, 2012/13,	R[3]	As specified at pruning the top shoot was cut off, and suckering was done strictly to one shoot per bearer.

[1] Vertical shoot positioning.
[2] Smart Dyson/Ballerina.
[3] Reduced canopy treatment

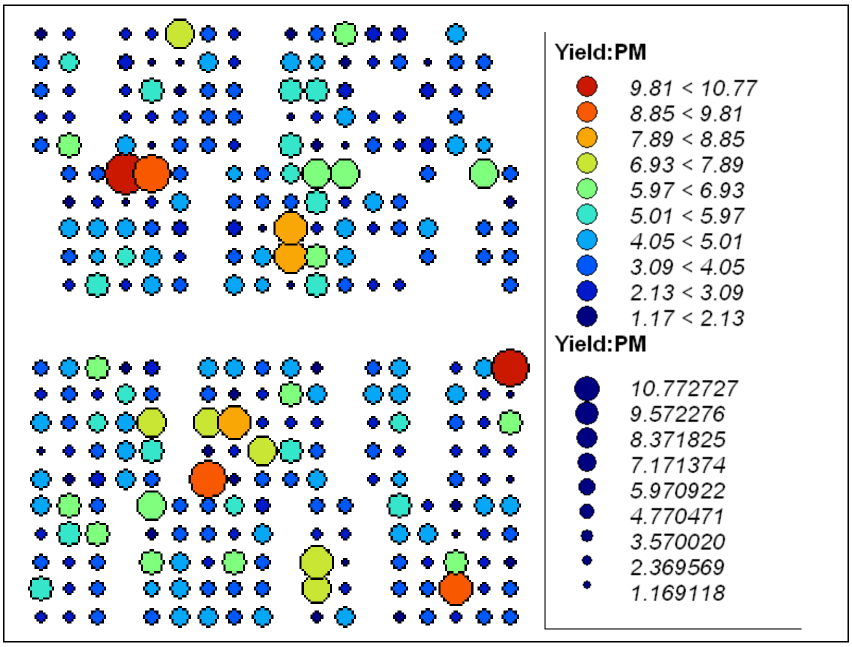

Figure 5 The ratio of yield and pruning mass per vine of the Shiraz trial vineyard in Stellenbosch

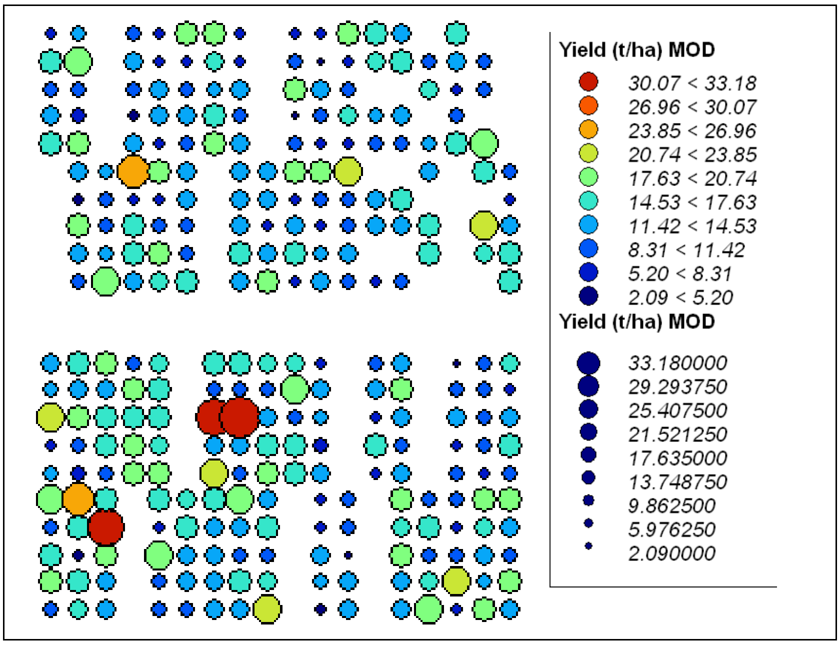

Figure 6 Yield per hectare (tonnes) (calculated from yields per grapevine and the spacing) of the Shiraz trial vineyard’s grapevines in Stellenbosch.

	Row number																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
Vine number 1	3		1				1		1						1		3	
2	2				1				2		3		2				2	
3	1				3				2		1		3		3			
4		3		1		3		1						1		1		
5						1				2		2		3		2		3
6		2		3		2		2		3		2		1		3		2
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
7			1						2		2		3		3			
8	1		1				1		1		1		3				3	
9					2		2		1		2				3		1	
10		1				1		2		3		2		1		2		
11		2		3		3		2		2		1		2		3		3
12		1				2				3				2		3		1
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
13	1				2		1		2				3				3	
14	2		1				1				2		2		3		2	
15					1		2		1		3		2					
16		1		3		1		1				2		3		3		
17		3		3						2		2		1				
18		3		2		1		1		2		3		2		1		3
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
19	2		1		1				2		2		3		3		1	
20			3						2		3		3		2		1	
21	1		2				1		2		1		3					
22								3		2		2		3		3		1
23		1		2		2		3		3		1		3		3		3
24				3				2		1		3		2		1		3
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
25	1		1		1		1		2		2						3	
26	2		3		1				2		2		3					
27	1		1		1		1						3				3	
28		1								2		2		3		3		
29		3				3		2				2		3		1		1
30				1				3		2		2		2		3		2
	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎
31	1				1		1		2								2	
32	3						1		3								3	
33	2		1		1		3		2		2		3		1		3	
34		1		3				2		3				3		3		3
35		2		1		1		2				2		1		2		3
36		3				1		2		1		1		3				2

Colour code	Canopy treatment	
(yellow)	Smart-Dyson	High mean cane mass
(light orange)	VSP Control	High mean cane mass
(red)	Smart-Dyson	Low mean cane mass
(orange)	VSP Control	Low mean cane mass
(green)	Reduced 1	
(blue)	Reduced 2	
(light green)	Reduced 3	

Figure 7 Randomised layout of all the treatments for both high and low vigour classification, with codes indicated for the various treatments.

Table 2 The pruning method applications for the different treatments during the 2011/2012, 2012/13 and 2013/14 growing seasons.

Season	**Treatment**	**Method**
2011/12, 2012/13, 2013/14	VSP[1]	Standard (two bud spurs) (control).
2011/12, 2012/13, 2013/14	SD[2] season one (conversion in 2011/12)	Standard (two bud spurs).
		No spur spacing was applied. All spurs were retained during pruning. The idea was to be able to select canes in the most appropriate positions – two pointing upwards, two bent down to the left, two bent down to the right, per bearer
2011/12, 2012/13,	R[3]	Standard (two bud spurs) during dormancy, and then with the top shoot, including any grapes, removed before flowering time.

[1] Vertical shoot positioning.
[2] Smart Dyson/Ballerina.
[3] Reduced canopy treatment

Table 3 Suckering method applications for the different treatments during the 2011/2012, 2012/13 and 2013/14 growing season.

Season	**Treatment**	**Method**
2011/12, 2012/13, 2013/14	VSP[1] (both low and high vigour classes for all three seasons)	Standard. Suckered to two shoots per spur position (control) (Figure 8)
2011/12, 2012/13, 2013/14	SD[2]	Shoots removed, apart from six shoots per bearer.
		Of these remaining six shoots, two are meant to stay upright. Four will, at 15 cm shoot length, be left to grow unhindered outside the foliage wire. Of these four, two will be positioned downwards to the left of the cordon wire, and two downwards to the right (Figure 9).
2011/12, 2012/13,	R[3]	As specified at pruning the top shoot was cut off, and suckering was done strictly to one shoot per bearer.

[1] Vertical shoot positioning.
[2] Smart Dyson/Ballerina.
[3] Reduced canopy treatment

Figure 8 The suckering method applied to both the controls entailed retaining two shoots per spur position

Figure 9 The suckering method applied on the SD vines entailed retaining all shoots per spur position

Due to the nature of the various levels at which the treatments can be analysed and interpreted it is important to make some points in how treatments are referred to throughout the thesis clear. Table 4 indicates the codes used throughout the thesis for each treatment. The VSP (control) and SD treatments are considered the main treatments and there are two main treatments per VSP and SD training system, based on the vigour of the vines, *i.e*. high vigour and low vigour. The four main treatments of the experiment are therefore high vigour VSP, low vigour VSP, high vigour SD and low vigour SD denoted by HC, LC, HSD and LSD respectively. These essentially entail entire vines. In the case of the HSD and LSD treatments, both are further divided into two sub treatments based on shoot position, *i.e*. upward positioned shoots and downward positioned shoots. These four sub treatments are denoted by HSDA, HSDB, LSDA and LSDB with A standing for upward positioned shoots (above) and B for downward positioned shoots (below). These contrast to the main treatments since these sub treatments essentially represent half a vine. The word "treatment" will therefore refer to HC, LC, HSDA, HSDB, LSDA, LSDB and R unless clearly stated "HSD treatment" or "LSD treatment" to indicate a per vine basis of analysis for the SD training systems.

Table 4 Codes used to describe the different treatments.

Main treatment	**Sub treatment**	**Main treatment code**	**Sub treatment code**
High vigour Smart Dyson	High vigour Smart Dyson (shoots pointing upwards)	HSD	HSDA
	High vigour Smart Dyson (shoots pointing downwards)		HSDB
Low vigour Smart Dyson	Low vigour Smart Dyson (shoots pointing upwards)	LSD	LSDA
	Low vigour Smart Dyson (shoots pointing downwards)		LSDB
High vigour VSP (control)		HC	
Low vigour VSP (control)		LC	
Reduced canopy		R	

Grapevine phenology was monitored throughout the whole block at least once per week. The dates are presented as an average of all treatments. Data from the phenological measurements for the 2011/2012 season is given in Table 5, the 2012/2013 season in Table 6 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2012/13 season. and the 2013/2014 season in

Table 7 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2013/14 season..

During the course of the three seasons, the treatments were monitored with regard to vegetative- and reproductive growth. The compensation reaction of the grapevine was assessed through the monitoring of shoot growth, leaf area, plant water status (predawn LWP) and yield components. Wines were prepared from grapes of each treatment and sensory evaluation performed on these wines using qualitative descriptive analysis (QDA).

Table 5 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments) during the 2011/12 season.

Phenological stage		Date	DAB
Budburst		19/09/2011	0
Flowering		08/11/2011	50
Full bloom		14/11/2011	56
Berry set		25/11/2011	67
Berry pea size		02/12/2011	74
Bunch closure		23/12/2011	95
Véraison		21/01/2012	124
Harvest	LSDA, LSDB, HSDA, HSDB	15/03/2012	178
	LC, HC	14/03/2012	177
	R	09/03/2012	172

Table 6 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2012/13 season.

Phenological stage		Date	DAB
Budburst		26/09/2012	0
Flowering		12/11/2012	47
Full bloom		18/11/2012	53
Berry set		28/11/2012	63
Berry pea size		04/12/2012	69
Bunch closure		23/12/2012	88
Véraison		21/01/2013	117
Harvest	LSDA, LSDB	19/03/2013	174
	LC, HC, HSDA, HSDB, R	18/03/2013	173

Table 7 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2013/14 season.

Phenological stage		Date	DAB
Budburst		24/09/2013	0
Flowering		20/11/2013	57
Full bloom		25/11/2013	62
Berry set		03/12/2013	70
Berry pea size		08/12/2013	75
Véraison		21/01/2014	119
Harvest	LSDA, LSDB, HSDA, HSDB	10/04/2014	198
Harvest	LC, HC	25/03/2014	182
Harvest	R	31/03/2014	188

3.2.3 Climate measurements

3.2.3.1 Macroclimate

The Heritage Garden weather station (Heritage Garden, Infruitec, Stellenbosch, Lat -33.92714; Long 18.87226, alt 112 m) is +/- 1.5 km from the site of the experiment, and all temperature data was obtained from this weather station (courtesy of the Institute for Soil, Climate and Water of the Agricultural Research Council in Pretoria).

The accumulation of heat units commenced at the EL5 phenological stage of to the Eichhorn-Lorenz system, as adapted by Coombe (1995). This stage corresponded with the stage where leaves had unfolded and were +/- 2 cm long, and it will hereafter be referred to as budburst. The decision of using the EL5 phenological stage as the starting point for heat summation calculations was based on the fact that leaf and shoot measurements can be conducted with ease from this stage onwards.

As proposed by Schultz (1992), Equation 1 can be used at any point in the growing season to calculate the summation of heat units or thermal time (TT) form the start of the growing season. The unit is growing degree days.

Base temperature (T_b) represents a theoretical lower limit for growth of the grapevine which was accepted to be 10°C (Strever, 2012).

Equation 1 Thermal time (growing degree days) calculation where i represents the first day of the growing season and n the last day (or the day up to which the calculation is done if this day is before the end of the season)

$$TT = \sum_{i=1}^{n} \frac{(T\,max, i + T\,min, i)}{2} - Tb$$

TT - Thermal time/ heat units
T max, T min - maximum and minimum temperatures respectively
T_b – base temperature

3.2.4 Soil and plant water status measurements

The soil water content in the experimental vineyard was measured using a neutron probe (Hydroprobe 503DR, CPN®, California). Access tubes were installed randomly in some of the grapevine rows. Due to constraints in the larger plot and the fact that soil water measurements were conducted on the block as a whole, it was not treatment specific. Water status could therefore not be monitored on a per-treatment basis. Measurements took place at three depths (0-30 cm; 30-60 cm and 60-90 cm) and were executed on a weekly basis.

Grapevine water status was quantified by measuring grapevine water potential by means of the pressure chamber technique (Scholander *et al.*, 1965). In all three seasons predawn leaf water potential (Ψ_{PD}) of the HSD, HC and R treatments was measured on a weekly basis from berry pea size (mid-December). Measurements commenced at 03:00 and were carried out on mature, unscathed primary shoot leaves using a Scholander pressure chamber. The leaf was placed in the chamber of the pressure bomb and the standard operating procedure for pressure bomb measurements used to obtain a reading. This was repeated for six expanded, primary shoot leaves of each replicate within each treatment. In order to categorize the values obtained from the predawn measurement categories, as defined by Carbonneau (1998) (Table 8), Ojeda *et al*., (2002) and Deloire *et al*. (2004), were used and adapted (Strever, 2012).

Table 8 Predawn leaf water potential (Ψ_{PD}) and grapevine water status classes (Carbonneau, 1998).

Class	Predawn leaf water potential (Ψ_{PD}) MPa	Level of water constraint or stress
0	0 MPa ≥ ΨPD ≥ -0.2 MPa	No water deficit
1	-0.2 MPa > ΨPD ≥ -0.4 MPa	Mild to moderate water deficit
2	-0.4 MPa > ΨPD ≥ -0.6 MPa	Moderate to severe water deficit
3	-0.6 MPa > ΨPD ≥ -0.8 MPa	Severe to high water deficit (=stress)
4	< -0.8 MPa	High water deficit (=stress)

3.2.5 Vegetative measurements

3.2.5.1 Cane measurements at pruning

During pruning, the number of spurs as well as the number of canes of each treatment were counted as well as weighed. This was done for all three seasons and each treatment individually. Detailed cane measurements were performed on ten canes per treatment during the 2011/2012 and 2012/13 seasons. This included measuring primary cane length and mass (individual and total), and total lateral cane length and mass.

3.2.5.2 Shoot growth (in field)

At the beginning of each season, five random grapevines were selected for each treatment and two shoots were tagged for the execution of the various measurements per treatment. For the controls and R treatments two shoots were chosen per vine – one on the left and the other on the right of the cordon. Four shoots per vine were selected from the vines representing the SD main treatments – two of these shoots were upward positioned shoots (thus representing the HSDA or LSDA treatments), and two were downward positioned shoots (thus representing the HSDB or LSDB treatments). Once every two weeks from the beginning of the season up to where vegetative growth ceased, shoot length was measured. Dates of measurements during 2011/12, 2012/13 and 2013/14 were recorded and are shown in Table 9, Table 10 and Table 11 respectively.

Table 9 Days after budburst (DAB) corresponding with the shoot length measurement dates during 2011/2012) for the different treatments (Note: DAB of 0 refers to the date of budbreak with no measurements on that day).

Date	DAB(1) for SD(2), VSP(3)(control), R(4)
19/09/2011	0
03/11/2011	44
14/11/2011	55
28/11/2011	69
09/12/2011	80
19/12/2011	90
28/12/2011	99
10/01/2012	112
17/01/2012	119
23/01/2012	125
01/02/2012	134

(1) Days after budburst.
(2) Smart Dyson.
(3) Vertical shoot positioning.
(4) Reduced canopy.

Table 10 Days after budburst (DAB) corresponding with the shoot length measurement dates during season 2012/13 for the different treatments. (Note: DAB of 0 refers to the date of budbreak with no measurements on that day).

Date	DAB[(1)] for SD[(2)], VSP[(3)](control), R[(4)]
26/09/2012	0
22 /11/2012	56
29/11/2012	63
11/12/2012	75
19/12/2012	83
07/01/2013	102
14/01/2013	109
30/02/2013	125

(1) Days after budburst.
(2) Smart Dyson.
(3) Vertical shoot positioning.
(4) Reduced canopy.

Table 11 Days after budburst (DAB) corresponding with the shoot length measurement dates during season 2013/14 for the different treatments. (Note: DAB of 0 refers to the date of budbreak with no measurements on that day).

Date	DAB[(1)] for SD[(2)], VSP[(3)](control), Red[(4)]
24/09/2013	0
15/11/2013	52
27/11/2013	64
06/12/2013	73
13/12/2013	80
20/12/2013	87
28/12/2013	95
10/01/2014	108
16/01/2014	114

(1) Days after budburst.
(2) Smart Dyson.
(3) Vertical shoot positioning.
(4) Reduced canopy.

3.2.5.3 Destructive shoot measurements

Destructive shoot measurements were performed at three phenological stages for each treatment during the three growing seasons, namely berry pea size, véraison and during ripening/before harvest. Ten shoots of each of the controls and the R treatment were collected, and 20 shoots of each of the four SD treatments were collected. Ten of these shoots were upward positioned shoots, and the other ten downward positioned shoots.

Shoot samples were measured with a tape measure to determine total length. The primary leaves were removed from the shoot by cutting them from the petiole *i.e*. only the leaf blade was sampled while the petiole remained attached to the shoot. The nodal position of each leaf was recorded by numbering the leaves from node 1 (the first basal node) to node *n* (most apical node with a fully expanded leaf). The main vein (L1) length for each leaf was measured using a tape measure and recorded. An electronic leaf surface area meter (Delta-T devices Ltd, Cambridge, UK) was used to determine the leaf area for each of the numbered primary leaves. As the leaves pass through the device the area for each was recorded in an output data sheet. The total primary leaf area is also given in the output data sheet as a sum of all leaf areas measured for the particular shoot.

The number of lateral shoots present on each of the primary shoots was also noted and each lateral shoot removed, its length measured and the leaves removed from the petiole as was done for the primary leaves. The lateral leaf area was measured using the same electronic leaf area meter. In the case of lateral leaf area all lateral leaves from all the lateral shoots on a primary shoot were passed through the apparatus and only the total leaf area from the output data file used. It should also be noted that the nodal position of the leaves on the lateral shoots were not recorded as in the case of the primary leaves since the exclusive use of total lateral leaf area and no measurement of the L1 vein for lateral leaves deemed it unnecessary to record individual leaf positions. The leaf area data captured per measured shoot thus included individual primary shoot leaf areas, total primary leaf area as well as total lateral leaf area. These measurements were done during the 2011/12 and 2012/13 seasons.

Using the data obtained during 2011/12 and 2012/13, a correlation between the L1 vein length and surface area of a leaf had been established. This correlation was then applied during 2013/14 to deduce leaf surface area from measured L1 lengths of both primary and lateral leaves.

3.2.6 Reproductive measurements

3.2.6.1 Berry sampling and analysis

Berry sampling for all treatments took place on a weekly basis from the period before the onset of véraison, *i.e*. when the sugar levels in the berries were between five- and ten-degrees Balling (˚B) up until harvest. Days after budburst (DAB) corresponding with the ripening measurement dates are given in Table 1, Table 2 and Table 3 in the Addendum. Each treatment was randomly split into three field replicates. A sample of one hundred berries was collected from each of these three field replicates. The average mass per berry was determined by weighing 50 of these berries with a three decimal digital scale (Precisa, Type. 280-9826, PAG Oerlikon AG, Zurich, Switzerland). Thereafter, the volume of these same 50 berries was determined by using the water displacement method. This method involved inserting berries into a measuring vial with a marked water level, and the displacement was noted for each sample set of 50 berries

To measure the total soluble solids (TSS) expressed as degrees Balling (°B), pH and titratable acidity (TA) of the berries, the remaining 50 berries of the 100 berries sample were coarsely liquidised using a handheld blender, and the clear juice was separated from the skins and seeds using a tea sieve. A few drops of the juice were placed onto a calibrated digital pocket refractometer (Atago PAL-1, Tokyo, Japan) to determine the balling of the grape juice. A pipet was used to extract 25 ml of the clear juice to which 25 ml of distilled water was added in a 100 ml glass beaker. The solution was analysed for pH and TA using an automatic titration device with sample changer (Metrohm 785 DMP Titrino, Herisau, Switzerland) connected to a bench pH meter (Crison Basic 20 with Crison 5531 PT1000 electrode, Barcelona, Spain).

3.2.6.2 Harvest and yield

The total number of bunches for each treatment in the trial was counted. The bunches from each individual treatment were then harvested and weighed together using a three decimal field scale (Viper SW 35 LA, Mettler-Toledo Pte Ltd, Ayer, Singapore) to give the total yield per treatment (kg). Furthermore, the average bunch mass per treatment could also be calculated using this data (yield per treatment/total bunch number). Grapes from each treatment and each field replicate were harvested and kept separate and was then used for micro-vinification. Harvest dates for all three seasons are displayed in Table 12 Harvest dates and corresponding days after budburst (DAB) for the treatments during both seasons..

The dates of harvest for each of the individual treatments during all three seasons, were determined by the results obtained from weekly berry sampling and analysis (refer to section 3.2.6.1). On the day of harvest, 150 berries were also sampled from each treatment and the same reproductive measurements conducted as during the ripening process.

Table 12 Harvest dates and corresponding days after budburst (DAB) for the treatments during both seasons.

Season	**Treatment**	**Harvest date**	**DAB**(1)
2011/12	HSDA(2), HSDB(3), LSDA(4), LSDB(5)	15/03/2012	177
	HC(6), LC(7)	14/03/2012	176
	R(8)	09/03/2012	171
2012/13	HSDA, HSDB	18/03/2013	173
	LSDA, LSDB	19/03/2013	174
	HC, LC	18/03/2013	173
	R	18/03/2013	173
2013/14	HSDA, HSDB, LSDA, LSDB	10/04/2014	198
	HC, LC	25/03/2014	182
	R	31/03/2014	188

(1) Days after budburst.
(2) High vigour Smart Dyson above
(3) High vigour Smart Dyson below
(4) Low vigour Smart Dyson above
(5) Low vigour Smart Dyson below
(6) High vigour control
(7) Low vigour control
(8) Reduced

3.2.7 Grapevine balance ratios

The yield:pruning mass ratio was determined on a per treatment basis using the yield and the pruning mass determined during harvest and winter pruning of the previous year respectively. Data obtained from destructive shoot measurements in order to determine leaf area (refer to section 3.2.5.3) was used to determine the ratio of leaf area to yield (LA/Y) on a per vine basis. Indices used in various sources of literature to determine grapevine fruit- and vegetative growth balances are specified in Table 13.

Table 13 Indices used to indicate vine balance [Iland *et al.* (2011) as modified by Davel (2015)].

Index	Description	Optimal value	References
Ravaz index (yield:pruning mass)	Yield per vine (kg)/ pruning mass per vine (kg)	5-12 7-10 4-10 4-10 5-10	Bravdo *et al*. (1984, 1985) Reynolds (2001) Kliewer & Dokoozlian (2000) Burger & Deist (1981) Smart (2001)
Potential exposed leaf area to fruit mass (SFEp)	Total exposed leaf area per vine (cm^2)/ yield per vine (g)	7-14	Carbonneau (1995) Carbonneau *et al*. (2000)
Leaf area/crop mass ratios	Total leaf area per vine (m^2)/ yield per vine (kg)	0.8-1.2m^2/kg (single canopy trellis systems) 0.5-0.8m^2/kg (horizontally divided canopy systems, such as Lyre and Geneva Double Curtain	Kliewer & Dokoozlian (2005)

3.2.8 Microvinification

During each individual season, wines of the three field replicates of all seven treatments were prepared at the DVO experimental cellar at Stellenbosch University according to their standard winemaking practices. This was done for all three seasons over which the trial ran.

3.2.9 Wine phenolic measurements

Samples from the field replicates were also split into three technical replicates each for phenolic analysis. A LKB Biochrom Ultraspec II E UV/Visible Spectrophotometer (LKB Biochrom Ltd, Cambridge, UK) was used to analyse wine colour. The spectrophotometric method as described by Iland *et al*. (2000a) was used to determine total red pigments, colour density, modified colour density, colour hue, modified colour hue and total phenolics.

3.2.10 Sensory evaluation

Wines made during all three seasons (2011/12, 2012/13 & 2013/14) underwent a pre-screening in order to determine whether the aroma, taste and mouth feel of various treatments within each season were distinctive enough to undergo quantitative descriptive analysis (QDA) (Lawless & Heymann, 1998). Since no clear distinctions could be found between the various treatments of the 2013/14 season, these wines were omitted, and only wines from the 2011/12 and 2012/13 underwent QDA in order to profile the aroma, taste and mouth feel properties. The wines evaluated comprised a total of 21 Shiraz wines (seven treatments with three field replicates each) of the 2011/12 season, and 12 wines of the 2012/13 season (four treatments of three field replicates each). The reduced number of wines that were analysed from the 2012/2013 season was due to samples of LC, LSDA and LSDB going missing from the storage area at the experimental cellar. The analysis was conducted in September 2014 using a panel consisting of nine females and one male between 25 and 60 years of age. The panel was trained to specifically recognise certain wine attributes and thereafter rate the defined set of attributes according to intensity on a line scale. Training for the 2012 vintage took place during eight sessions after which two final tests were conducted. For the 2013 vintage, six training sessions and three final tests were conducted. The descriptive analysis of the experimental wines was performed under controlled conditions, with each wine also being tasted with three technical replicates

Initially 16 aroma and two mouth feel attributes were identified for the wines of the 2011/12 vintage, and 19 aroma and four mouth feel attributes for the 2012/13 season (Table 14**Error! Reference source not found.** and

Table 15). Standards were prepared in order to train the panel to accurately identify these aromas in the experimental wines during the final tasting. The standards used for training purposes are also listed in the tables.

Table 14 List of attributes and standards used, defined by tasting panel for the sensory evaluation of 21 Shiraz wines (2011/12 season).

	Aroma	**Standard used**	**Mouth feel**
Attributes	Dark berries	Solution of 5 frozen blackberries "Hillcrest" + 10 ml distilled water	Bitterness
	Red berries	2 spoons of mixed strawberries, red currents and raspberries – “Hillcrest”	Astringency
	Vanilla/caramel	1/2 teaspoon "Vahine" vanilla essence	
	Eucalyptus	1 drop solution of Eucalyptol	
	Herbaceous	Half bottle of fresh grass	
	Cooked vegetables	1 teaspoon of chopped canned green beans – Koo	
	Woody	5 g new wood	
	Pencil shavings	1 tablespoon of pencil shavings - Staedtler	
	Soy/bovril/marmite	5 ml of Bovril	
	Balsamic	10 ml Balsamic vinegar Wellington’s	
	All spice	A small spatula of "Robertsons" All spice	
	Black pepper	2 g whole berries black pepper crushed	
	Tobacco	Dried tobacco from two cigarettes	
	Floral	Violet syrup (“Vendrenne”). 2 ml + 4 ml distilled water	
	Elastic band	Rubber bands	

Table 15 List of attributes and standards used, defined by tasting panel for the sensory evaluation of 15 Shiraz wines (2012/13 season)

	Aroma	Standard used	Mouth feel
Attributes	Earthy	Half a bottle wet soil	Sweetness
	Blueberry	2 spoons Blueberry sauce "St Dalfour"	Sourness
	Blackcurrant	Solution of 5 frozen berries "Hillcrest" + 10ml distilled water	Bitterness
	Black berry	Solution 5 ml "Vedrenne" syrup + 15 ml distilled water	Astringency
	Balsamic	10 ml Balsamic vinegar Wellington’s	
	Soy sauce	10 ml Kikkoman Naturally brewed Soy sauce	
	Vanilla/caramel	1/2 teaspoon "Vahine"vanilla essence	
	Black pepper	Robertson’s Black and white pepper mixed – 1 teaspoon (5 g)	
	Port	15 ml of Allesverloren Port	
	Prune/raisin	1 dried prune "Safari" cut into pieces	
	All spice	A small spatula of "Robertsons" All spice	
	Pencil shavings	1 tablespoon of pencil shavings - Staedtler	
	Woody/planky	5 g new wood	
	Tobacco	Dried tobacco from two cigarettes	
	Dry herbs	A small spatula of "Robertsons" mixed dried herbs	
	Eucalyptus	1 drop solution of Eucalyptol	
	Cooked vegetables	1 teaspoon of chopped canned green beans – Koo	
	Red berries	2 spoons of mixed strawberries, red currents and raspberries – “Hillcrest”	
	Coriander	2 teaspoons of crushed coriander seeds – Robertson’s spices	

3.3 Results and discussion

3.3.1 Climate measurements

3.3.1.1 Macroclimate

Although VINPRO reported on atypical rainy and cold conditions occurring during the phenological stage of flowering in the 2011/12 season (VINPRO, 2012), rainfall was not particularly high during November 2011 (**Error! Reference source not found.Error! Reference source not found.**). Over the three seasons, there was a progressive increase in total rainfall. When comparing cumulative rainfall during all three growing seasons (September until March of each season) it is evident that the 2011/12 was the driest of the three, with an accumulative rainfall of ~147 mm. 2012/13 and 2013/14 had ~273 mm and ~359 mm of rain respectively (**Error! Reference source not found.**).

The harvest of red grape cultivars was particularly challenging in the 2013/14 season due to untimely rainfall occurring when the grapes were ready to be harvested. This led to berry sugar concentration fluctuations and grapes struggling to achieve desired ripeness, as well as delayed harvest dates during 2014. Although there was also high rainfall during February 2013, ripening and harvest was not affected to the same extent as in the 2013/14 season when high rainfall was recorded during March. The reasons for this was that high rainfall was only present during three consecutive days in February 2013 and during the early stages of ripening, while the rainfall in March 2014 occurred every day for 16 consecutive days and during the time of harvest.

Table 16 Monthly rainfall (mm) with accumulative winter and summer rainfall indicated per season.

Season 2011/12		Season 2012/13		Season 2013/14	
Month	Rainfall (mm)	Month	Rainfall (mm)	Month	Rainfall (mm)
11-Sep	36.82	12-Sep	98.53	13-Sep	101.84
11-Oct	30.21	12-Oct	67.05	13-Oct	40.13
11-Nov	38.36	12-Nov	9.14	13-Nov	120.39
11-Dec	0	12-Dec	1.27	13-Dec	4.81
12-Jan	2.28	13-Jan	13.97	14-Jan	43.94
12-Feb	5.84	13-Feb	65.53	14-Feb	2.02
12-Mar	33.53	13-Mar	17.26	14-Mar	45.46
12-Apr	55.62	13-Apr	56.64		
12-May	64.23	13-May	68.07		
12-Jun	132.07	13-Jun	149.34		
12-Jul	131.55	13-Jul	85.86		
12-Aug	173.72	13-Aug	231.14		
Accumulated summer rainfall (Sept - March)	147.04		272.75		358.59
Accumulated winter rainfall (April-Aug)	557.19		591.05		

Rainfall during the winter months (July and August) seemed to be similar for 2011/12 and 2012/13. Due to the cold temperatures in the winter of 2011 sufficient cold units had accumulated relatively early, resulting in earlier budburst (VINPRO, 2012).

Initially, all three seasons displayed similar temperature accumulation. During the 2011/12 season, there was a slightly higher accumulation in temperature between 40 and 60 days after 1 September (indicated by higher growing degree days [GDD]), after which it was again similar to that observed in the 2012/13 and 2013/14 season up until 100 days after 1 September. For the remainder of the season the temperature accumulation for 2011/12 was lower when compared to the 2012/13 and 2013/14 seasons (Figure 10). This lowered temperature accumulation coincided with the flowering stage of 2011/12.

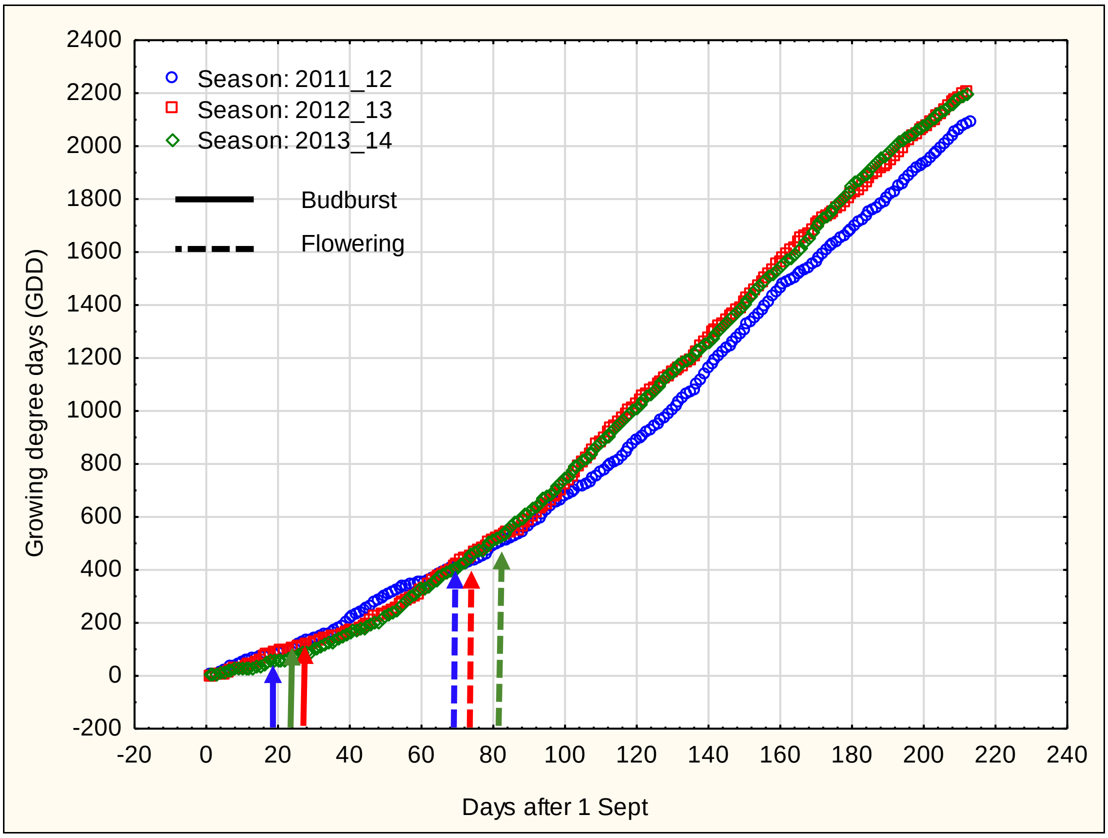

Figure 10 Growing degree days (GDD) relative to days after 1 September in all three seasons from budburst to the end of March.

As to be expected, the average daily temperatures measured at the trial site during all three seasons increased slightly from budburst to +/- 40 DAB but higher average daily temperatures were recorded for this period in time during 2011/12 compared to the same period of time for 2012/13 and 2013/14 seasons (Figure 11). However, thereafter average temperatures for the 2011/12 season decreased sharply between 40 to 60 DAB, which coincided with the phenological stage of flowering (Table 5), whereas mean average temperatures recorded during the same time for the 2012/13 and 2013/14 seasons where constantly higher and kept on increasing. Even though temperatures did increase during the 2011/12 season, it was consistently +/- 2˚C lower than the temperatures measured during 2012/13 and 2013/14

It should be noted that the phenological stages of flowering and full-bloom for all three seasons coincided with 40 to 60 DAB (Table 5, Table 6 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2012/13 season. and

Table 7 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2013/14 season.), which coincided with the month of November. Between 60 DAB and 150 DAB there was a steady increase in average temperatures for all three seasons. It was reported in the VINPRO harvest report of 2012 (VINPRO, 2012) that higher than usual temperatures were experienced during January 2012, but this was not evident when considering the mean temperatures measured during this stage of +/- 115 DAB (Figure 11).

Average daily temperatures during the 2011/12 flowering stage in November (50 DAB) were much cooler when compared to the temperatures experienced during the same time in the 2012/13 and 2013/14 seasons. The latter two seasons displayed similar accumulations in temperature throughout the growing seasons indicating that temperature differences between these two seasons were not substantial (Figure 11). The maximum GDD during 2011/12 was 2100, and during 2012/13 and 2013/14 it reached maximums of 2200 (Figure 10).

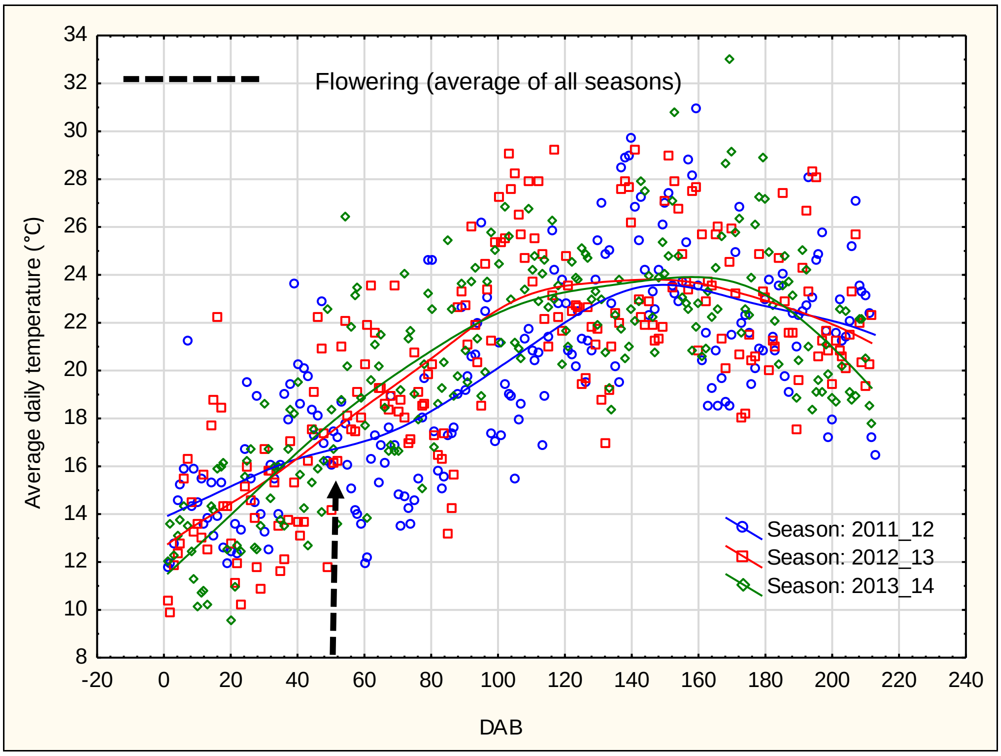

Figure 11 Average daily temperature relative to date of budburst (DAB) of all three seasons from budburst to harvest (end of March). The lines represent least-squares mean fits.

The 2011/12 season displayed the highest minimum temperatures initially, up until 24 DAB, after which the minimum temperatures for the rest of the season decreased and remained consistently lower when compared to the 2012/13 and 2013/14 seasons until 150 DAB. Thereafter, minimum temperatures for all three seasons decreased slightly until the respective harvest dates (Figure 12).

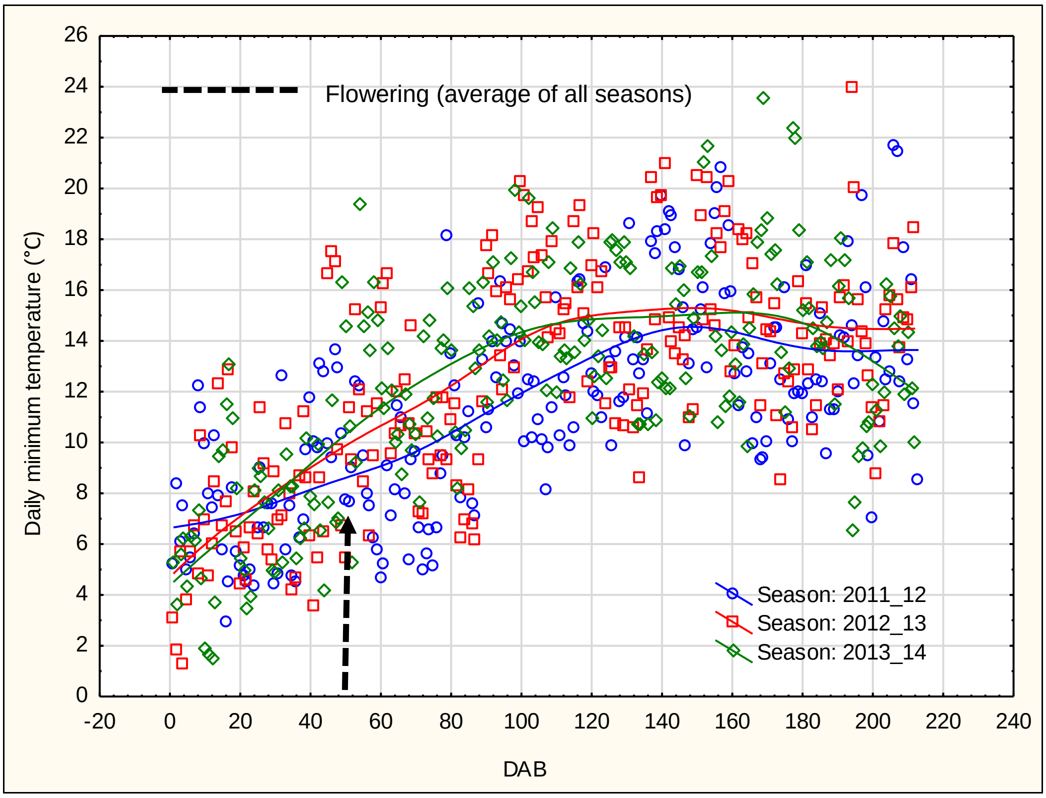

Figure 12 Minimum daily temperature relative to date of budburst (DAB) of all three seasons from budburst to harvest (end of March). The lines represent least-squares mean fits.

Maximum daily temperatures were initially higher during 2011/12 when compared to the following two seasons, but were substantially lower between 40 and 140 DAB when compared to 2012/13 and 2013/14 (Figure 13).

Maximum temperatures peaked at around 110 to 170 DAB during the 2012/13 and 2013/14 seasons, and only around 150 to 160 DAB during the 2011/2012 season. Even though 2011/12 was a much cooler season than both 2012/13 and 2013/14, temperatures increased sharply towards the end of November 2012. In general, temperatures reached over 40°C in all three seasons. The overall highest maximum temperature of 43°C was measured at 160 DAB (06/02/2012) in the 2011/12 season (Figure 13). The highest average daily temperatures were recorded during the 2013/14 season, and reached a maximum average daily temperature of 33°C on 170 DAB which was 16/02/2014 (Figure 11).

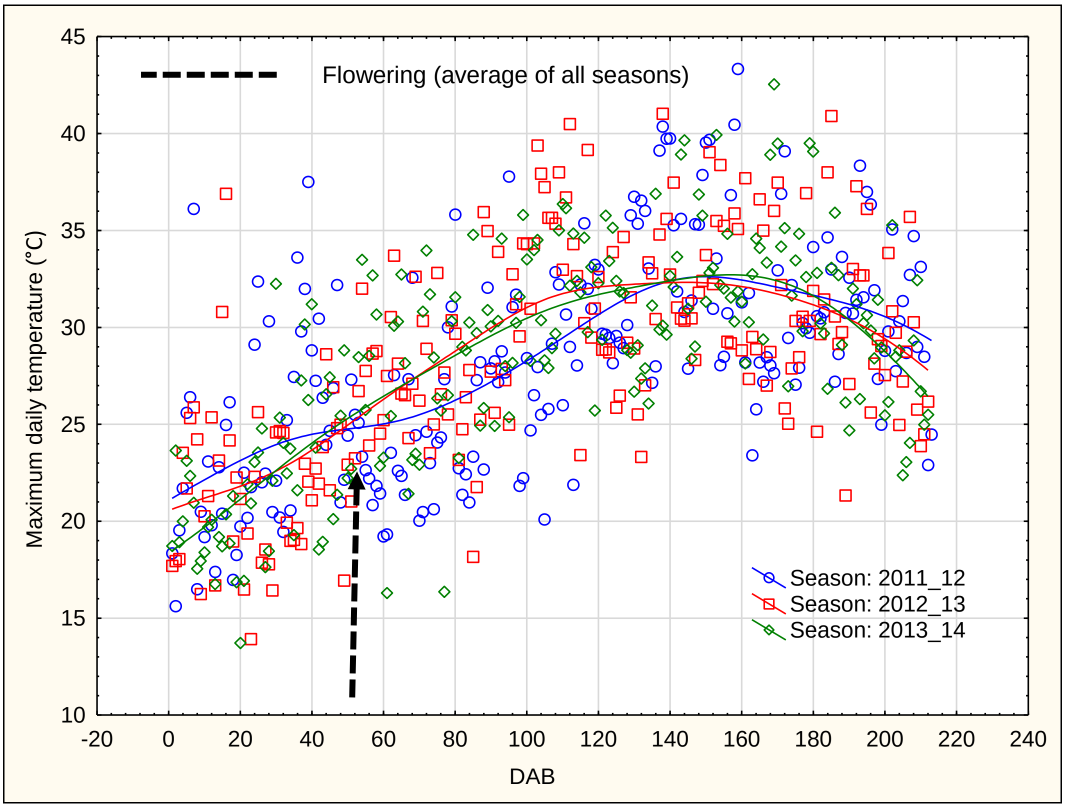

Figure 13 Maximum daily temperature relative to date of budburst (DAB) of all three seasons from budburst to harvest (end of March). The lines represent least-squares mean fits.

The region can be classified as a IV region according to Le Roux (1974), suggesting that it is capable of producing standard quality table wines (Table 17). Mean February temperatures (MFT) of 22.35°C, 23.15°C and 24.50°C were recorded for the 2011/12, 2012/13 and 2013/14 seasons respectively. This also confirmed that this region has a moderate to hot climate. However, it is notable that there is a vast difference in wine potential from the "moderate" to "hot" classification according to Table 18, suggesting that MFT in the 2011/12 should have theoretically produced wines with higher acids, lower pH and excellent cultivar character when compared to the following two warmer seasons.

Table 17 Classification of Western Cape wine growing regions with regard to growing degree days (GDD) according to Le Roux (1974).

Degree Days (°C)	Region	Viticulture potential
<1389	I	High quality red and white wine
1389-1666	II	Good quality red and white table wine
1667-1943	III	Red and white table wine and port. Natural sweet table wine
1944-2220	IV	Dessert wine, sherry and standard quality table wine
>2200	V	Dessert wine and brandy

Table 18 A guide to the mean February temperature (MFT) and the terms used to describe the climate for a growing region (adapted from de Villiers *et al*., 1996).

MFT (°C)	Description	Potential
17-18.9	Cold	High quality white table wine (high acids, low pH, excellent cultivar character)
19-20.9	Cool	High quality white and red table wines (high acids, low pH, excellent cultivar character)
21-22.9	Moderate	High quality red table wines (high acids, low pH, excellent cultivar character)
23-24.9	Hot	Low acid, high pH
>25	Very hot	Low acid, high pH

During the 2012/13 season, many vineyards in Stellenbosch were affected by strong winds (C. Schutte, personal communication, 2013). The mean wind speed for 2012/13 and 2013/14 is given in Figure 14 and it is clear that stronger winds occurred during the 2012/13 season. Two clear peaks of strong winds occurred around 19 DAB, and 66 DAB of the 2012/13 season. These dates corresponded with 15 October and 2 December 2012 respectively. Berry set was recorded to have taken place 63 DAB (Table 6 The dates and corresponding days after budburst for main phenological stages (as averages of all treatments, except in the case of harvest) during the 2012/13 season.), but despite of these strong winds occurring during flowering and set, there seems to have been no negative impact on set, since bunch mass, the number of bunches per treatment and total yield per treatment actually increased from 2011/12 to 2012/13.

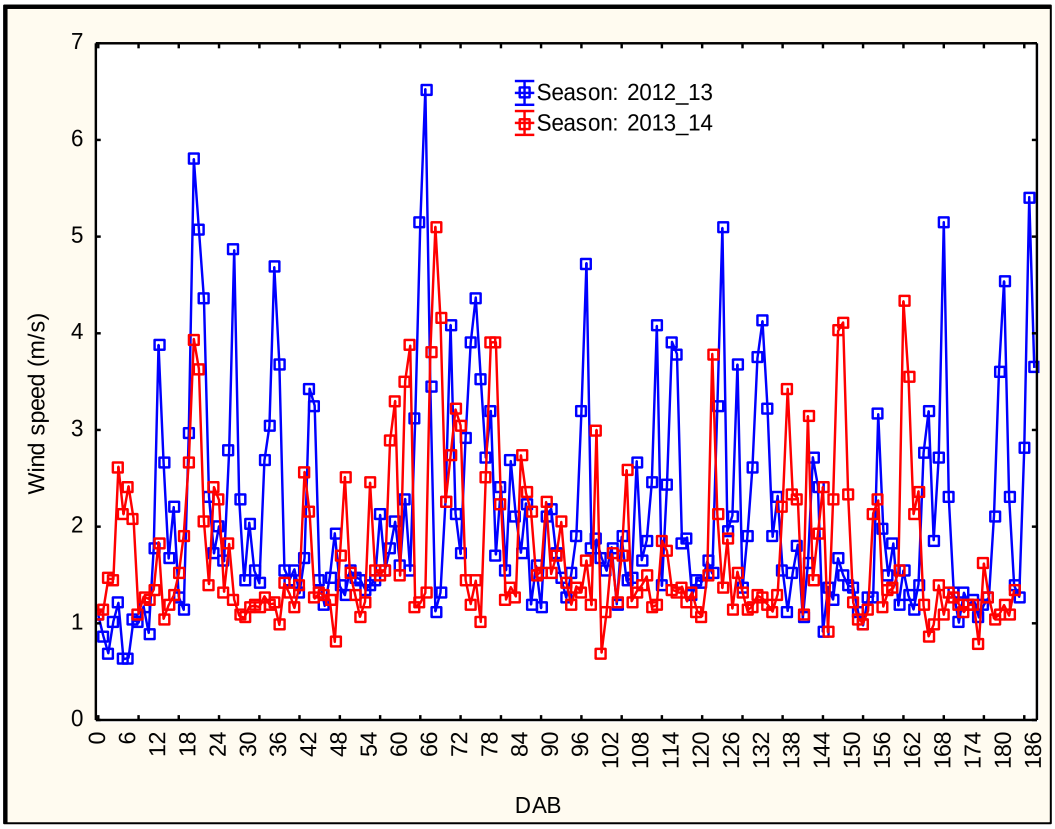

Figure 14 Wind speed relative to days after budburst (DAB) during 2012/13 and 2013/14.

3.3.2 Soil and plant water status measurements

3.3.2.1 Soil water status

Irrigation was applied similarly over all treatments based on plant water status. Soil water measurements were conducted on the block as a whole, and it was not treatment specific. When comparing rainfall recorded during the three growing seasons, it is clear that 2011/12 was a much drier season compared to 2012/13 and 2013/14 (**Error! Reference source not found.**). This was confirmed by VINPRO's findings in the harvest reports for 2011/12 and 2012/13 (VINPRO, 2012; VINPRO, 2013). Of all three seasons, 2013/14 received the highest rainfall during the growing season. Winter rainfall was similar during 2011/12 and 2012/13. Considering neutron probe data and pre-dawn leaf water potential (Ψ_{PD}) measurements, it was evident that vines experienced little stress during 2011/12 when compared to the 2013/14 season, even though the latter season received much more rain during the growing season. 2011/12 was also the coolest of the three seasons, which might explain why more vigorous growth, higher transpiration rates, higher water loss and higher water usage were experienced during 2012/13 and 2013/14. During 2013/14, vines experienced the highest stress levels of all three seasons. Less irrigation was applied during the 2013/14 compared to the other two seasons (Figure 15). Unfortunately the 2011/12 irrigation data is not available. As mentioned before, 2013/14 received the highest summer rainfall of all three seasons, and that is most likely why less irrigation was applied. Still the highest levels of stress were observed in all treatments during this season, which indicates that plant water status and soil water status was not enough to determine the actual water requirement of the converted vines.

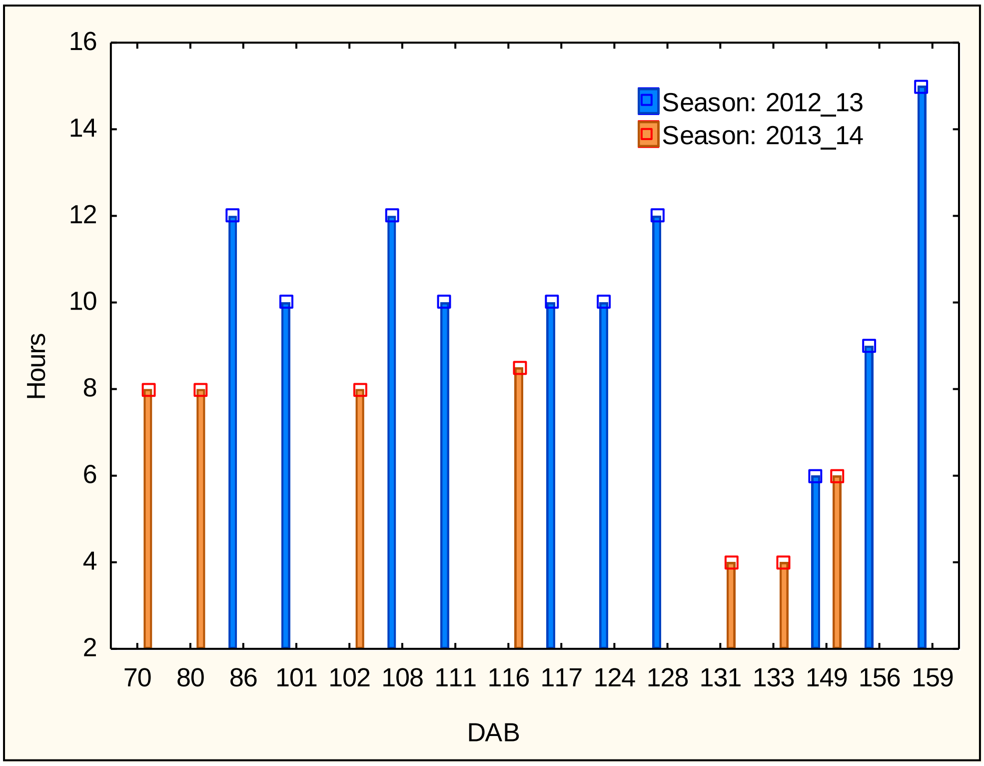

Figure 15 Hours of irrigation relative to days after budburst (DAB) during the 2012/13 and 2013/14 seasons.

As is indicated by the lower count ratio values, soil water levels in 2011/12 were consistently lower than that of the 2013/14 season for the period between 30 DAB and 130 DAB (Figure 16). It should also be noted that soil water levels in both the 2011/12 and 2013/14 seasons also decreased at similar tempos during this period between 30 DAB and 130 DAB. From 130 DAB onward the soil water levels for these two seasons were similar and consistently lower than that measured in the 2012/13 season. This trend is noticeable up until 165 DAB. From 165 DAB to 185 DAB, the soil water level for 2013/14 shows an increase and this coincided with late-season rainfall observed in March 2014 (harvest time). No measurements were conducted for the 2011/12 and 2012/13 seasons post 165 DAB and thus no speculation can be made for soil water level behaviour during this period for these two seasons.

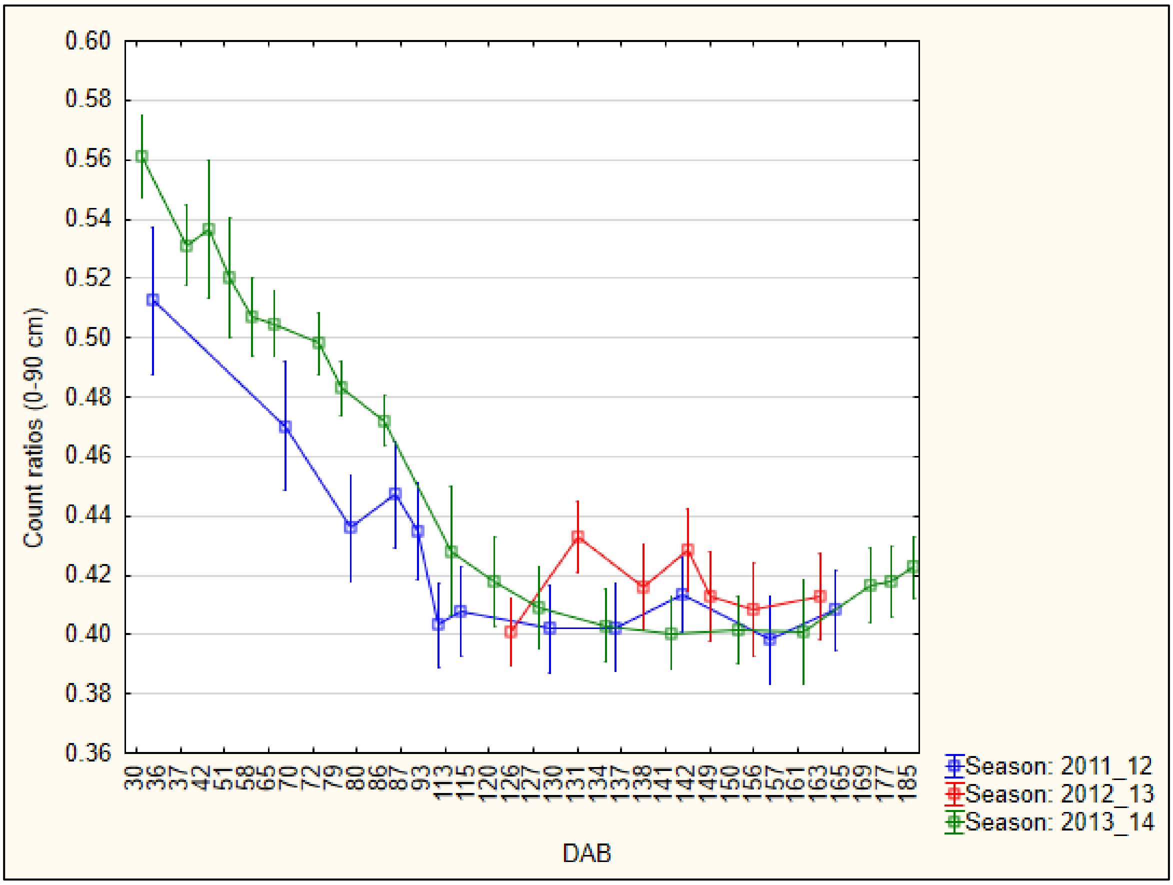

Figure 16 Soil water content for the 2011/12, 2012/13 and 2013/14 seasons represented by neutron probe readings (count ratios) using the average of the readings taken at 0-30 cm, 30-60 cm and 60-90 cm depths for each measurement point. Measurements commenced at 30 DAB for 2011/12 and 2013/14, and at 126 DAB for 2012/13.

3.3.2.2 Plant water status

During the 2011/12 season, the Ψ_{PD} of both HSD sub treatments was more negative than that of the HC and R treatment (Figure 17), the latter treatments therefore experiencing less water stress. When comparing the upward and downward positioned treatments, the HSDB initially displayed higher water stress levels with more negative values, but after 120 DAB (véraison), stress levels were similar to that of the HSDA treatment (Figure 17). The HC and R treatment displayed similar patterns of plant water status throughout the season. Between 123 and 130 DAB Ψ_{PD} became more negative for all four treatments indicating an increase in stress due to the reduced irrigation during véraison and fruit ripening.

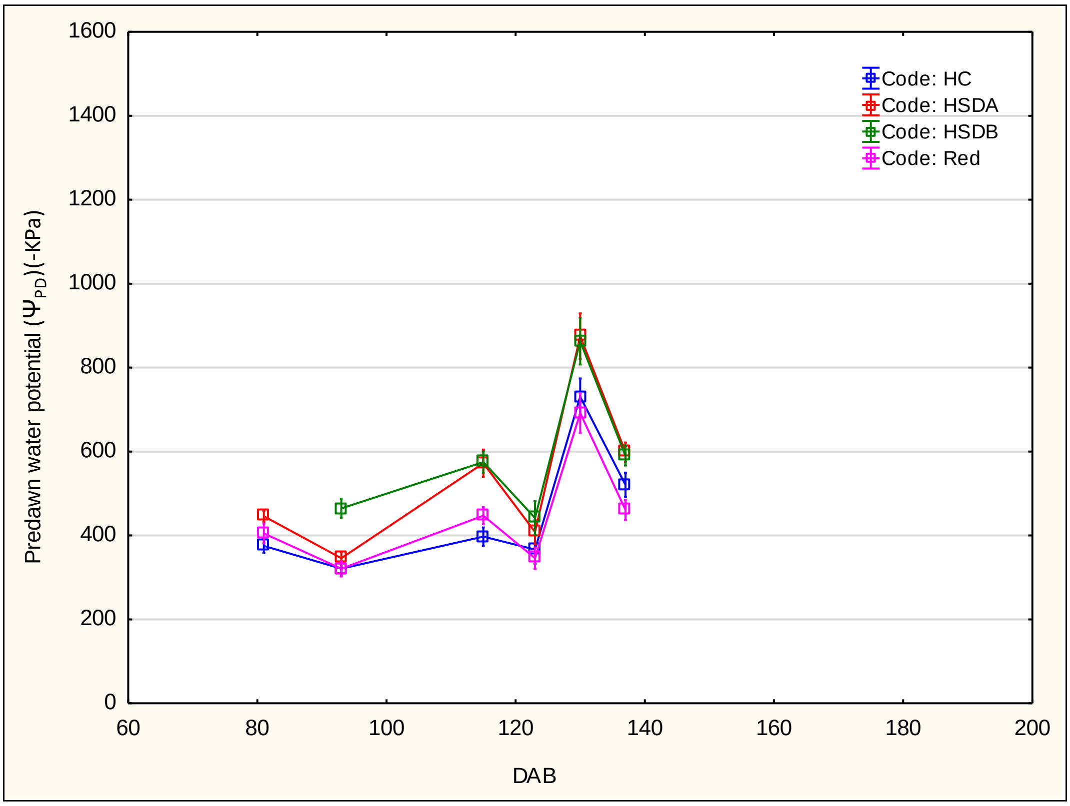

Figure 17 Predawn leaf water potential (Ψ_{PD}) relative to date of budburst (DAB) for the treatments in the 2011/12 season (means with ± standard errors shown).

During the 2012/13 and 2013/14 seasons, the pattern of water stress levels in all four monitored treatments was much more similar. However, whereas the maximum water stress during the 2011/12 season was experienced by the two SD treatments, with Ψ_{PD} reaching a value of -900 kPa at 130 DAB, maximum water stress levels increased during the 2012/13 and 2013/14 seasons to -1050 kPa and -1350 kPa respectively (Figure 18 and Figure 19) which is considered to be levels of severe stress which may start to have a negative impact on grape quality (Ojeda *et al*, 2002; Girona *et al*., 2009). All rapid increases where Ψ_{PD} values became less negative, indicating decreased water stress during the three seasons, corresponded with irrigation applications (Figure 15**Error! Reference source not found.**). When comparing Ψ_{PD} values at 140 DAB for 2012/13 and 2013/14, the values were less negative during the 2012/13 season indicating less water stress in this season than for 2013/14. It should be noted that this difference is extreme. Between 140 and 160 DAB of 2012/13, Ψ_{PD} values became increasingly negative, with stress levels for all treatments peaking at 160 DAB for this season (Figure 18). The opposite was noticed in the 2013/14 season during the same time span, with water stress levels actually decreasing between 140 DAB and 160 DAB. During this time, soil water levels remained relatively constant for all seasons (Figure 16). The high rainfall that occurred during March 2014 (Table 16), accounts for the decrease in water stress and increase in soil water levels post 160 DAB for 2013/14.

In general, 2013/14 displayed consistently more negative Ψ_{PD} values over the course of the season when compared to the values recorded during 2011/12 and 2012/13 This was despite the fact that the highest accumulative rainfall was recorded during 2013/14. Factors other than soil water levels or climate could therefore have played a role in these elevated water stress levels. Such factors could include an increase in vegetative and reproductive growth and more exposed canopies, causing higher transpiration rates and thus increased water demand (Van Zyl & Van Huyssteen, 1980; Smart & Robinson, 1991; Schmid & Schultz, 1999; Netzer *et al*., 2009).

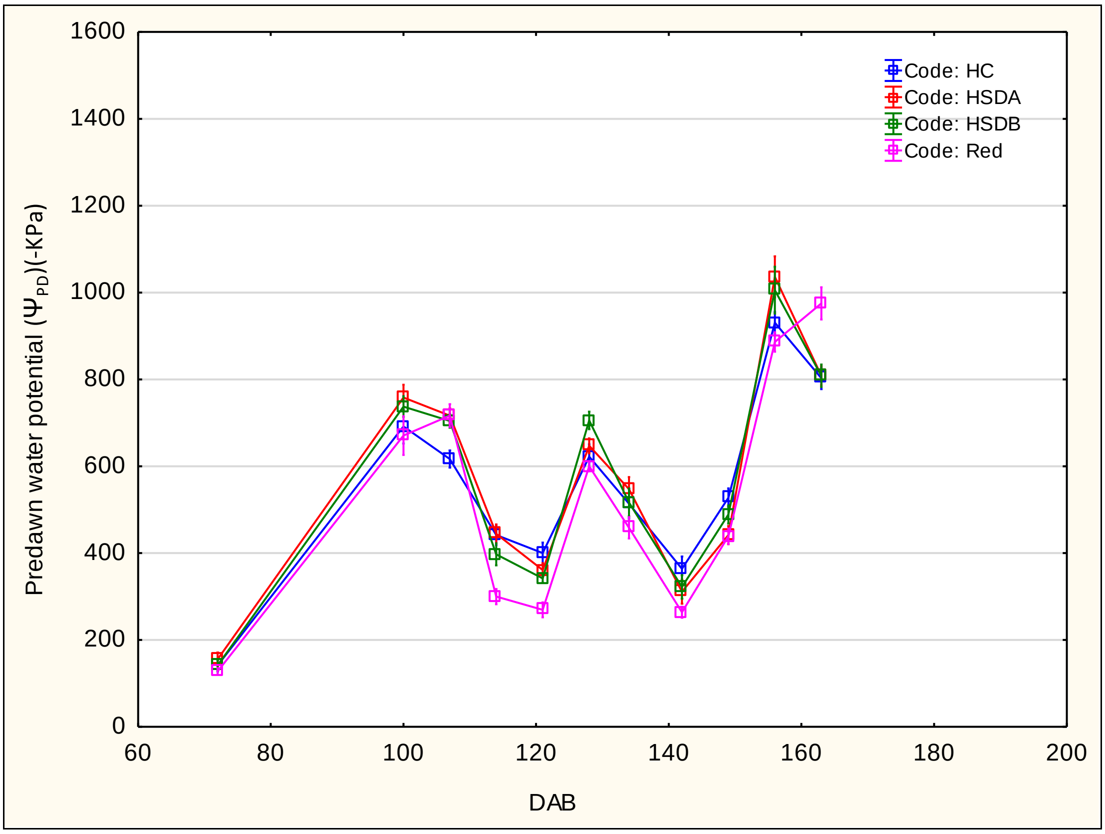

Figure 18 Predawn leaf water potential (Ψ_{PD}) relative to date of budburst (DAB) for the treatments in the 2012/13 season (means with ± standard errors shown).

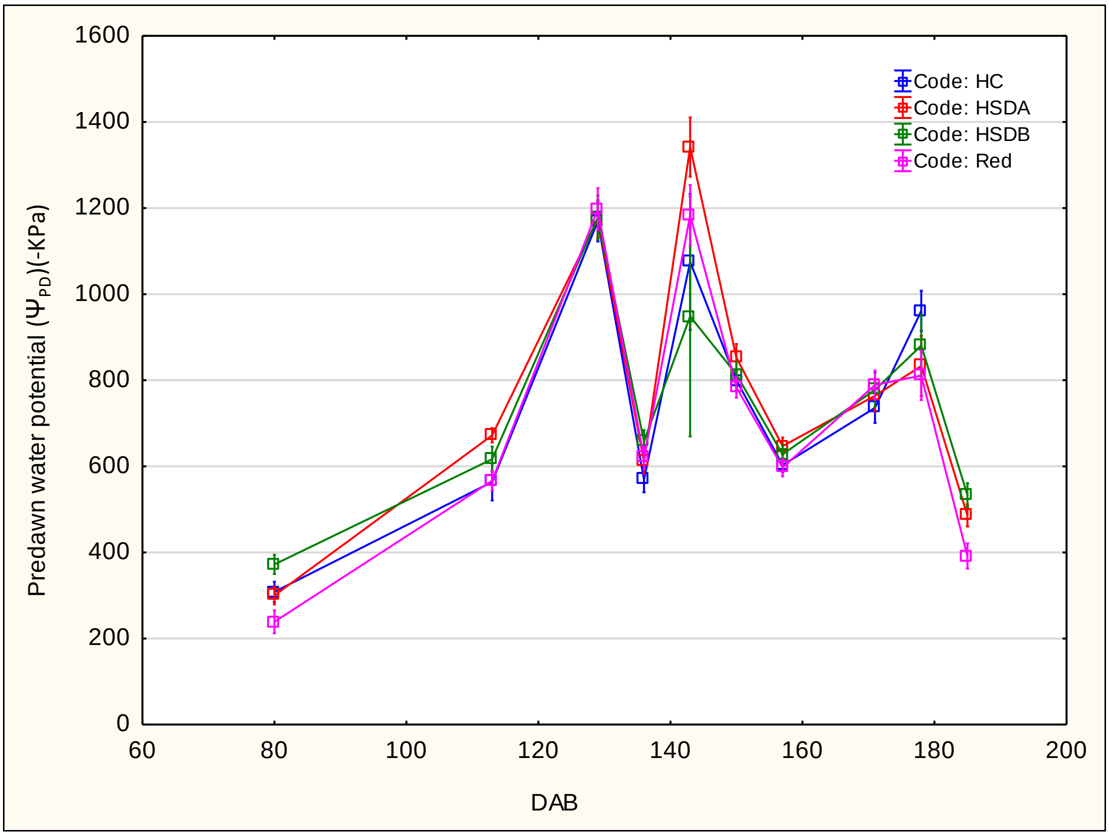

Figure 19 Predawn leaf water potential (Ψ_{PD}) relative to date of budburst (DAB) for the treatments in the 2013/14 season (means with ± standard errors shown).

3.3.3 Vegetative and reproductive measurements

3.3.3.1 Pruning

The increase in bud load of the SD treated vines (all four sub treatments) led to the obvious differences in cane numbers, as well as to differential effects on yield components. Over the course of the trial, there was a progressive increase in the number of canes per treatment for all four SD treatments, and the observed increase in this parameter can be ascribed to the fact that the treatments became more established over time (Figure 20). The initial number of canes for the two downward positioned SD treatments (HSDB and LSDB) was much lower than that of any of the other treatments and this was expected since the downward positioned canes for these two treatments had not yet been properly established. However, the number of canes of these two treatments increased steadily as the trial continued. Despite the increase in total cane numbers from 2011/12 to 2012/13 for the two upward positioned SD treatments (HSDA and LSDA), vigour decreased in terms of total pruning mass per treatment (Figure 21) and mean cane mass per treatment (Figure 22**Error! Reference source not found.**). This could be anticipated due to competition between the larger numbers of shoots for carbohydrate assimilate since the available resources had to be distributed amongst an increasing number of sinks (Sommer *et al*., 1995).

The two downward positioned SD treatments (HSDB and LSDB) reacted differently in terms of total pruning mass per treatment and mean cane mass per treatment. Total pruning mass per treatment steadily increased throughout the course of the trial (Figure 21) and the mean cane mass per treatment remained quite consistent over the three seasons (Figure 22). This indicates that the upward positioned treatments compensated for the higher demand created by the additional shoots of the downward positioned treatments by further distributing reserves and adding biomass to the downward positioned shoots. The number of canes per treatment was similar for the HC, LC, HSDA and LSDA treatments during the year of conversion (2011/2012). Figure 20 Number of canes per treatment for the different study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment.Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.There was a progressive increase in vegetative growth in the controls from 2011/12 to 2013/14, which was evident when considering the increases in cane numbers, total pruning mass per vine, mean cane mass per treatment, shoot length and shoot growth tempo. This was to be expected since higher temperatures and rainfall were recorded during 2012/13 and 2013/14 when compared to 2011/12 (VINPRO, 2012; VINPRO, 2013; VINPRO, 2014). This increased vegetative growth resulted in the higher transpiration rates, higher water loss and higher water usage identified as contributing factors to the increased water stress levels noted in the previous section (Figure 18 and Figure 19).

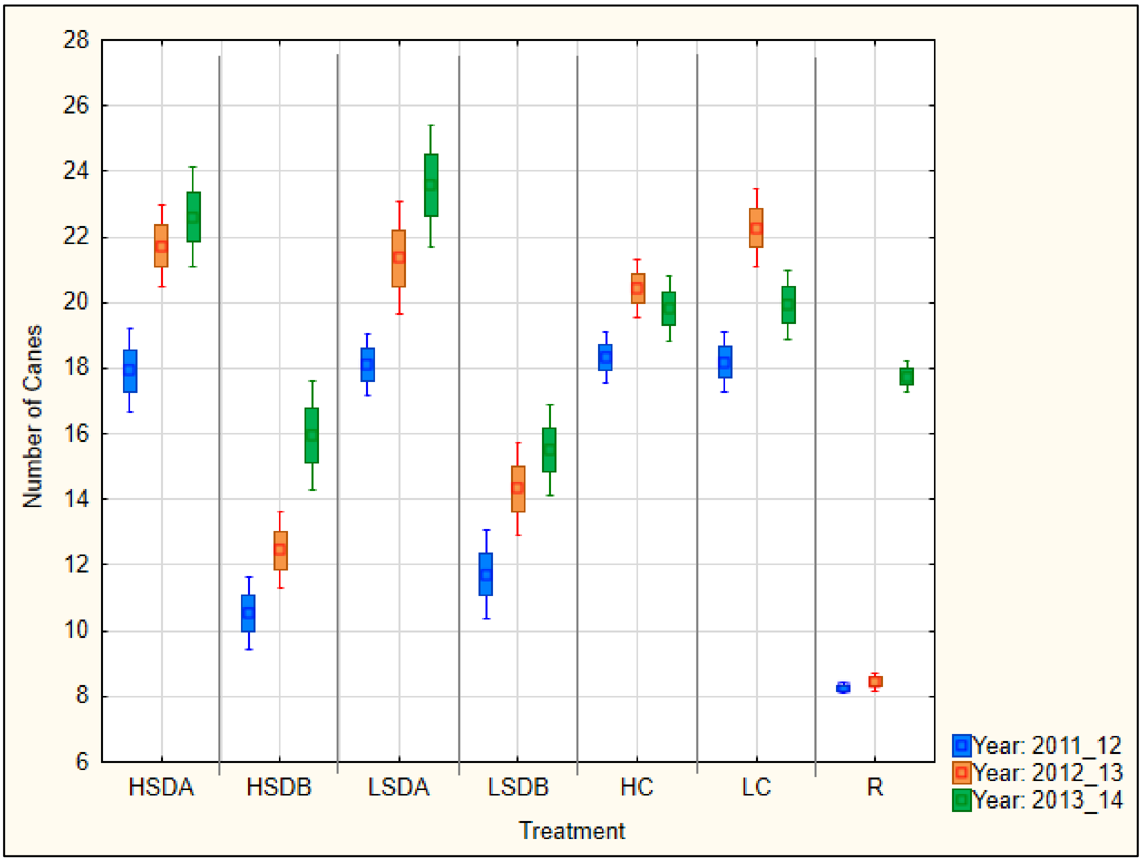

Figure 20 Number of canes per treatment for the different study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

The R treatment's number of canes remained unchanged from 2011/12 to 2012/13, but increased to more than double during 2013/14. This treatment was not executed in 2013/14 which explains the similarity in canes per vine between the R and controls for this season as is depicted in Figure 20.

Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment.There was a slight decrease in total pruning mass of HSDA and LSDA over the three seasons, while the HSDB and LSDB treatments displayed a continuous increase in total pruning mass. The mean cane mass of the latter two treatments remained unchanged. (Figure 21 and Figure 22). This could be expected considering that more biomass was consistently allocated to lower positions as the seasons progressed, combined with a treatment establishing effect. Despite the decrease in total pruning mass per treatment of HSDA and LSDA over the three seasons, these treatments still had higher total pruning mass per treatment compared to HSDB and LSDB. In the case of the modified training system treatments, another important factor is the contribution of both the upward and downward positioned canes (SD sub treatments) to the total vegetative components (pruning mass) of the vine (main SD treatment).

In the case of the HSDB canes, contribution to total pruning mass of the vine increased from 18% in 2011/12 to 36% in 2013/14 (which is an increase of 18%), with the ratio of HSDB:HSDA increasing from 0.22 to 0.56 (Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment.). A similar pattern was observed in the low vigour vines, where the downward positioned canes' contribution to total pruning mass of the LSD main treatment increased from 20% to 36%, with the ratio of LSDB:LSDA increasing from 0.25 in 2011/12 to 0.57 in 2013/14 (Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.). Even though the downward positioned canes in both of the SD main treatments seemed to become stronger over the three seasons, there were extremely large variations in the total pruning mass of the vines. The coefficient of variance (CV) of total pruning mass for the HSDB treatment in 2011/12 was 105% and decreased to 67% and 69% in the following two seasons, indicating less variability in the latter two seasons. The LSDB treatment displayed CV's with values of 77% (2011/12), 58% (2012/13) and 99% (2013/14), (Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment. and Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.). The increase in CV values of total pruning mass of the LSDB treatment from 2011/12 to 2013/14 indicated more variability in the 2013/14 season. This increased variability for the LSDB treatment, is a clear indication that low vigour vines are simply not equipped to compensate in full in reaction to a training system conversion such as a SD.

The total pruning mass of both HC and LC increased substantially from 2012/13 to 2013/14 (Figure 21) even though there was a slight decrease in the average canes per vine for 2013/14 (Figure 20). This in turn led to a much larger mean cane mass during 2013/14 (Figure 22). This observation might be ascribed to the fact that 2013/14 was the wettest of all three monitored seasons with the highest accumulative rainfall during the growing season including rain occurring as late as March 2014 (Table 16). This combined with the high average daily temperatures experienced during this season (Figure 11), initiated the higher vigour.

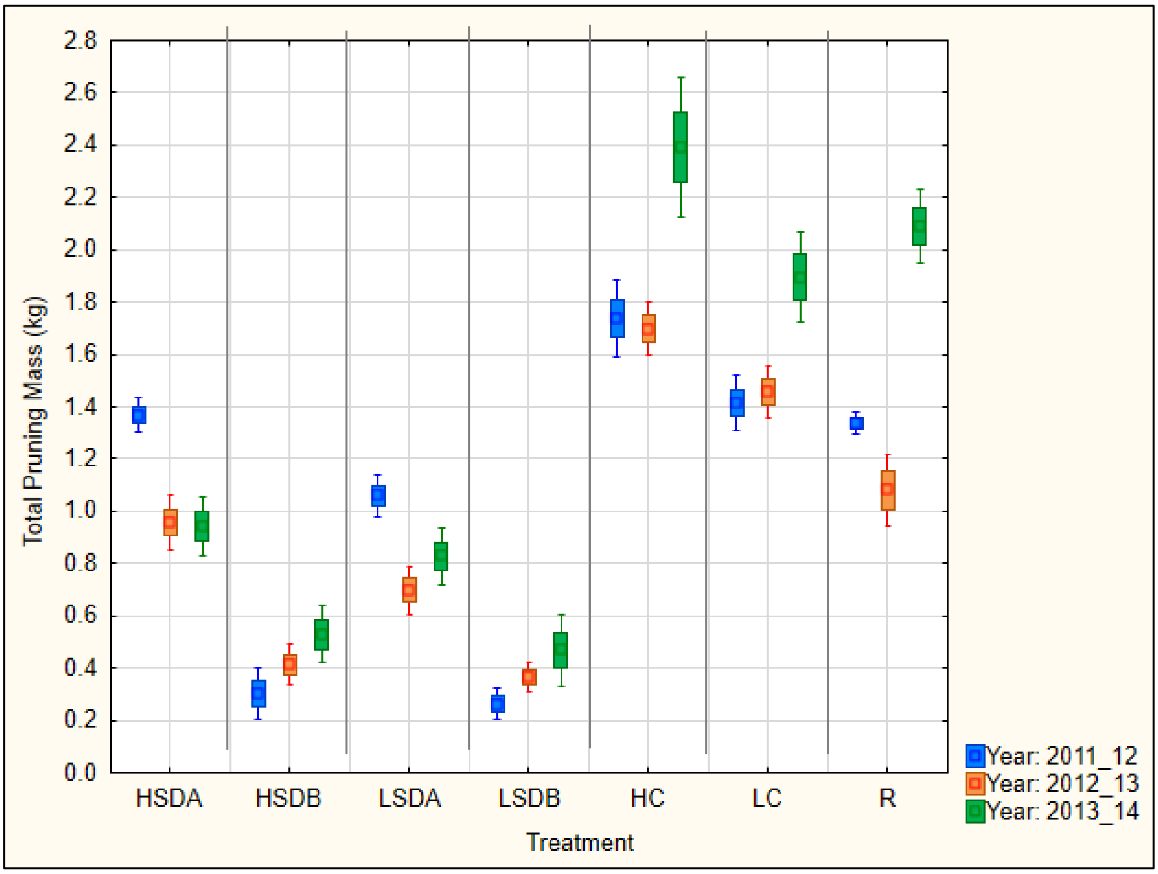

Figure 21 Total pruning mass (kg) per treatment for the different VSP treatments and SD sub treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

The mean cane mass of the HSDA and LSDA sub treatments determined during the initial measurements of the 2011/12 season were much higher in comparison to that of the HSDB and LSDB treatments respectively (Figure 22**Error! Reference source not found.** During the

2012/13 season, the mean cane mass of both the HSDA and LSDA sub treatments was greatly reduced to values very similar to that reported for the HSDB and LSDB treatments. This was due to a decrease in total pruning mass for the HSDA and LSDA treatments, as well as an increase in total number of canes. In 2012/13, the mean cane mass of the HSDB and LSDB sub treatments remained unchanged even though both total pruning mass and number of canes increased slightly (Figure 22, Table 19 and Table 20).

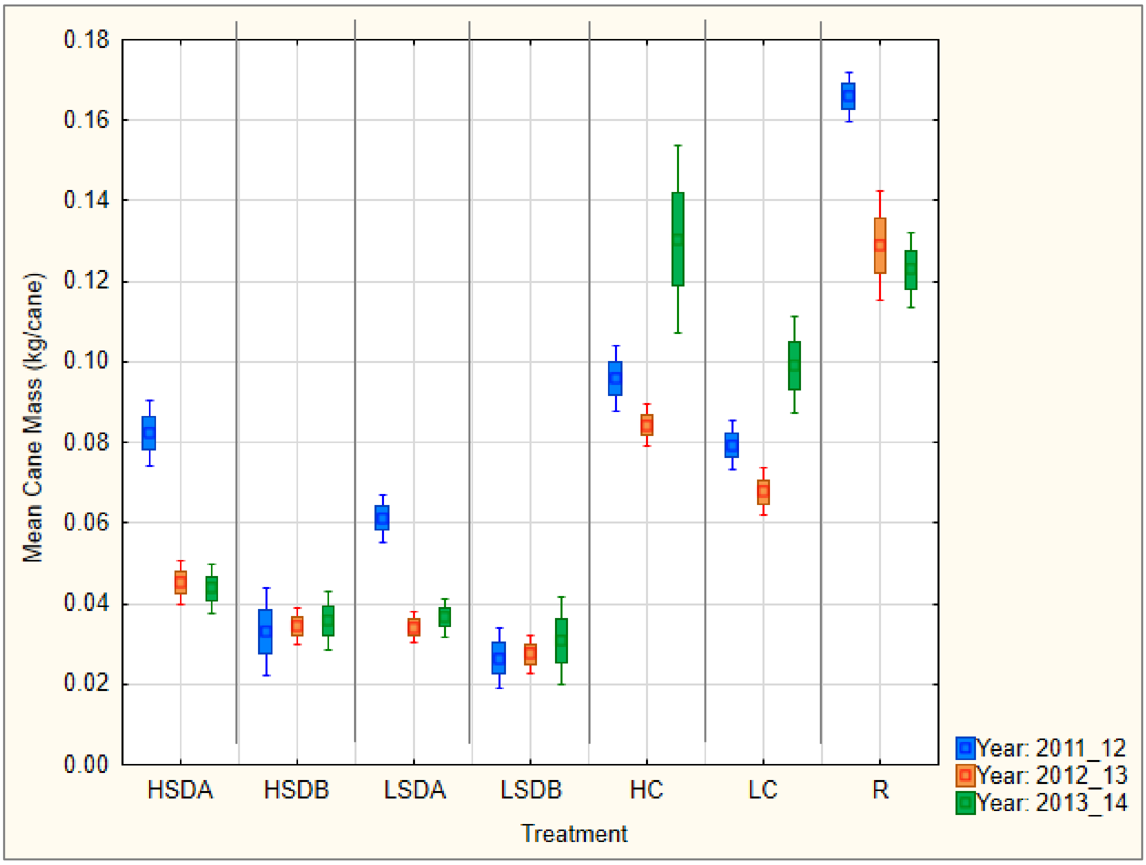

Figure 22 Mean cane mass (kg/cane) per treatment for the different VSP main treatments and SD sub treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

The total pruning mass per vine for the two controls (HC and LC) were consistently higher through the course of the trial, when compared to the combined total pruning mass for the HSD (HSDA+HSDB) and LSD (LSDA+LSDB) main treatments respectively (Table 21 Comparative statistical analysis for grapevine components as executed on the combined SD (above and below), HC, LC and R treatments.). When comparing the LC with the low vigour SD treatments (LSDA and LSDB), mean cane masses on a per treatment basis were consistently lower in the case of the latter. The same trend was observed when the mean cane mass per vine for the HC was compared to that of the high vigour SD treatments (HSDA and HSDB (Table 21 Comparative statistical analysis for grapevine components as executed on the combined SD (above and below), HC, LC and R treatments.).

Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment.

Season	Grapevine components	HSDA[1]				HSDB[2]					
		Mean	SD	CV (%)	n	Mean	SD	CV[)] (%)	n	HSD(A+B)[3]	Ratio HSDB:HSDA
2011/12	Yield/treatment (kg)	5.49	1.76	32	56	2.09	1.1	53	44	7.58	0.38
	Mass/bunch (kg)	0.17	0.04	24	56	0.11	0.03	27	44		0.65
	Number of bunches	34	10.3	31	56	18	6.6	36	44	52	0.53
	Canes/treatment	18	4.8	27	57	11	3.67	35	44	29	0.61
	Total pruning mass (kg)	1.37	0.26	19	57	0.3	0.32	105	45	1.67	0.22
	Mean cane mass (kg/cane)	0.08	0.03	37	57	0.03	0.04	109	44		0.38
	Ravaz	4.1	1.41	34	56	9.16	5.05	55	44		2.23
2012/13	Yield/treatment (kg)	6.72	1.8	27	49	4.1	1.57	38	51	10.82	0.61
	Mass/bunch (kg)	0.17	0.03	16	49	0.15	0.04	29	51		0.88
	Number of bunches	41	11	28	49	28	9.4	34	51	69	0.68
	Canes/treatment	22	4.6	21	54	12	4.1	33	52	34	0.55
	Total pruning mass (kg)	0.96	0.4	40	54	0.41	0.28	67	52	1.37	0.43
	Mean cane mass (kg/cane)	0.05	0.02	43	54	0.03	0.02	49	52		0.6
	Ravaz	7.93	3.11	39.28	49	11.45	5.49	48	51		1.44
2013/14	Yield/treatment (kg)	4.92	1.66	34	51	3.84	1.45	38	45	8.76	0.78
	Mass/bunch (kg)	0.12	0.03	26	51	0.1	0.03	33	45		0.83
	Number of bunches	43	14.5	34	51	38	13.66	36	45	81	0.88
	Canes/treatment	23	5.5	24	51	16	5.4	34	44	39	0.70
	Total pruning mass (kg)	0.94	0.4	42	51	0.53	0.37	69	45	1.47	0.56
	Mean cane mass (kg/cane)	0.04	0.02	51	51	0.04	0.02	67	44		1
	Ravaz	5.72	2.34	41	51	8.61	3.81	45	44		1.5

(1) High vigour Smart-Dyson above
(2) High vigour Smart-Dyson below
(3) High vigour Smart-Dyson above + high vigour Smart-Dyson below

Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.

Season	Grapevine components	LSDA[1]				LSDB[2]					
		Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	LSD(A+B)[3]	Ratio LSDB:LSDA
2011/12	Yield/treatment(kg)	4.6	1.28	28	59	2.01	0.95	47	42	6.61	0.44
	Mass/bunch (kg)	0.14	0.04	25	59	0.09	0.02	24	42		0.64
	Number of bunches	34	8	24	59	21	8.72	41	42	55	0.62
	Canes/treatment	18	3.68	20	59	12	4.32	37	43	30	0.67
	Total pruning mass (kg)	1.06	0.31	29	59	0.26	0.2	77	43	1.32	0.25
	Mean cane mass (kg/cane)	0.06	0.02	37	59	0.03	0.02	93	43		0.50
	Ravaz	4.64	1.65	36	59	9.3	4.44	48	42		2.00
2012/13	Yield/treatment (kg)	5.12	1.54	30	50	3.59	1.5	42	48	8.71	0.7
	Mass/bunch (kg)	0.14	0.04	26	50	0.13	0.02	19	48		0.92
	Number of bunches	39	12.13	31	50	28	11.14	39	48	67	0.72
	Canes/treatment	21	6.3	30	54	14	4.83	34	49	35	0.67
	Total pruning mass (kg)	0.7	0.33	47	54	0.37	0.19	53	49	1.07	0.53
	Mean cane mass (kg/cane)	0.03	0.01	43	54	0.03	0.02	58	49		1.00
	Ravaz	8.7	3.69	42	50	11.03	5.53	50	48		1.27
2013/14	Yield/treatment (kg)	4.03	1.56	39	47	3.27	1.08	33	46	7.3	0.81
	Mass/bunch (kg)	0.1	0.02	24	47	0.09	0.03	35	46		0.90
	Number of bunches	41	13	31	47	37	13.44	37	46	78	0.90
	Canes/treatment	24	6.3	27	47	16	4.6	30	45	40	0.67
	Total pruning mass (kg)	0.83	0.38	46	47	0.47	0.46	99	46	1.3	0.57
	Mean cane mass (kg/cane)	0.04	0.02	43	46	0.03	0.04	117	45		0.75
	Ravaz	5.4	2.5	46	47	9.47	4.3	45	46		1.75

(1) Low vigour Smart-Dyson above
(2) Low vigour Smart-Dyson below
(3) Low vigour Smart-Dyson above + low vigour Smart-Dyson below

Table 21 Comparative statistical analysis for grapevine components as executed on the combined SD (above and below), HC, LC and R treatments.

Season	Grapevine components	HC[(1)]				LC[(2)]				R[(3)]				HSD(A+B)[(4)]	LSD(A+B)[(5)]
		Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n		
2011/12	Yield/vine (kg)	5.63	1.61	29	59	4.7	1.62	34	60	2.77	1.11	40	323	7.58	6.61
	Mass/bunch (kg)	0.2	0.05	24	59	0.17	0.04	22	60	0.18	0.05	28	323		
	Number of bunches	29	6.3	22	59	28	6.26	23	60	15	4.25	29	323	52	55
	Canes/vine	18	2.96	16	59	18	3.6	20	60	8	1.5	18	325	29	36
	Total pruning mass (kg)	1.74	0.56	32	59	1.41	0.4	29	60	1.34	0.4	30	325	1.67	1.32
	Mean cane mass (kg/cane)	0.1	0.03	32	59	0.08	0.02	30	60	0.17	0.06	34	325		
	Ravaz	3.45	1.14	33	59	3.46	1.19	34	60	2.20	1.0	45	323		
2012/13	Yield/vine (kg)	6.51	1.92	30	54	5.52	1.59	29	55	3.17	1.19	38	148	10.82	8.71
	Mass/bunch (kg)	0.2	0.04	19	54	0.18	0.03	19	55	0.19	0.05	27	148		
	Number of bunches	32	6.4	20	54	31	6.97	23	55	16	4.55	28	151	69	67
	Canes/vine	20	3.21	16	56	22	4.4	20	55	8	1.65	20	151	34	35
	Total pruning mass (kg)	1.7	0.37	22	56	1.46	0.37	25	55	1.08	0.87	81	151	1.37	1.07
	Mean cane mass (kg/cane)	0.08	0.02	24	56	0.07	0.02	32	55	0.13	0.08	66	151		
	Ravaz	3.94	1.18	30	54	3.89	1.11	29	55	3.44	1.8	52	148		
2013/14	Yield/vine (kg)	5.52	1.17	31	50	4.79	2.05	43	59	5.73	1.86	33	156	8.76	7.3
	Mass/bunch (kg)	0.18	0.04	23	50	0.16	0.04	23	59	0.19	0.04	22	156		
	Number of bunches	31	7.42	24	50	29	9.87	34	59	31	8.06	26	156	81	78
	Canes/vine	20	3.60	18	54	20	4	20	58	18	3.06	17	159	39	40
	Total pruning mass (kg)	2.39	0.98	41	54	1.9	0.67	35	59	2.09	0.89	42	159	1.47	1.3
	Mean cane mass (kg/cane)	0.13	0.09	65	54	0.1	0.05	46	58	0.12	0.06	49	159		
	Ravaz	2.63	0.96	37	50	2.75	1.24	45	59	3.14	1.41	45	156		

(1) High vigour control
(2) Low vigour control
(3) Reduced canopy treatment
(4) High vigour Smart-Dyson above + high vigour Smart-Dyson below
(5) Low vigour Smart-Dyson above + low vigour Smart-Dyson below

3.3.3.2 Shoot growth tempo and shoot length

During 2011/12, the HSDA and LSDA treatments initially had shoot growth tempos and lengths similar to that of the R treatment, but at +/- 65-70 DAB, the growth tempo for these two SD treatments slowed down whereas the growth tempo of the R treatment increased. At 100 DAB, the shoots of all SD treatments stopped growing further, but this cessation of shoot growth was only observed at +/- 120 DAB for the R treatment and no cessation was noticed as yet for the controls at 130 DAB (when measurements stopped) (Figure 23). As expected, all three low vigour treatments (LSDA, LSDB and LC) had slower growth tempos and attained shorter shoot lengths by 130 DAB than the respective high vigour treatments (HSDA, HSDB and HC).

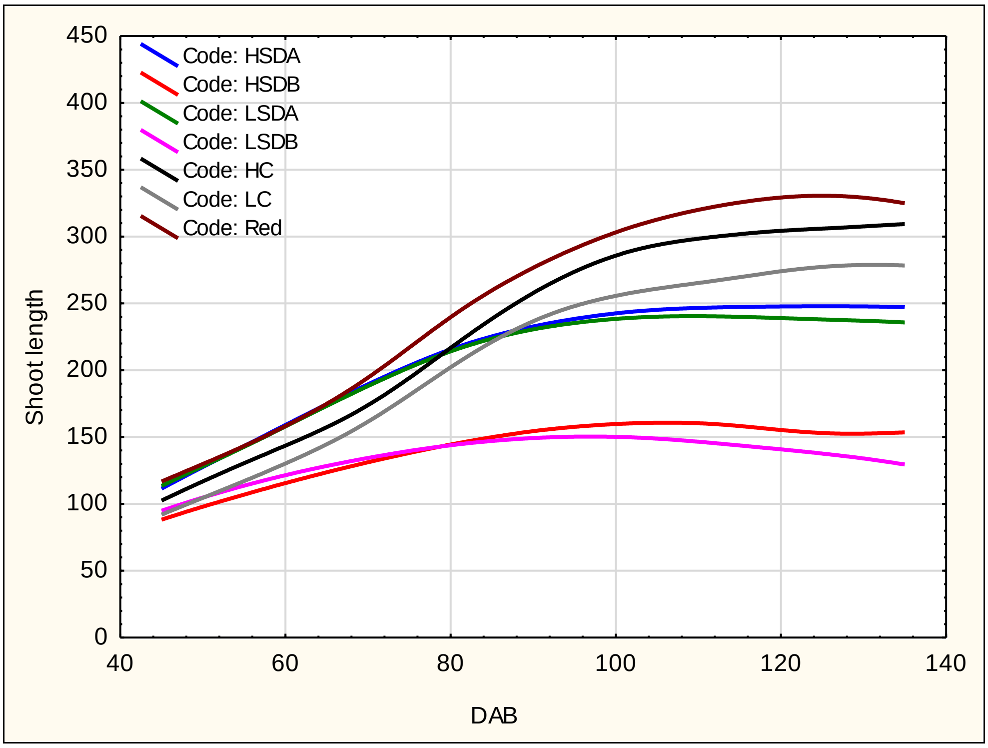

Figure 23 Primary shoot length (cm) relative to days after budburst (DAB) for the different treatments during season 2011/12 (distance weighted least squares fits are shown) through the mean of the data.

Shoot length of all treatments was less during 2012/13 when compared to 2011/12. During the 2012/13 season, the LC treatment started off with shoot lengths similar to that of the HSDB and LSDB treatments, thereafter displaying a substantial spike in both shoot length and growth tempo between 60 and 90 DAB, after which shoot length actually decreased, indicating that these shoots were topped (Figure 24). The HC treatment displayed consistent growth throughout the season with active growth as late as 125 DAB. There was almost a parallel growth curve when comparing the HC treatment with the R treatment, but the shoot lengths of the latter were shorter. Active growth was also still noticeable in the R treatment at 125 DAB. Starting off with the shortest shoot lengths of all treatments, both downward positioned SD treatments presented very little growth during this season and consistently had the shortest shoot lengths of all treatments. HSDA displayed a slightly higher growth tempo when compared to the three other SD treatments, but shoot length for HSDA decreased from 90 DAB onwards, just as for the other SD treatments, suggesting that the shoots of these four treatments were topped. When compared to the 2011/12 season, the difference in shoot length and -growth between the upward (HSDA and LSDA) and downward positioned (HSDB and LSDB) shoots was less pronounced, but the two low vigour SD treatments still fell in the lower regions of shoot length and -growth when compared to the high vigour SD treatments. There was a bigger discrepancy between the shoot lengths and growth of the two upward positioned SD treatments during 2012/13 than during 2011/12 (Figure 24).

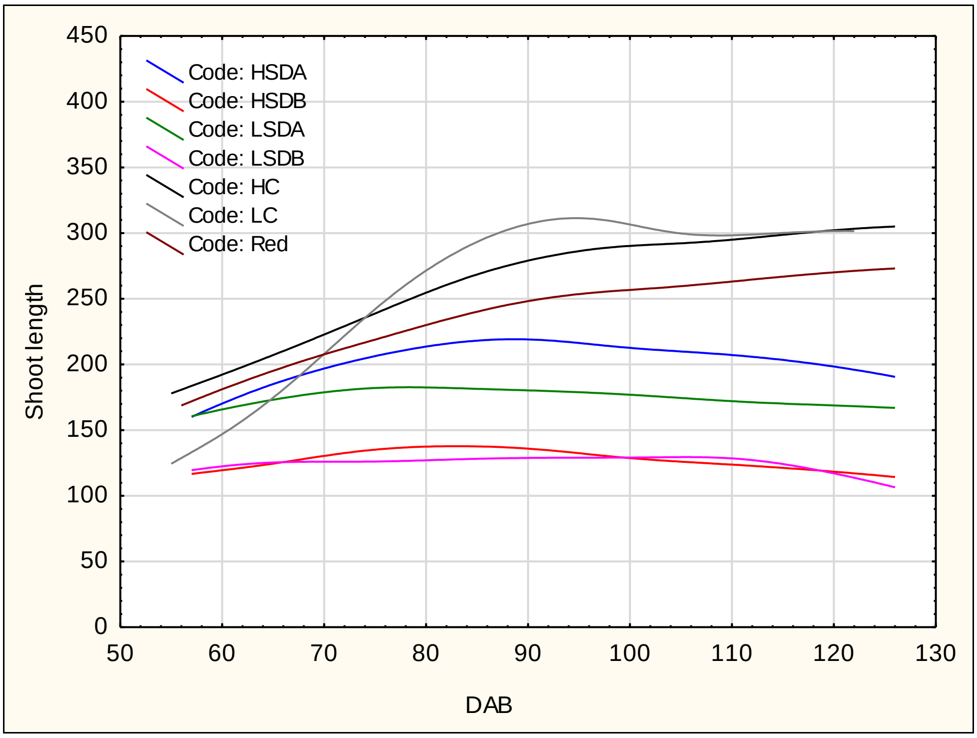

Figure 24 Primary shoot length (cm) relative to days after budburst (DAB) for the different treatments during season 2012/13 (distance weighted least squares fits are shown) through the means of the data.

During 2013/14, the shoots of the two downward positioned SD treatments were once again the shortest shoots of all treatments from 60 DAB onwards and exhibited virtually no growth (Figure 25Figure 24). For the same period, all SD treatments had shoots that were shorter than that of both controls and the R treatment. When comparing the shoot growth tempo for the HSDA and LSDA treatments for the 2012/13 and 2013/14 seasons, these treatments exhibited a faster rate of shoot growth in the 2013/14 season between 60 and 90 DAB. The shoot length attained at 90 DAB was, however, very similar for both HSDA and LSDA for these two seasons, with HSDA shoot lengths being almost identical and LSDA shoot length only approximately 20 cm shorter in 2013/14. Where the HSDA treatment exhibited a shoot growth tempo similar to that of the R treatment and controls, the growth tempo of the LSDA treatment decelerated earliest, and growth ceased at +/- 95 DAB along with the growth of HSDA and the two controls. After 95 DAB, shoot length of both HC and HSDA diminished, suggesting that the shoots were topped.

The R treatment had the longest shoots, and exhibited shoot growth until 100 DAB (Figure 25). It was clear that the R treatment’s high vegetative growth stimulated shoot growth as well as thickening (Dry & Loveys, 1998). This high vigour was evident from the mass per cane data, but also from shoot growth measurements.

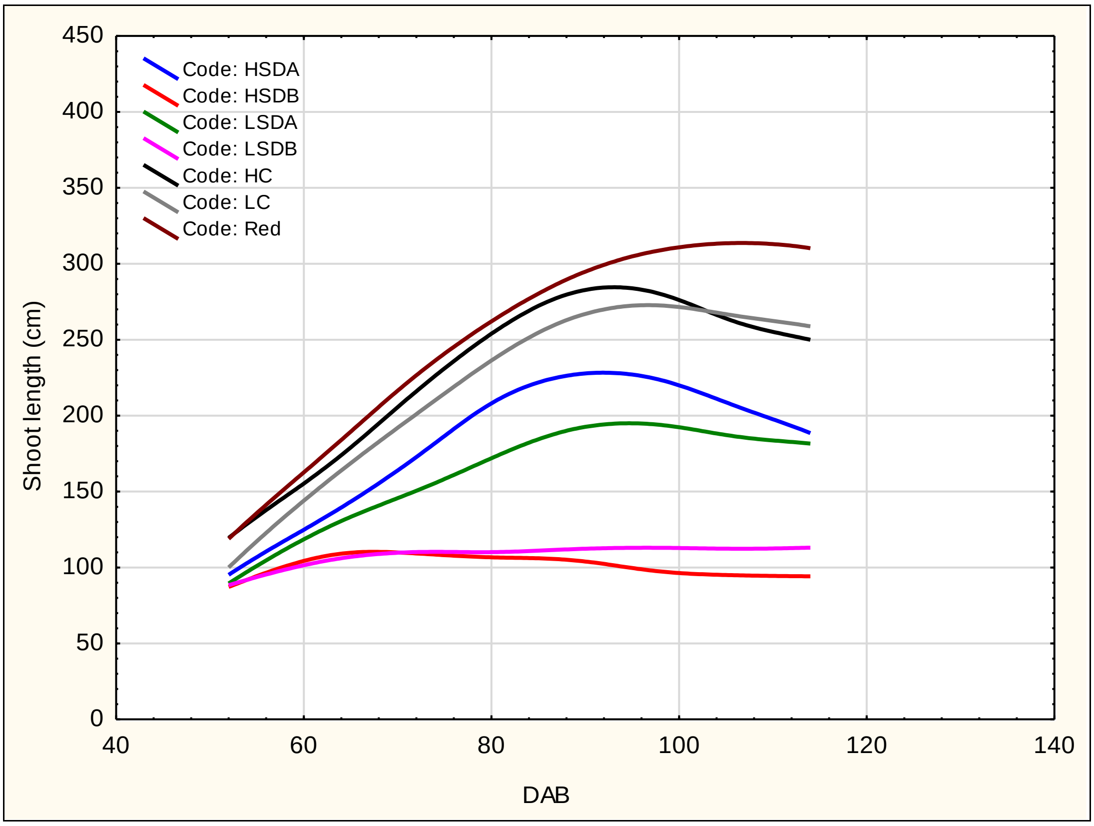

Figure 25 Primary shoot length (cm) relative to days after budburst (DAB) for the different treatments during season 2013/14 (distance weighted least squares fits are shown) through the means of the data.

Even though vegetative growth increased for the low vigour SD treatments (LSDA and LSDB) and control (LC), they consistently exhibited slower shoot growth tempos, attained shorter shoots lengths and had lower estimated total leaf areas per treatment relative to that of the three respective high vigour treatments (HSDA and HSDB) and control (HC). Increased leaf size and leaf number in the case of the low vigour SD treatments may have led to the increase in estimated total leaf area, since there were no large differences when comparing the shoot lengths of the HSDA with that of LSDA, or of the HSDB with that of LSDB.

Stronger vigour in terms of shoot growth tempo, shoot length and estimated total leaf area (cm^2) per treatment was observed in the upward positioned SD treatments (HSDA and LSDA), when compared to the downward positioned SD treatments (HSDB and LSDB). The latter treatments showed less increase in vegetative growth over the course of the field trial. Continuous topping actions on the downward positioned shoots contributed to this effect, but this observation was no surprise since it is also known that vegetative growth is encouraged in upward positioned shoots and suppressed in downward positioned shoots (Kliewer *et al*., 1989; Lovisolo & Schubert, 2000;). The decrease in the vegetative component as is usually found in downward positioned shoots is mainly due to lower total leaf area, decreased shoot lengths and lower levels of exposure relative to that of upward positioned shoots (Schubert *et al*., 1995). Regardless of this observation, the two downward positioned SD treatments still displayed an increase in vegetative growth, but it remained consistently less than that of the upward positioned SD treatments. This is a clear indication of the grapevine's ability to partially compensate in reaction to a modification in its balance by allocating more biomass to the downward positioned treatments. In the case of a divided canopy like the SD, leaves borne on the upward positioned shoots could compensate to an extent for the limitations in the downward positioned shoots by nature of increasing the potential exposed leaf area (A. Strever, personal communication, 2020). When considering that the difference in vegetative components, such as total pruning mass per treatment and mean cane mass per treatment, became less pronounced between the low vigour and high vigour SD vines over the course of the trial, it can be concluded that the treatment effects were more evident over time as the treatments became more established.

3.3.3.3 Destructive shoot measurements.

During the season of conversion, 2011/12, the estimated total leaf area (cm^2) per treatment of the upward positioned shoots of both SD main treatments (HSDA and LSDA) were more or less 60% more than that of the respective downward positioned SD treatments (HSDB and LSDB). In the seasons to follow, the upward positioned treatments continuously had larger estimated total leaf areas when compared to that of the downward positioned treatments. Leaf area can be affected by both leaf number and leaf size, therefore the increase in total estimated leaf area could have been due to an increase in the number of leaves present per treatment (due to longer shoot lengths and/or an increase in number of canes), an increase in the size of the leaves present or both. The substantial differences in the number of canes between the upward positioned treatments and the downward positioned treatments, with the combined effect of longer mean primary shoot lengths as in this case, explain the larger values for estimated total leaf area for the HSDA and LSDA treatments when compared to the HSDB and LSDB treatments (Table 22).

When comparing the two upward positioned treatments with each other over the course of the three seasons, the HSDA treatments displayed a decrease in shoot length, whereas the shoot lengths as measured in the LSDA treatment remained similar. The LSDB treatment's shoot lengths were consistently the shortest of all treatments. This may be due to a topping effect, but may also be an indication of the lower vigour converted vine being unable to compensate fully in reaction to a modified balance.

A lower average number of canes per vine combined with shorter mean primary shoot lengths led to the HSDB treatment displaying the lowest estimated total leaf area per treatment of all treatments during 2012/13 and 2013/14. Only during 2011/12 was the estimated total leaf area the lowest for LSDB, but this parameter increased for LSDB over the next two seasons.

As the seasons progressed, the two low vigour SD treatments (LSDA and LSDB) consistently exhibited lower total leaf areas per treatment when compared to that of the two high vigour SD treatments (HSDA and HSDB) respectively (Table 22). This was quite surprising, since when comparing the shoot lengths of the HSDA with the LSDA, and the shoot lengths of the HSDB with

LSDB, there were no large differences in shoot length. In this case, increased leaf sizes may have played a role.

The estimated total leaf area per vine for the LSD main treatment (LSDA and LSDB combined) was initially lower than that of the HSD main treatment (HSDA and HSDB combined) during the season of conversion, but as the seasons progressed, this parameter for the LSD main treatment increased, whereas it decreased for the HSD main treatment. Estimated total leaf area per vine for the HSD main treatment was lower than that of the LSD main treatment during both 2012/13 and 2013/14, and it can partly be attributed to a general decrease in both mean main shoot lengths as well as mean lateral shoot lengths for both the HSDA and HSDB treatments over these seasons. The estimated total leaf area per vine for the main LSD treatment increased continually over the three seasons, with an increase of 30% from 2011/12 to 2013/14, whereas this parameter kept on decreasing for the main HSD treatment, with a reduction of 32% from 2011/12 to 2013/14 (Table 22).

When looking at estimated total leaf area per vine, it was 28.5% larger for the HSD main treatment than for the HC for the 2011/2012 season, but the former's leaf area decreased over the next two seasons to values lower than that of the HC. During 2011/12 and 2012/13, the HC consistently had higher estimated total leaf areas when compared to the LC (data pertaining to the LC during 2013/14 was lost, and there cannot be speculated about the reasons for the observed values for estimated total leaf area during that season). The estimated total leaf area for the HC increased steadily over the three seasons, with a total increase of 28% in this parameter by the 2013/14 season. Percentage wise, the largest overall increase in estimated total leaf area over the three seasons was recorded for the R treatment, showing an increase of 54% from 2011/12 to 2013/14. This was expected since the treatment was not executed during 2013/14, leading to a drastic increase in number of canes and this was combined with long shoot lengths. The later also contributing to the observed increase in estimated total shoot length per treatment.

From 2011/12 to 2012/13, the estimated total leaf area per treatment for LSDB increased substantially by 35%, even though the number of canes per treatment only increased slightly and there was a reduction in both mean primary shoot length and mean lateral shoot length (Table 22). Taking that into consideration, the increase in estimated total leaf area for the LSDB treatment must have been due to an increase in the size of the primary and lateral leaves. The other six treatments displayed very little difference in estimated total leaf area per treatment during this same period. From 2012/13 to 2013/14, the LSDB treatment displayed a decrease in this parameter attaining a value similar to that measured in 2011/12. The estimated total leaf area per treatment generally increased over the course of the trial for the high vigour control and from 2011/12 to 2012/13 for the low vigour control (no 2013/14 data for the latter). When comparing the four SD sub treatments, the largest increase in total estimated leaf area per treatment from 2011/12 to 2013/14 occurred in the LSD sub treatments (LSDA and LSDB).

Table 22 Comparative table of vegetative components measured during detailed shoot destruction throughout the 2011/12, 2012/13 and 2013/14 seasons.

Season	Vegetative component	HSDA[1]	HSDB[2]	LSDA[3]	LSDB[4]	HC[5]	LC[6]	R[7]	HSD(A+B)	LSD(A+B)
2011/12	Mean primary shoot length (cm)	265	135	226	126	208	184	273		
	Mean lateral shoot length (cm)	30	19	38	34	32	29	44		
	Estimated mean primary shoot leaf area (cm^2)	2386.08	1336.47	2074.08	1258.97	1928.83	1728.80	2450.99		
	Estimated mean lateral shoot leaf area (cm^2)	1253.07	806.49	806.49	466.12	1610.46	1190.28	1659.75		
	Estimated mean total leaf area per shoot (cm^2)	3609.15	2142.95	2880.56	1725.09	3539.28	2919.08	4110.74		
	Estimated total leaf area per treatment (cm^2)	65504.70	23572.45	51850.08	20701.08	63707.04	52543.44	32885.92		
	Estimated total leaf area per vine (cm^2)					63707.04	52543.44	32885.92	89077.15	72551.13
	Estimated leaf area:fruit mass ratio (cm^2/g)	11.93	11.28	11.27	10.30	11.31	11.18	11.87	11.75	10.98
2012/13	Mean primary shoot length (cm)	109	105	223	108	183	203	211		
	Mean lateral shoot length (cm)	30	11	23	27	54	49	36		
	Estimated mean primary shoot leaf area (cm^2)	1118.23	1091.82	2045.27	1116.56	1722.31	1883.79	1947.89		
	Estimated mean lateral shoot leaf area (cm^2)	878.86	285.18	345.82	1148.81	2089.32	1207.88	1623.37		
	Estimated mean total leaf area per shoot (cm^2)	1997.09	1376.99	2391.08	2265.37	3811.63	3091.67	3571.26		
	Estimated total leaf area per treatment (cm^2)	43935.98	16523.88	50212.68	31715.18	76232.6	68016.74	28570.08		
	Estimated total leaf area per vine (cm^2)					76232.6	68016.74	28570.08	60459.86	81627.86
	Estimated leaf area:fruit mass ratio (cm^2/g)	6.54	4.03	9.81	8.83	13.81	11.71	5.17	5.58	9.35

[1] High vigour Smart-Dyson above
[2] High vigour Smart-Dyson below
[3] Low vigour Smart-Dyson above
[4] Low vigour Smart-Dyson below
[5] High vigour control
[6] Low vigour control
[7] Reduced canopy treatment

Table 22 (Continued) Comparative table of vegetative components measured during detailed shoot destruction throughout the 2011/12, 2012/13 and 2013/14 seasons.

Season	Vegetative components	HSDA(1)	HSDB(2)	LSDA(3)	LSDB(4)	HC(5)	LC(6)	R(7)	HSD(A+B)	LSD(A+B)
2013/14	Mean primary shoot length (cm)	147	96	258	91	232		277		
	Mean lateral shoot length (cm)	18	26	65	59	190		122		
	Estimated mean primary shoot leaf area (cm^2)	1430.19	1014.73	2329.28	977.40	2119.92		2488.12		
	Estimated mean lateral shoot leaf area (cm^2)	264.64	354.62	812.35	746.63	2277,11		1475.48		
	Estimated mean total leaf area per shoot (cm^2)	1694.83	1369.35	3141.63	1724.03	4397.03		3963.6		
	Estimated total leaf area per treatment (cm^2)	38981.09	21909.60	75399.12	27584.48	87940.6		71344.8		
	Estimated total leaf area per vine (cm^2)					87940.60		71344.80	60890.69	102983.6
	Estimated leaf area:fruit mass ratio (cm^2/g)	7.92	5.70	18.71	8.44	15.93		12.45	6.95	14.11

(1) High vigour Smart-Dyson above
(2) High vigour Smart-Dyson below
(3) Low vigour Smart-Dyson above
(4) Low vigour Smart-Dyson below
(5) High vigour control
(6) Low vigour control
(7) Reduced canopy treatment

Total leaf area is not the only factor contributing to the efficiency of the canopy of a grapevine. The composition of the total leaf area per vine also needs to be considered, since it plays a great role in bunch development and the contribution to the level of productivity of the canopy (Hunter, 2000). The concept of composition of the total leaf area per vine refers to the contribution of primary leaf area and lateral leaf area to the total leaf area of the vine. Therefore, the contribution of lateral leaves towards the estimated total leaf area also needs to be considered. The ratios of mean lateral shoot leaf area to mean primary shoot leaf area are presented in Table 23.

The contribution of lateral leaves towards the estimated total leaf area decreased from 2012/13 to 2013/14 for the HSDA and HSDB treatments. There was an increase in the ratio of mean lateral shoot leaf area to mean primary shoot leaf area for the LSDB treatment and the HC from 2011/12 to 2012/13, after which it decreased slightly during 2013/14. However, during 2013/14 these two treatments still had the highest ratios of all the treatments. Together with a very high ratio of lateral leaf area to primary leaf area, the shortest primary shoots of all treatments during the 2013/14 season was measured for the LSDB treatment. This indicates the effect that topping had on these shoots, stimulating the formation of lateral shoots. The LSDA treatment's ratio decrease from 2011/12 to 2013/14, after which it increased again during 2013/14 to a value close to that measured during 2011/12. There did not seem to be a big fluctuation in the contribution of lateral leaves to total leaf area per treatment for the R treatment and LC over the course of the trial.

Table 23 Comparative table of mean lateral shoot leaf area:mean primary shoot leaf area measured during detailed shoot destruction throughout the 2011/12, 2012/13 and 2013/14 seasons

Treatment	Lateral shoot leaf area:primary shoot leaf area		
	2011/12	2012/13	2013/14
HSDA[1]	0.53	0.79	0.19
HSDB[2]	0.60	0.26	0.35
LSDA[3]	0.39	0.17	0.35
LSDB[4]	0.37	1.03	0.76
HC[5]	0.83	1.21	1.07
LC[6]	0.69	0.64	
R[7]	0.68	0.83	0.60

(1) High vigour Smart-Dyson above
(2) High vigour Smart-Dyson below
(3) Low vigour Smart-Dyson above
(4) Low vigour Smart-Dyson below
(5) High vigour control
(6) Low vigour control
(7) Reduced canopy treatment

3.3.3.4 Yield

The number of bunches per vine for both controls was quite consistent over the three seasons (Figure 26). The LSDA and HSDA treatments produced a similar number of bunches per treatment during 2011/12 and it was slightly more than that of the controls during this particular season. In 2012/13, the number of bunches per treatment for both LSDA and HSDA increased and was more than that of either of the two controls even though there were no substantial differences in the number of canes per treatment or per vine from the previous season for either of these two treatments or the two controls respectively (Figure 20). Compared to the controls and the upward positioned treatments (HSDA and LSDA), the number of bunches for HSDB and LSDB were lower during the season of conversion. The lower initial number of canes per treatments for the HSDB and LSDB explains the lower number of bunches. During the last two seasons, the number of bunches increased greatly for the LSDB and HSDB treatments (Figure 26). The ratio (HSDB:HSDA) in number of bunches per vine increased from 0.53 in 2011/12 to 0.88 in 2013/14, indicating that the number of bunches in the downward positioned treatment increased progressively more than for the upward positioned treatment which exhibited a smaller increase in the number of bunches (Table 19 Comparative statistical analysis for grapevine components on the high vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per treatment.). A similar trend was observed in the low vigour SD treatments, with LSDB:LSDA ratios increasing from 0.62 in 2011/12 to 0.90 in 2013/14 (Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.).

As expected, the R canopy treatment had the least number of bunches per treatment of all the treatments during 2011/12 and 2012/13, and this was due to the marked reduction in the number of canes for this particular treatment. For the first two seasons the R treatment had almost half the number of bunches as the HC and LC, but in 2013/14, the number of bunches for this treatment was similar to that of HC and LC. This observation in 2013/14 can be ascribed to the fact that the R treatment was not applied in this particular season (Figure 26Figure 26 Number of bunches per treatment for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.).

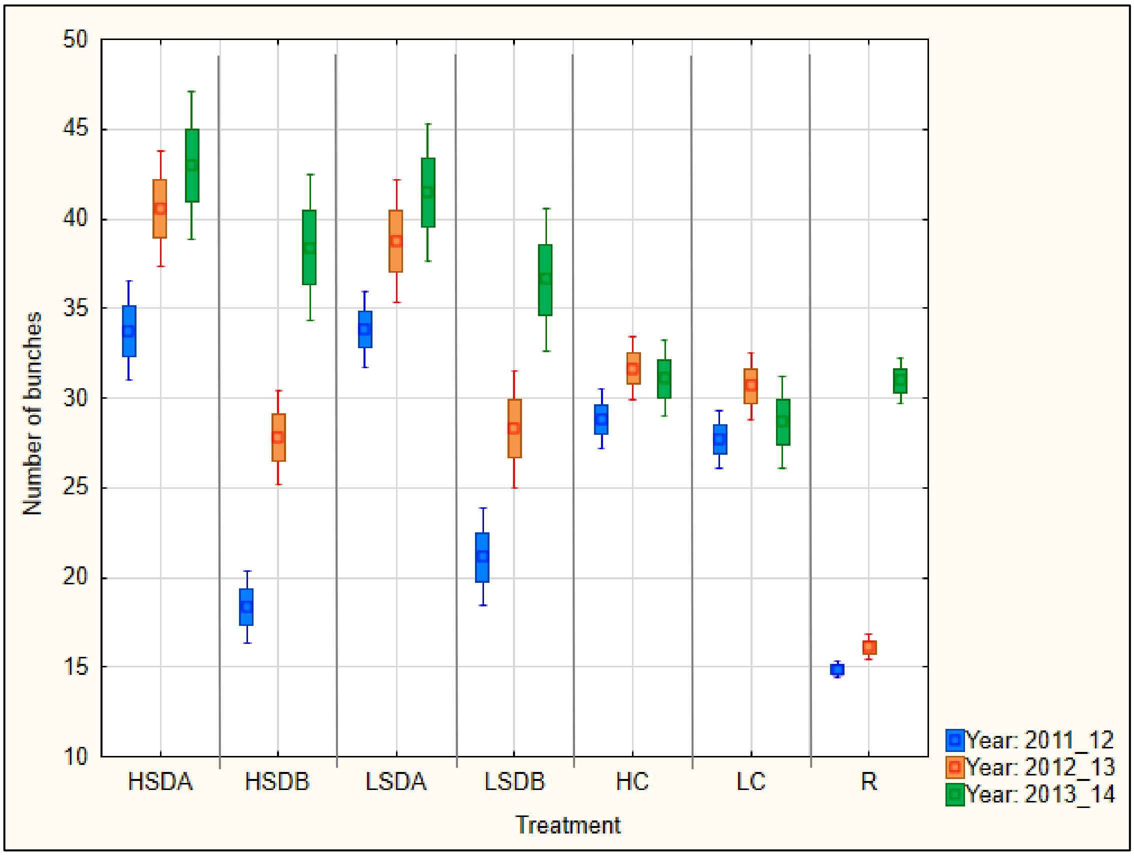

Figure 26 Number of bunches per treatment for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

There was an increase in yield per treatment from 2011/12 to 2012/13 for all treatments (Figure 27Figure 27 Yield per treatment (kg) for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.). This was associated with better climatic conditions during 2012/13 when compared to 2011/12, where the latter was characterised by abnormally cold conditions during the flowering stage. The more favourable weather experienced during 2012/13 led to an increase in not only the number of bunches, but also in berry size. Furthermore, treatment effects such as an increase in number of canes also contributed to the increase in yield. During 2013/14, the yield of all treatments apart from the R treatment decreased again.

The initial yield ratio of HSDB:HSDA increased from 0.38 in 2011/12 to 0.61 in 2012/13 and 0.78 in 2013/14, indicating that the total yield of the HSDB treatment increased over the three seasons, contributing progressively towards the total yield per vine. Whereas in 2011/12 the contribution in yield by the HSDB treatment to the total yield per vine (HSD main treatment) was 28%, it increased to 44% in 2013/14.

A similar trend was observed in the LSDB treatment, with LSDB:LSDA yield ratios increasing from 0.44 in 2011/12, to 0.70 in 2012/13 and 0.81 in 2013/14 (Table 20 Comparative statistical analysis for grapevine components on the low vigour class converted Smart Dyson treatments, specifically comparing upward and downward positioned canes and the proportional contribution of each to the total vegetative and reproductive components per vine.). The contribution of the LSDB treatment to the total yield for the main LSD treatment in 2011/12 was only 30%, but it increased to 45% in 2013/14.

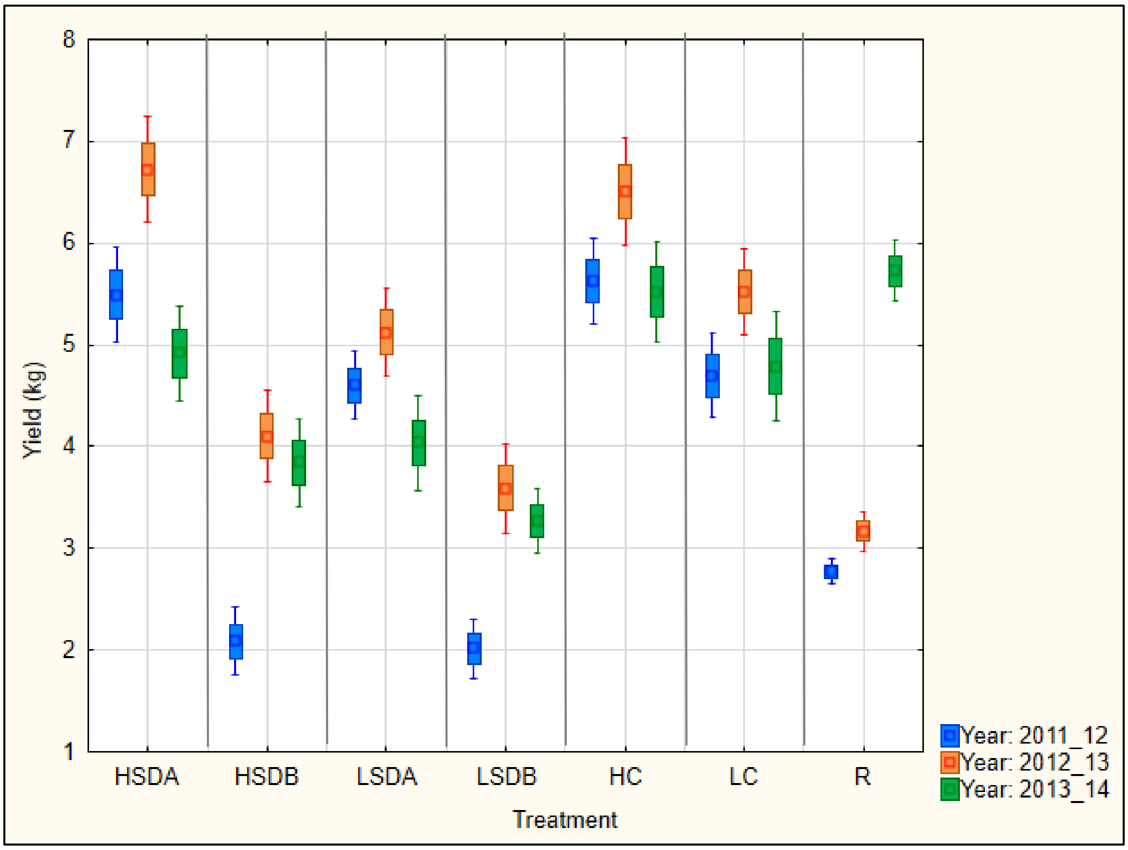

Figure 27 Yield per treatment (kg) for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

It was evident that the downward positioned treatments consistently contributed less to the total average yield on a per vine basis, when compared to the contribution made by the upward positioned treatments (Table 19 and Table 20). Nevertheless, the fact that the CV in mean yield per treatment decreased for HSDB and LSDB over the three seasons suggests that the vine progressed towards balance due to its self-regulation mechanism in reaction to the modified training systems.

During 2012/13, the average yield per vine for the R treatment was substantially less than that of the HC and LC (51% and 43% less respectively), and approximately one third of that of both the high vigour and low vigour main SD treatments. There was also a similar trend with the number of bunches and canes per vine, since the R treatment entailed the removal of bearing shoots in order to maintain only one bearing shoot per spur position. As was the case with number of canes per vine, the yield per vine and number of bunches per vine of the R treatment was very similar to that of both controls for the 2013/14 season. This further strengthens the observation that these changes were due to the R treatment not being applied in the 2013/14 season, hence the vines reverted back to VSP vines comparable in growth and performance to the control vines (Figure 27 and Table 21 Comparative statistical analysis for grapevine components as executed on the combined SD (above and below), HC, LC and R treatments.).

It was evident in all seven treatments that the average mass per bunch increased from 2011/12 to 2012/13 (Figure 28), and it might be assumed that factors other than the treatment effect itself played a role in bunch development or fertility. The 2011/12 season was characterised by abnormally cold and rainy conditions during the second part of flowering, and this could definitely have had an influence causing uneven berry set and, as a result, lower average bunch masses (VINPRO, 2012). From the 2012/13 to 2013/14 season, the average bunch mass per vine of all treatments, except for the R treatment, decreased again to values even lower than those recorded during 2011/12. Although the R treatment's number of bunches and canes per vine increased substantially from 2012/13 to 2013/14, there was very little difference in the mass per bunch between these two years (Figure 28).

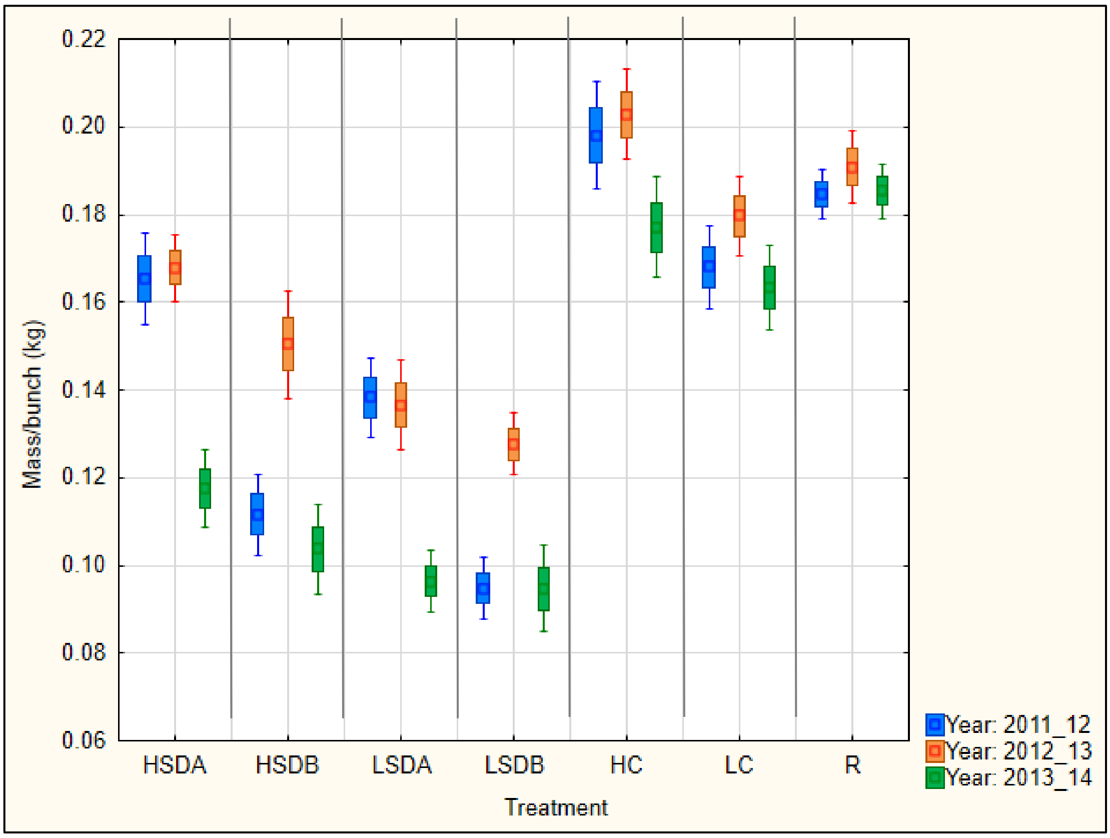

Figure 28 Mass per bunch (kg) for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

There was a clear trend over all three seasons that yield for all high vigour treatments (HSDA, HSDB and HC) was consistently higher than the yield of the lower vigour treatments (LSDA, LSDB and LC, respectively). During 2013/14, the number of bunches for all four SD treatments still increased from the previous season, leading to the conclusion that the yield component effect in especially the main HSD treatment initiated increased productivity, leading to yields during 2013/14 that were 37% higher than that of the HC. The HSD treatment vines seemed to have become more in balance when considering the favourable decrease in leaf area:fruit mass ratios over the course of the seasons. The LSD main treatment vines also seem to have increased in productivity, but to a lesser extent than the HSD main treatment vines. This increase in productivity for both main treatments is proof of the grapevines' ability to self-regulate in a process of restoring balance once it is modified.

3.3.3.5 Vegetative and reproductive ratios

The leaf area:fruit mass ratio can be used as an indication of the extent to which a vine is balanced, since it indicates the relationship and balance between vegetative and reproductive growth, and to what degree competition between these two aspects occur (Parker *et al*., 2014). Any modification to the grapevine's balance by means of canopy management or training/trellising system conversion will cause an effect in growth and/or reproductive compensation, impacting on this ratio (Hunter, 2000; Volschenk & Hunter, 2001). Once this ratio is manipulated, the grapevine will react with a compensatory reaction regarding carbohydrate partitioning to the various sources and sinks (Candolfi-Vasconcelos & Koblet, 1991; Edson *et al*., 1995a). The leaf area:fruit mass ratio should not be considered in isolation, since factors such as composition of this leaf area, spatial distribution of leaves and the level of leaf exposure also play a major role in contributing to the level of grapevine productivity (Mabrouk *et al*., 1997; Hunter, 2000).

Many different optimum values for this ratio have been suggested and one has to keep in mind that these values should be applied relative to the context in which the research was conducted. Findings and conclusions vary between different climatic regions, level of irrigation versus dryland vineyards, various planting distances and the extent to which canopy manipulations such as leaf- and crop removal was applied. Kliewer and Dokoozlian (2005) recommended a leaf area:fruit mass of 8 cm^2/g to 12 cm^2/g for single canopy training systems, and 5 cm^2/g to 8 cm^2/g for divided canopies. During a plant spacing trial, Archer and Strauss (1991) found that a great range of values were optimal, ranging between 13.26 cm^2/g for narrowly spaced vines, up to 27.06 cm^2/g for widely spaced vines. The great differences between these two sets of reported ranges confirms that many factors, as mentioned previously, impact on optimal leaf area:fruit mass ratio in specific contexts.

Be as it may, a low ratio can be the result of either an increase in yield relative to a constant leaf surface area, or a decrease in leaf surface area relative to a constant yield over time.

Considering the two SD main treatments, the total leaf area:fruit mass ratio of the LSD main treatment was slightly lower than that of the HSD main treatment during 2011/12 (Table 22). During 2012/13 and 2013/14, however, the LSD main treatment consistently had a higher leaf area:fruit ratio when compared to the HSD main treatment reaching a ratio of almost double that of HSD in 2013/14. This difference in the leaf area:fruit mass ratio observed between the HSD and LSD main treatments for the 2012/13 and 2013/14 seasons can be explained by the combined influence of both longer mean shoot lengths (primary and lateral) and a steady increase in total canes per vine for the LSD main treatment. This led to a much larger estimated total leaf area per vine. The estimated total leaf area of the LSD main treatment increased with 30% from 2011/12 to 2013/14, while yield only increased with 9% during the same period (Table 20 and Table 22). The very large leaf area:fruit mass ratio can therefore be attributed to a much larger increase in vegetative growth, relative to the coinciding smaller increase in yield. These low vigour vines therefore showed a compensation reaction favouring vegetative growth, rather than obtaining a balance between the vegetative and reproductive components.

In 2011/12, the leaf area:fruit mass ratio for both HSDA and LSDA, was higher than HSDB and LSDB respectively (Table 22). This was to be expected since the treatments were still in the process of conversion in reaction to the altered balance.

In 2012/13, the leaf area:fruit mass ratio for the HSDB treatment decreased with 64%. This indicated clearly the inability of the downward positioned shoots to compensate in reaction to the altered balance. Reproductive growth was favoured to the detriment of vegetative growth to the extent of overcropping, evident from the fact that estimated total leaf area for the treatment reduced with 30%, while the yield increased by 49%.

Just the opposite was observed in the LSDA treatment during 2013/14, for which the highest leaf area:fruit mass (18.71) of all treatments across all seasons was recorded. The estimated total leaf area of the LSDA treatment increased with 50% from 2012/13 to 2013/14, while there was a 21% reduction in yield, clearly indicating an imbalance in favour of vegetative growth.

Higher temperatures and water levels may have favoured vegetative growth in the controls, but to the detriment of vine balance. A lesser increase in yield relative to a drastic increases in vegetative parameters, such as estimated total leaf area and total pruning mass of the HC, led to an increase of 28% in the leaf area:fruit mass ratio from 2011/12 to 2013/14.

The fact that the R treatment was not executed during 2013/14 had a great effect on the estimated total leaf area, since the number of canes for this treatment more than doubled from 2011/12 and 2012/13, to 2013/14. This becomes clear when considering that the total leaf area per vine, as measured during 2013/14, showed a massive increase of 217 % from 2011/12. High leaf area:fruit mass ratios of 11.87 and 12.45 were recorded for 2011/12 and 2013/14 respectively, but this ratio was much lower during 2012/13, at only 5.17. This low ratio was mainly due to the fact that the yield of the R treatment increased with 14% from 2011/12 to 2012/13, with a coinciding reduction of +/- 13% in estimated total leaf area.

3.3.3.6 Berry mass (g/100) and berry volume/100 berries against DAB

For all three seasons, the berries of the four SD treatments were consistently smaller than those of the HC, LC and R treatment. The lower vigour treatments (LSDA, LSDB and LC) also consistently had smaller berries over the three seasons when compared to the high vigour treatments (HSDA, HSDB and HC, respectively). Refer to Figure 29, Figure 30, Figure 31, Figure 32, Figure 33 and Figure 34.

Berry mass for the 2011/2012 season and the 2012/13 season highlighted the variability between treatments and showed consistent berry size limitations in the downward positioned shoots of the low vigour SD treatment (LSDB). This highlights two possible effects, namely the possible over-bearing on these shoots, as well as a physiological limitation since photosynthetic activity is known to be lower in downward positioned shoots when compared to upward positioned shoots (Schubert *et al*., 1995). The supply of photosynthetic products in the downward positioned shoots was further reduced by the continuous topping action that removed the younger leaves at the apical tip. This probably lowered the availability of the substrates that would be produced by these younger leaves and therefore also the extent to which they could contribute to bunch and berry development (Hunter *et al*., 1994; Hunter, 2000).

During the year of conversion (2011/12 season), berry mass (Figure 29) and berry volume (Figure 30) was monitored from +/-6°B (115 DAB) until the various days of harvest for the different treatments. Initial berry mass for the treatments ranged from 0.74 g per berry to 1.00 g per berry - a difference of 0.26 g per berry between the treatments. Berry volume varied between 0.72 cm^3 and 0.96 cm^3 per berry. Initially, there were no consistent treatment effects on berry mass and volume. It was also evident that the field replicates of the seven different treatments had berry masses and volumes in both the lower and higher regions of the scale.

As the 2011/12 season progressed, the LSDB and LSDA treatments showed a smaller increase in berry mass and -volume when compared to the HSDB and HSDA treatments respectively (Figure 29 and Figure 30). A similar pattern was observed when comparing these parameters of the LC to those of the HC. The LC, however, displayed a higher increase in berry mass and -volume when compared to both LSDB and LSDA. The R treatment displayed an increase in both parameters similar to that of the HC.

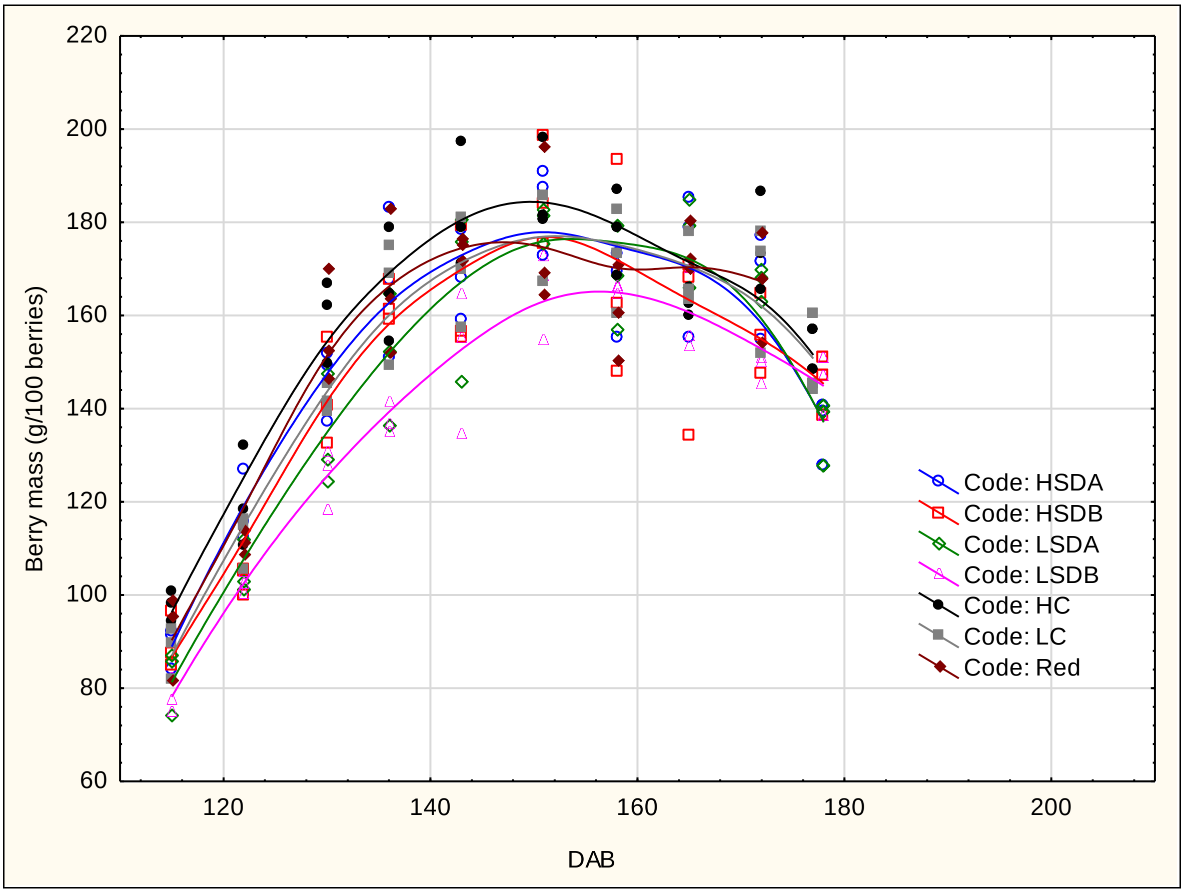

Figure 29 Berry mass (g/100 berries) relative to days after budburst (DAB) for the treatments during season 2011/12 (distance weighted least square fits are shown).

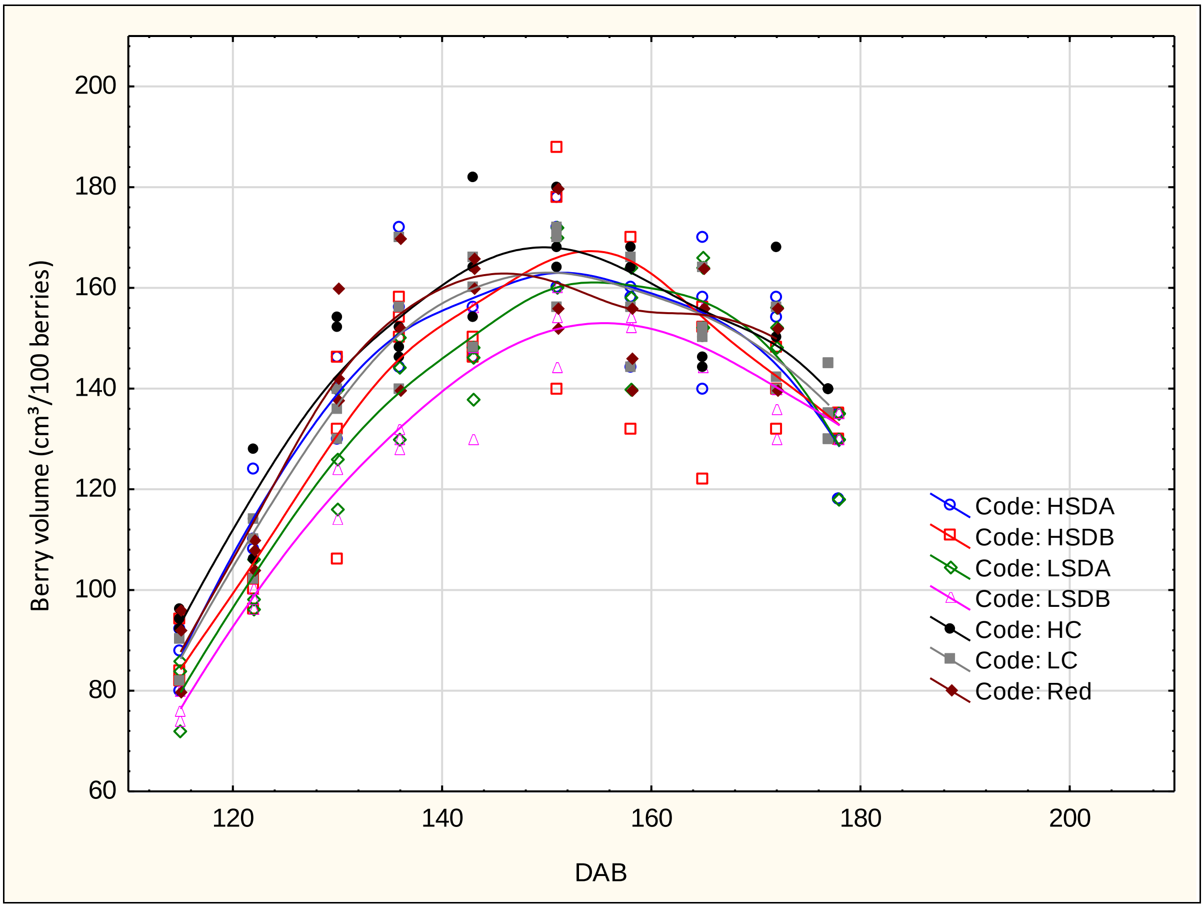

Figure 30 Berry volume (cm^3/100 berries) relative to days after budburst (DAB) for the treatments during season 2011/12 (distance weighted least square fits are shown).

During the 2012/13 season, berry mass and volume was monitored from +/-10°B (113 DAB) until the various days of harvest for the different treatments (Figure 31 and Figure 32). Initial berry mass for the treatments ranged from 0.86 g per berry to 1.24 g per berry. It was therefore clear that there was an increase in berry mass range to 37.5 g per berry when compared to 2011/12 (Figure 29). Initial ranges in berry volumes of the treatments were more evident when compared to 2011/12, with the HC, LC and R treatment falling in the higher ranges, and the SD treatments falling in the lower ranges.

When looking at the increase in berry mass and volume during the 2012/13 season, there were pronounced treatment differences (Figure 31 and Figure 32). All four SD treatments showed less of an increase in both berry mass and volume when compared to the controls and the R treatment. The berry mass and volume of the downward positioned treatments (HSDB and LSDB) displayed the least increase in both these parameters of all treatments.

The consistent berry size constrictions in specifically the HSDB treatment emphasises the effect that overcropping can have on grapevines when considering the very low leaf area:fruit mass ratios for this treatment during 2012/13 and 2013/14. The more open canopy of the HSDB treatment experienced more direct sunlight exposure of the berries, and this could have enhanced the berry transpiration rate, causing dehydration, shrinking and thus a decrease in berry size (McCarthy & Coombe, 1999; Bergqvist *et al*., 2001;). In addition to possible photosynthetic limitations in downward positioned shoots (as has already been discussed), elevated water stress levels as confirmed by pre-dawn leaf water potential results (refer to section 3.3.2.2), no doubt also played a role in the reduction of berry sizes for these two treatments.

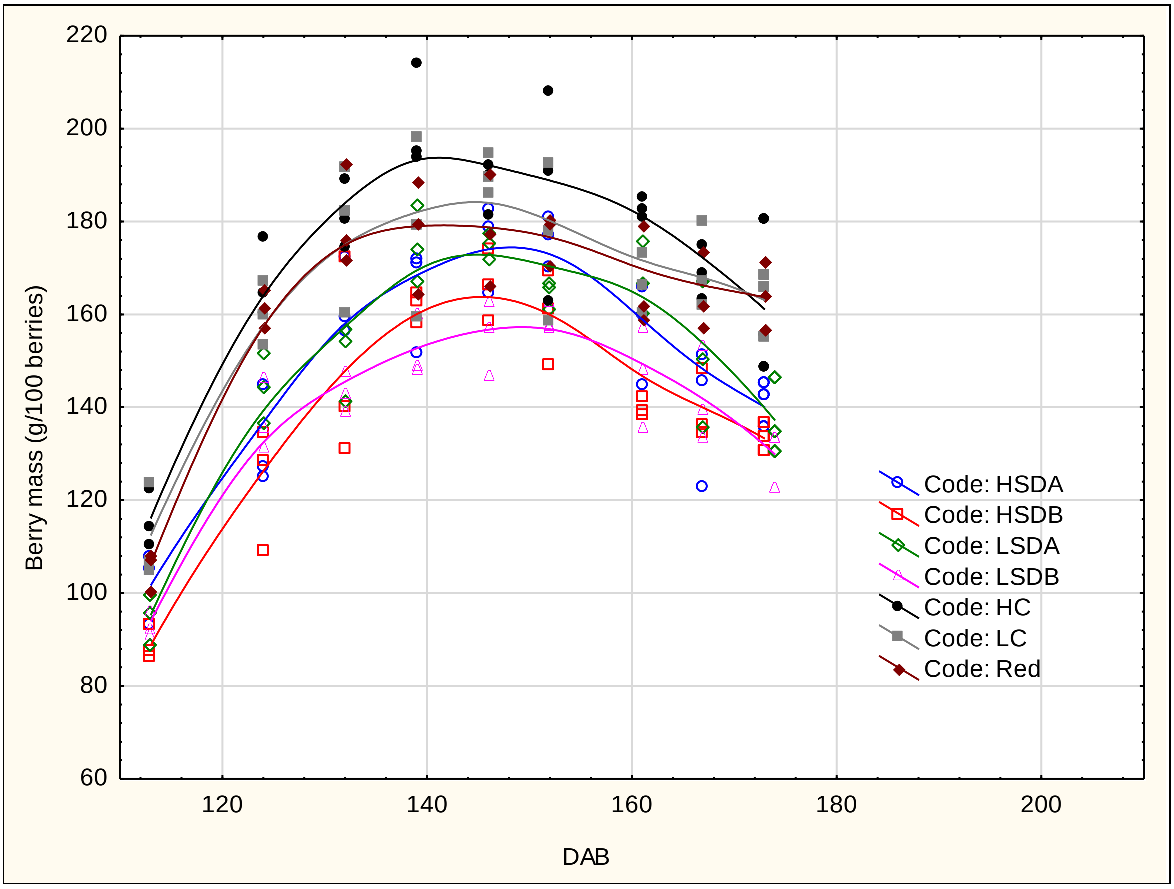

Figure 31 Berry mass (g/100 berries) relative to days after budburst (DAB) for the treatments during season 2012/13 (distance weighted least square fits are shown).

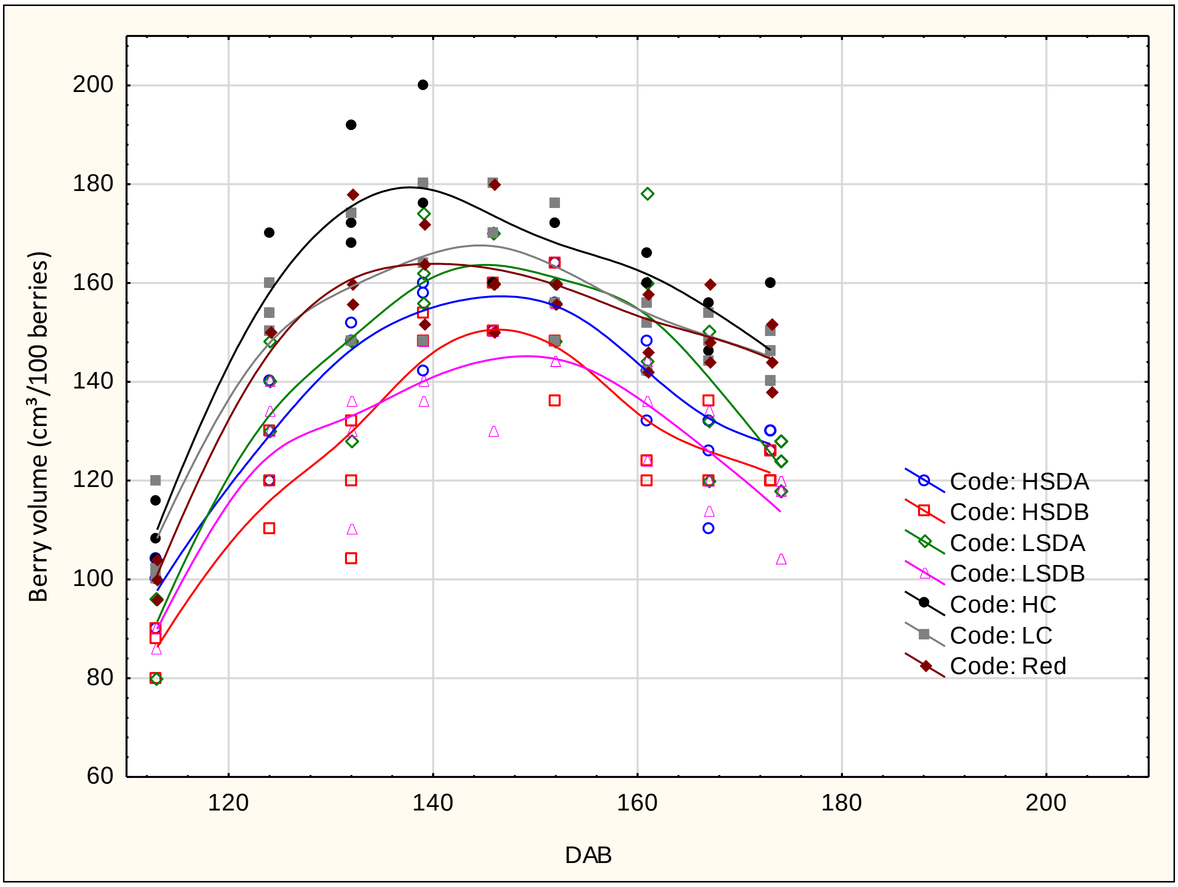

Figure 32 Berry volume (cm³/100 berries) relative to days after budburst (DAB) for the treatments during season 2012/13 (distance weighted least square fits are shown).

During the 2013/14 season, berry mass and -volume was monitored from +/-13°B (126 DAB) until the various days of harvest for the different treatments (Figure 33 and Figure 34). Initial berry mass for the treatments varied between 1.34 g per berry, to 1.70 g per berry, which was a similar berry mass range as that of the 2012/13 season (Figure 31).

The four SD treatments also had a smaller increase in berry mass and volume when compared to the HC, LC and R treatment. The LSDB treatment showed very little increase and/or variation in both berry mass and -volume, with mass ranging only between 1.39 g per berry and 1.59 g per berry (Figure 33). Between +/- 164 DAB and the day of harvest (198 DAB), all four SD treatments displayed decreases in berry size. Berry exposure to sunlight due to the open structure of the canopies could have caused increased transpiration rates and water loss, leading to dehydration and thus shrinking of berries (Hale & Buttrose, 1974; Crippen & Morrison, 1986; Bergqvist et al., 2001). All treatments displayed less of a variation in berry mass and -volume throughout the 2013/14 season (Figure 33 and **Error! Reference source not found.**), when compared to the 2011/12 (Figure 29 and Figure 30) and 2012/13 (Figure 31 and Figure 32) seasons. Generally, berry mass increased during the 2013/14 season when compared to 2011/12 and 2012/13 and this was probably due to high November rainfall and high temperatures in 2013/14 (refer to section 3.3.1.1).

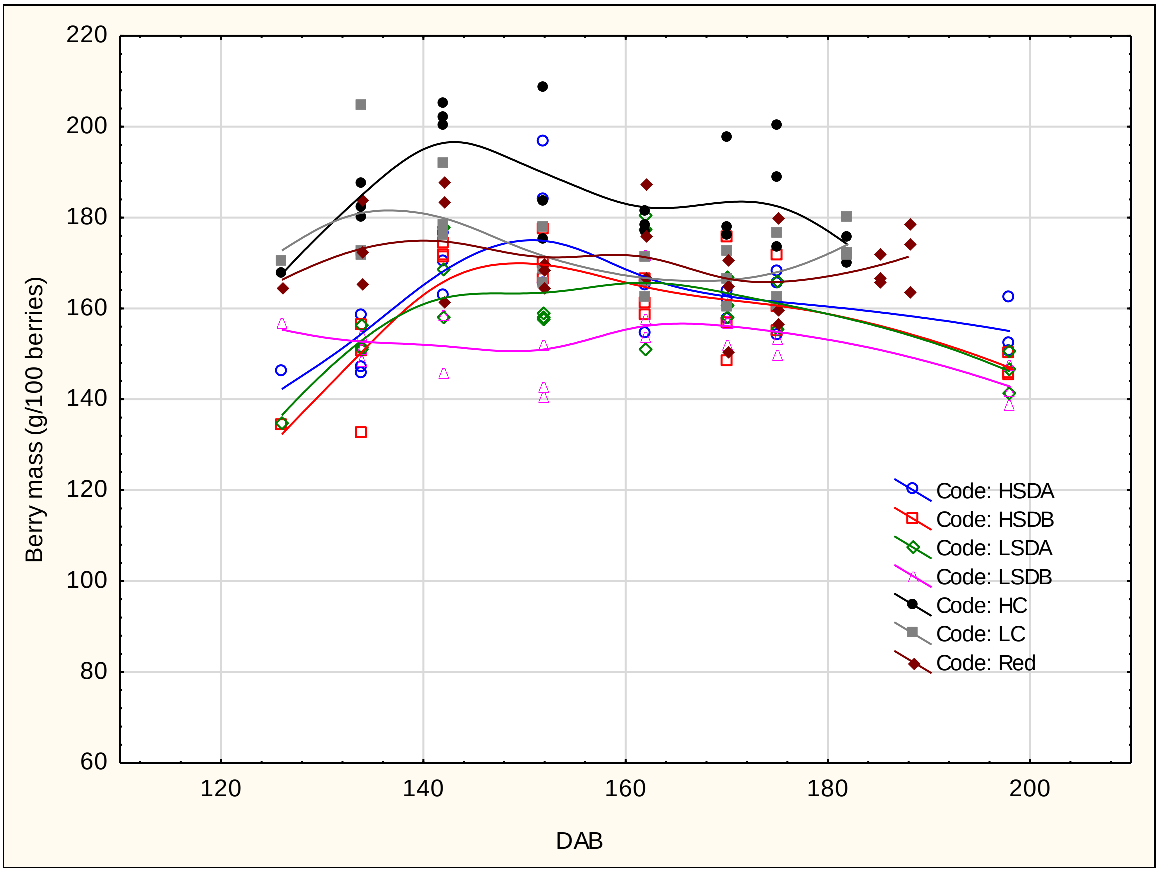

Figure 33 Berry mass (g/100 berries) relative to days after budburst (DAB) for the treatments during season 2013/14 (distance weighted least square fits are shown).

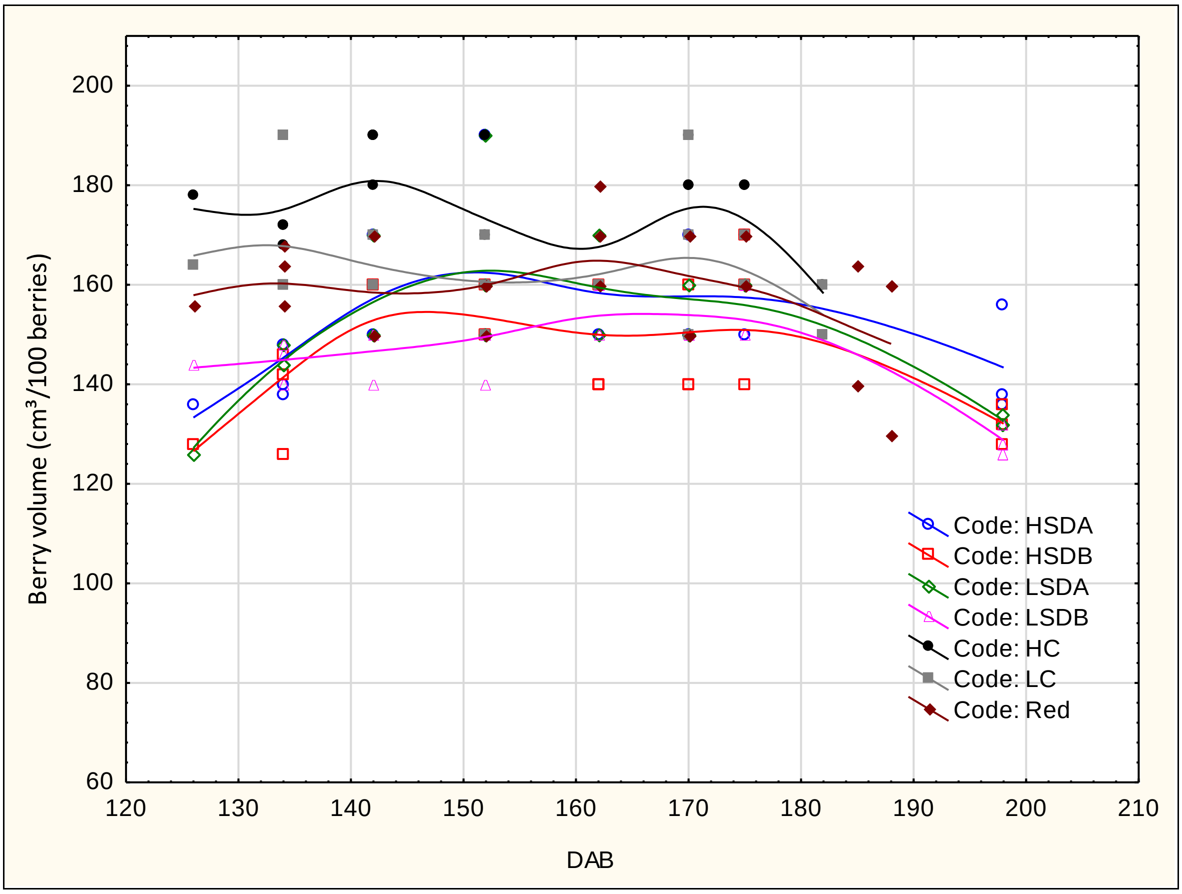

Figure 34 Berry volume (cm^3/100 berries) relative to days after budburst (DAB) for the treatments during season 2013/14 (distance weighted least square fits are shown).

3.3.4 Grapevine balance ratios

The Ravaz indices (Ravaz, 1911), which refers to the yield:pruning mass ratio, (Figure 35) for both controls increased slightly from 2011/12 to 2012/13, but from 2012/13 to 2013/14, this value decreased to such an extent for both controls that it was even lower than that recorded during 2011/12 when the trial was started. This decrease was not ascribed to decreases in yield, since total yield per vine during 2013/14 was very similar to yield recorded for the two controls during 2011/12. The fact that total pruning mass for the HC and LC increased with 54% and 30% respectively from 2012/13 to 2013/14, lead to this decrease in Ravaz index values.

When the yield component effects in the trial are considered, the HSD main treatments did express significant benefits in terms of productivity. This was true for the 2012/13 and 2013/14 seasons especially, where the combined yield for the HSDA and HSDB treatments (*i.e.* for an entire vine) was about 40% higher than the yield of the HC. Yield ratios for the HDSB:HSDA and LSDB:LSDA treatments increased from 2011/12 to 2013/14 over the seasons as the downward positioned treatments became more established.

During the conversion year (2011/12), the Ravaz indices for LSDA and HSDA were very similar to that of LC and HC, and the Ravaz indices of HSDB and LSDB was very high compared to that of the HSDA and LSDA treatments, respectively. The Ravaz indices of the four SD treatments increased substantially from 2011/12 to 2012/13, not due to higher yields, but rather due to reduced vigour relative to the increase in yield (Table 19 and Table 20). This reduced vigour did not seem to favour ripening, as it seemed to coincide to high water demands from the more exposed canopy.

From the large variation in the Ravaz indices of the four SD treatments, it was clear that not all these treatments displayed a similar tempo in adapting to the modifying balance further implying that it was a challenge to establish the SD treatments consistently on all grapevines. The fact that the Ravaz values of the downward positioned treatments decreased suggests that, due to the self-regulation mechanism of the vine, compensation occurred with the vines striving towards achieving a balance in vegetative growth (Figure 35). However, within all four SD treatments, and in all three seasons, the large variation of Ravaz index values (wide confidence intervals) indicated that there was substantial variation within each treatment (Table 19 and Table 20). This was particularly noticeable in the HSDB treatment.

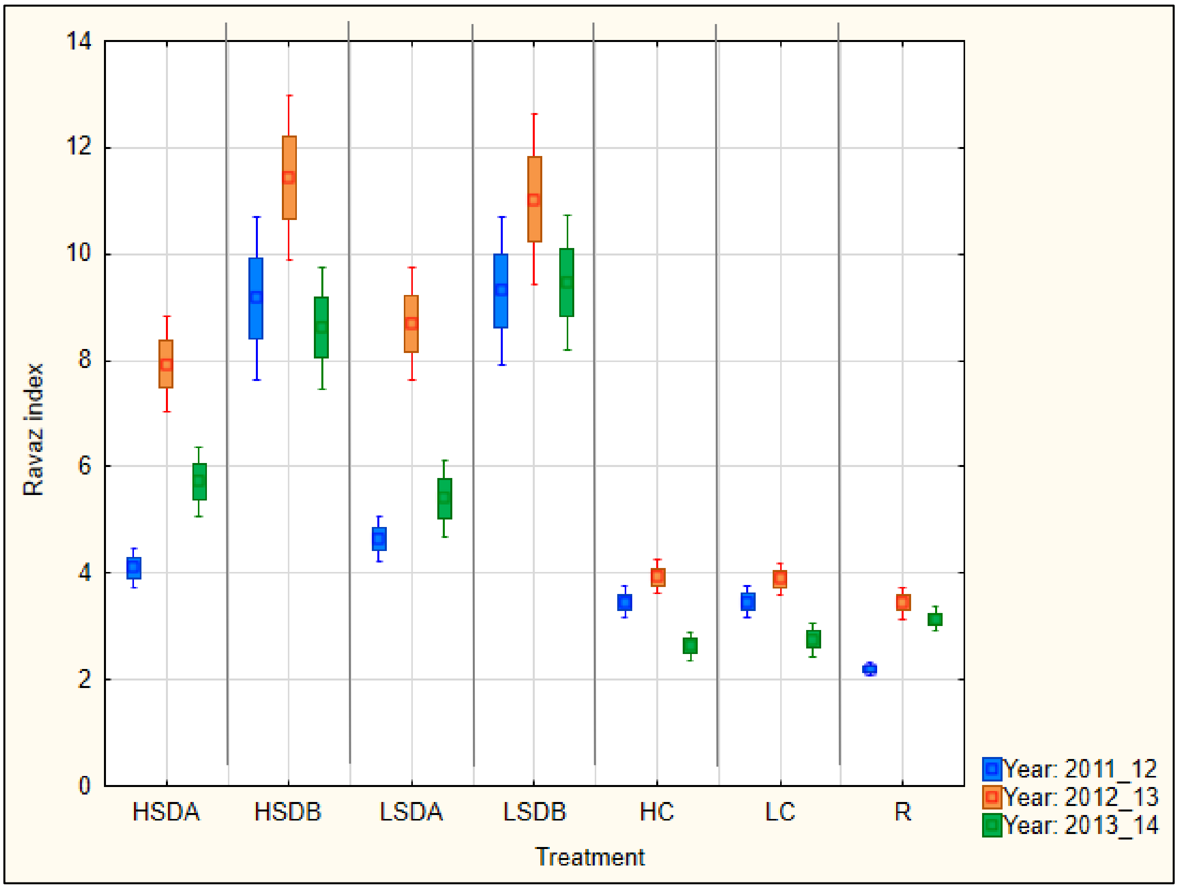

Figure 35 Ravaz indices (yield:pruning mass) per vine for the different treatments and study seasons. Points indicate mean values, boxes indicate standard errors and whiskers indicate 95% confidence intervals.

When the yield per treatment (kg) and the total pruning mass per treatment (kg) is compared, a general relationship seems to exist (Figure 36), but a high variability in both components between treatments is also clear. Certain treatments with very low pruning masses were capable of producing very high yields, which is specifically apparent in the HSDB and LSDB treatments (Figure 37). The consistently lower pruning mass of the replicates of these treatments leads to the conclusion that the overcropping in these cases may have led to a reduction in reserves, therefore decreasing the vine's capacity to accumulate dry matter in the form of carbohydrate reserves (Edson *et al*., 1995b).

It is also evident that the LSDB treatment's total pruning mass was consistently lower when compared to that of the HSDB treatment (Figure 21). In general, a steeper slope in the yield:pruning mass graph would indicate higher relative productivity in the treatments.

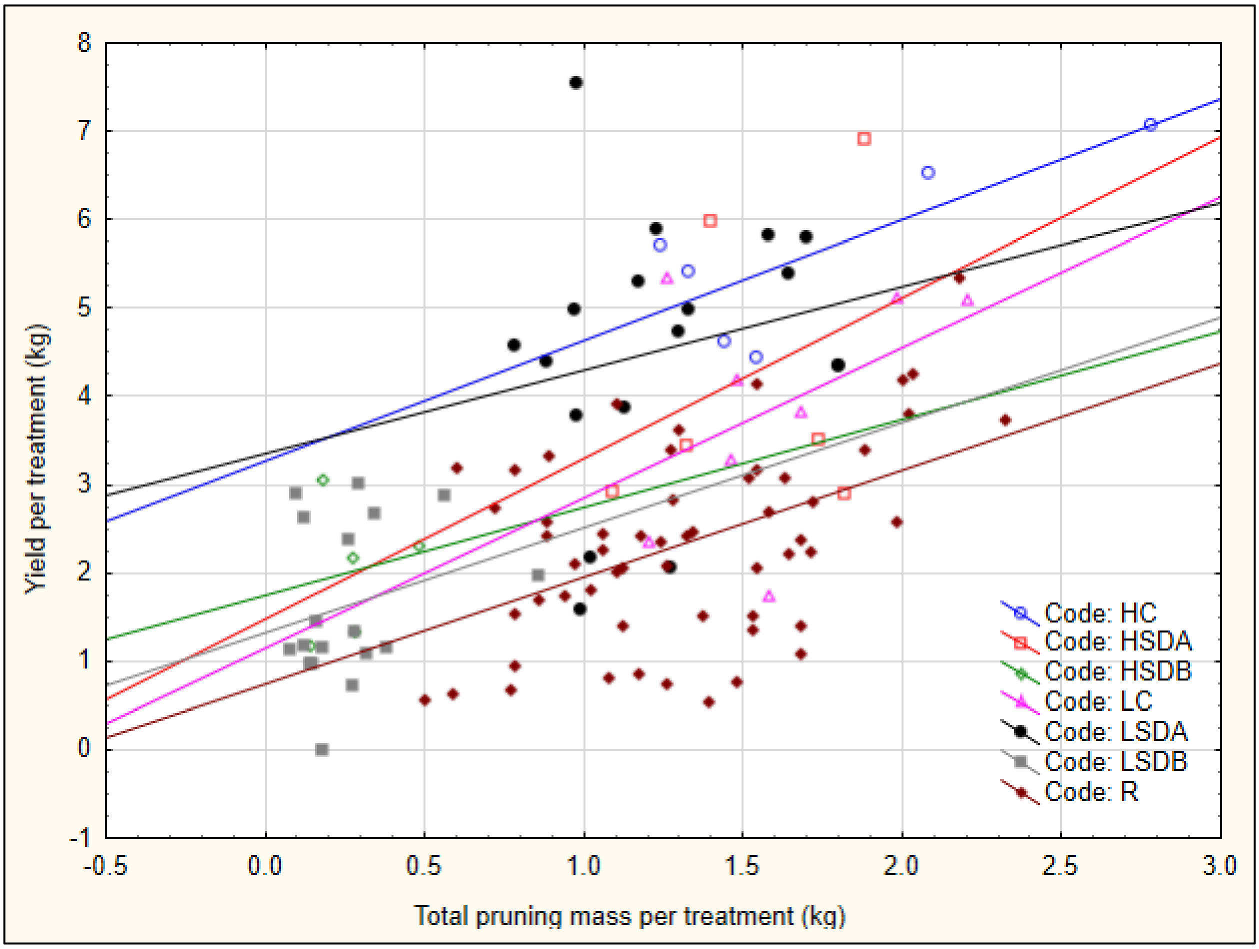

Figure 36 Relationship between yield per treatment (kg) and total pruning mass (kg) per treatment for the 2011/2012 growing season, using 2012 pruning data.

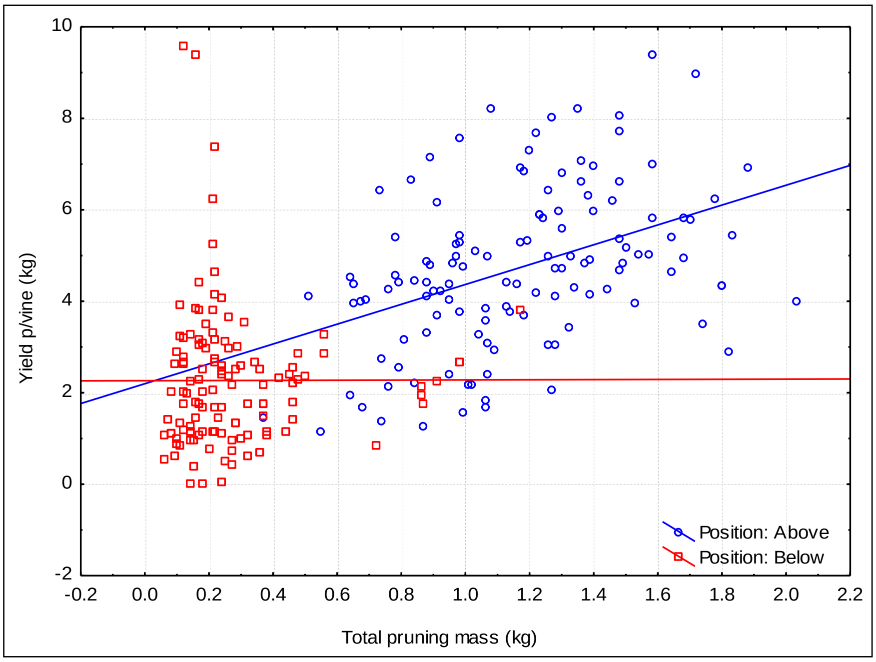

Figure 37 Relationship between yield per vine (kg) and total pruning mass (kg) per vine for the SD upward ("above") and downward ("below") orientated shoots/canes for the 2011/2012 growing season and 2012 pruning data.

3.3.5 Ripening parameters

3.3.5.1 Total soluble solids accumulation

Monitoring of the accumulation of total soluble solids (TSS), measured in °B, commenced at +/-6°B (115 DAB) during the 2011/12 season. The LSDA treatment's initial measurement was the lowest, with an average of 4.7°B for the three field replicates, and that of the HC treatment the highest with an average of 6.5°B. The TSS of all treatments, except for the R treatment, increased at a similar rate (Figure 38). The rate of accumulation was higher for the R treatment. The HC and LC controls were both harvested at 177 DAB. The HC treatment had an average of 23.5 °B (field replicates ranging between 22.8°B & 23.9°B) and the LC treatment an average of 24.2°B (field replicates ranging between 22.9°B & 25.1°B) (Figure 38 Total soluble solids accumulation (°B) relative to days after budburst (DAB) for the treatments during season 2011/12 (distance- weighted least- square fits are shown). Red = R

All four SD treatments were harvested at 178 DAB. Sugar accumulation for all four SD treatments increased slightly until the day of harvest, with the LSDA treatment displaying the largest range in values between the field replicates, varying between 22.3°B and 25.5°B (a difference in 3.2°B within the field replicates of the same treatment). The rest of the SD treatments (LSDB, HSDB and HSDA) only displayed variation in final measurements between their field replicates of 1.5°B, 1.3°B and 1.4°B, respectively.

The fastest accumulation in TSS during 2011/12 was reported for the R treatment up until 159 DAB, after which sugar accumulation decreased slightly, eventually stopping at an average of 22.4°B on the day of harvest (172 DAB). Even though the accumulation rate was still high for this treatment in the following two seasons, the accumulation rate of the two controls surpassed that of the R treatment during 2013/14 (Figure 40).

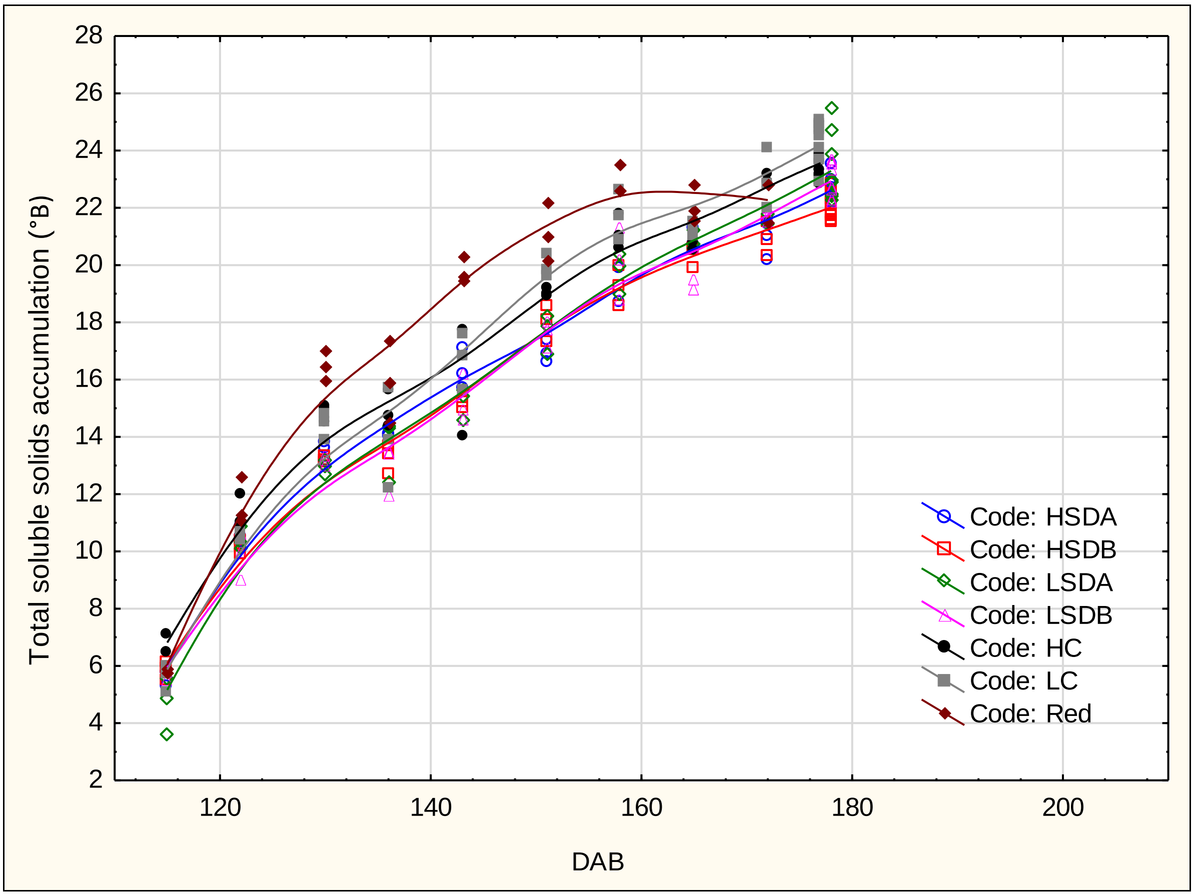

Figure 38 Total soluble solids accumulation (°B) relative to days after budburst (DAB) for the treatments during season 2011/12 (distance- weighted least- square fits are shown). Red = R

Monitoring of the accumulation of TSS, measured in °B, commenced at +/-10°B (113 DAB) during the 2012/13 season. Compared to the 2011/12 season, there was a more distinct difference between the rate of accumulation of sugar in the four SD sub treatments when compared to the control and R treatments, where the SD sub treatments displayed a slower increase in sugar accumulation (Figure 39).

The TSS accumulation rate for all four SD treatments were similar to each another during 2012/13 and, as previously mentioned, slower than that of the controls and R treatment (Figure 39). The rate of TSS accumulation is known to slow down where leaf area:fruit mass ratios were reduced (Parker *et al*., 2015) and this was specifically the case in the HSDA and HSDB treatments. The fact that the TSS accumulation rate for these treatments during 2012/13 was actually similar to that of the LSDA and LSDB treatments with relatively high leaf area:fruit mass ratios, is probably an indication that although the total leaf areas per treatment decreased, the vines were able to compensate by means of increasing the effectiveness and productivity of those existing leaf areas. The conversion of the training system was also conducive to more open canopies with an increased number of exposed leaves. The greatest reduction in leaf area:fruit mass ratio was observed in the HSDB treatment, where this parameter decreased with 64% from 2011/12 to 2012/13.

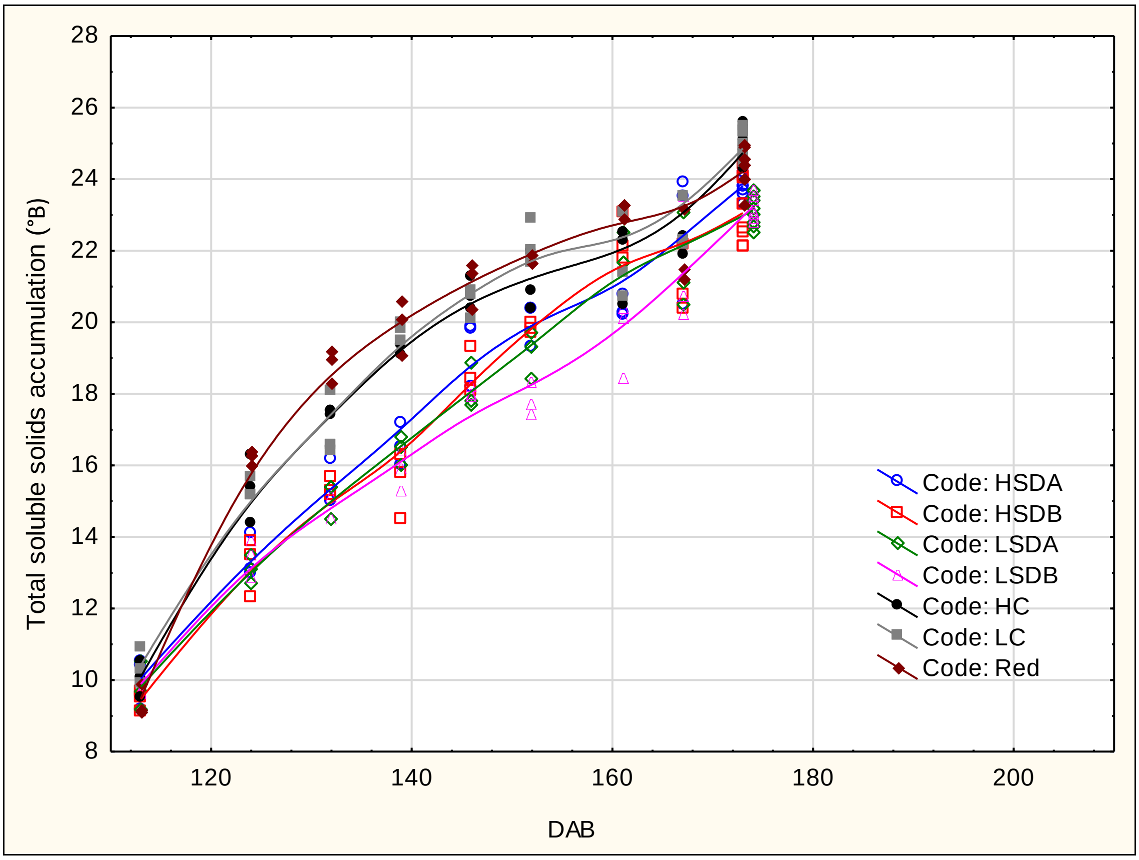

Figure 39 Total soluble solids accumulation (°B) relative to days after budburst (DAB) for the treatments during season 2012/13 (distance- weighted least- square fits are shown). Red = R

Initial measurements for the 2013/14 season (commencing at 126 DAB) displayed the widest range of TSS values between treatments of all three seasons (Figure 40). Furthermore, there was once again a clear distinction between the four SD treatments at the lower end of the range (between 11.8˚B & 13.5˚B) and the controls and R treatment (which were all at 14.3˚B). Progression of sugar accumulation followed the same pattern as the two previous seasons, with the four SD treatments exhibiting a slower accumulation, and the controls and R treatment a much quicker accumulation (Figure 40). Even though initial readings for the 2011/12 and 2012/13 season commenced at a near similar point in the season (115 DAB for season 2011/12 & 113 DAB for season 2012/13), initial measurements for the 2012/13 season were much higher when compared to the previous season, ranging between 9.1°B and 10.5°B (Figure 39). It should be noted that the sugar accumulation seemed much more accentuated during the 2013/14 season (Figure 40 Total soluble solids accumulation (°B) relative to days after budburst (DAB) for the treatments during season 2013/14 (distance- weighted least- square fits are shown). Red = R

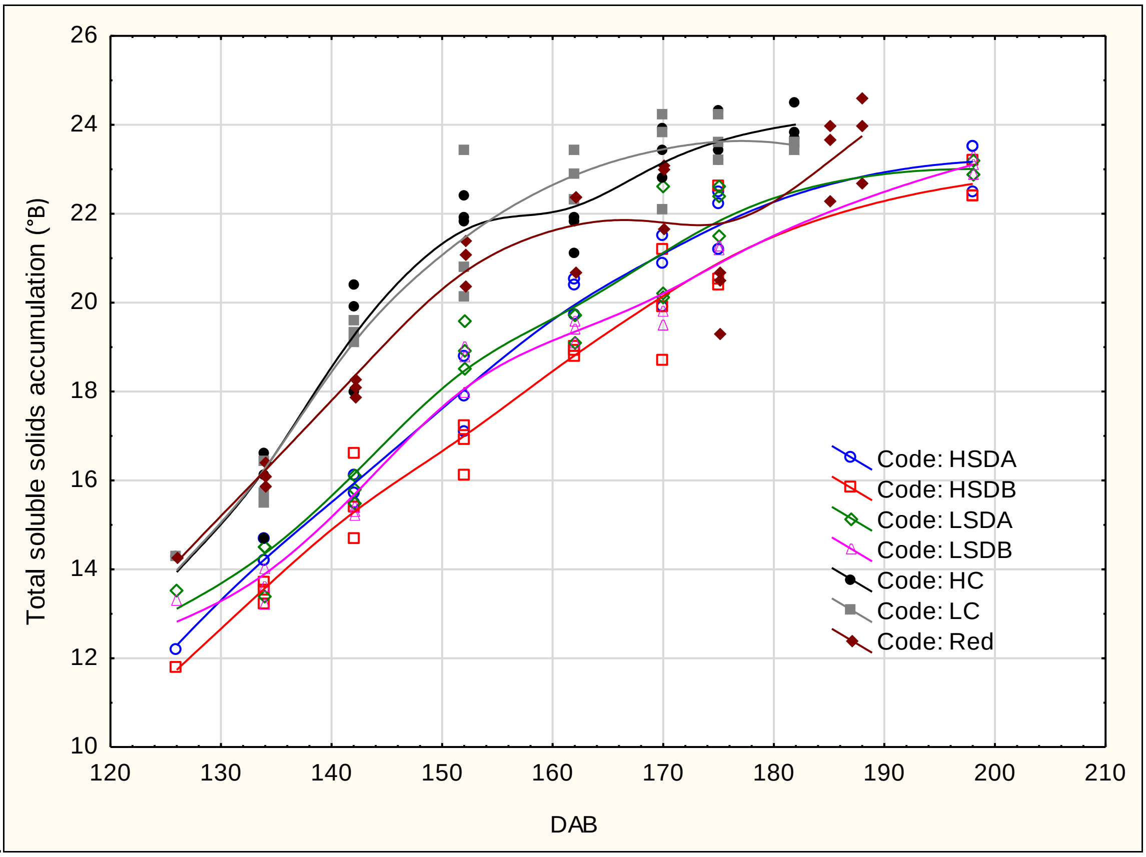

Figure 40 Total soluble solids accumulation (°B) relative to days after budburst (DAB) for the treatments during season 2013/14 (distance- weighted least- square fits are shown). Red = R

Total soluble solids accumulation during all three seasons showed the fastest increase in the R canopy and controls, and this points to possible limitations to ripening in the four SD treatments due to elevated stress levels, which were also confirmed in the per-berry sugar accumulation ("sugar loading") results. Moderate water stress is known to increase quality, but once pre-dawn leaf water potential values exceed -1120 kPa, it is considered to be severe stress (Ojeda *et al*, 2002; Girona *et al*., 2009). Pre-dawn leaf water potential levels for 2013/14 confirmed that the vines experienced severe water stress (refer to section 3.3.2.2). Factors such as an increased leaf area as a result of a compensation reaction of the vines in response to an altered balance, and increased transpiration rates may have contributed to the elevated water stress levels. This water stress led to a delay in ripening in the four SD treatments, causing a decreased rate of sugar loading and decreased sugar concentration in the berries, which corresponds with the findings of Ojeda *et al*. (2002) and Girona *et al*. (2009).

In 2012/13, the leaf area:fruit mass ratio for the HSDB treatment decreased with 64%. This clearly indicated the inability of the downward positioned shoots to compensate in reaction to the altered balance. Reproductive growth was favoured to the detriment of vegetative growth to the extent of overcropping, evident from the fact that estimated total leaf area for the treatment reduced with 30%, while the yield increased by 49%. When leaf area:fruit mass ratios are reduced to such an extent as was the case here and a grapevine experiences increased water stress due to heavy crop loads, it is expected that total soluble solid (TSS) accumulation will slow down, and ripening will be delayed (Poni *et al*., 1994; Parker *et al*., 2015)). This didn't seem to be the case, as the TSS accumulation rate of the HSDB treatment was very similar to that of the three other SD treatments, all of which had both high and low leaf area:fruit mass ratios ratios during 2012/13. No concrete correlation was therefore observed between leaf area:fruit mass ratio and the rate of TSS accumulation. It may be presumed that compensation on a whole-vine basis occurred here, where the leaves of the HSDA treatment probably compensated for the shortcomings of the leaves in the HSDB treatment by mobilising carbon reserves and increasing carbon partitioning towards the increased sinks (berries) of the HSDB treatment. Another explanation might be that due to the open canopy structure, the leaves that where present in the HSDB treatment, albeit relatively few when compared to the crop load, were optimally exposed. This means that these leaves would be photosynthetically fully efficient therefore being able to ripen the increased crop. The improvement of the canopy microclimate had a direct effect on the source:sink relationship in the vine, decreasing vigour and increasing effective leaf area.

3.3.5.2 Sugar accumulation per berry

Sugar loading (expressed in mg/berry) refers to the evolution of the sugar concentration on a per-berry basis between the phenological stages of véraison and harvest. Measurements commenced at 115 DAB during the 2011/12 season, and the sugar accumulation per berry (mg/berry) for all SD treatments was slightly slower when compared to the HC, LC and R treatment. The latter three treatments not only displayed a faster increase in sugar accumulation per berry when compared to the four SD treatments, but they also reached the highest values at harvest (Figure 41). When comparing the SD treatments, the low vigour treatments (LSDA and LSDB) displayed a slightly lower increase than the high SD treatments (HSDA and HSDB).

When compared to season 2011/12, the difference in sugar accumulation per berry between the various treatments for season 2012/13 was much more accentuated. The distinction between the higher rate of sugar loading in the HC, LC and R treatment compared to the SD treatments was already clear at 124 DAB (Figure 42). The lowest rate of sugar accumulation occurred in the downward positioned shoots of the SD treatments (LSDB and HSDB). Overcropping in the HSDB treatment as a result of an excessive increase in yield relative to a lower effective leaf area led to a decrease in sugar loading and delayed ripening during 2012/13, which is in accordance with findings by Carbonneau and Deloire (2001). This delay in ripening and decreased sugar accumulation per berry could be related to the shortage of lateral leaves in the HSDB treatment during 2012/13 (Table 23), which did not favour phloem unloading (Quinlan & Weaver, 1970; Hunter & Visser, 1988a; Hunter & Visser, 1988b).

Even though the LSDB treatment exhibited the lowest rate of sugar loading of all treatments, very high leaf area:fruit mass ratios were recorded during 2012/13. Furthermore, the ratio of lateral to primary leaf area for this particular treatment was very high (1.03) during 2012/13 (Table 23). Since lateral leaves are known to support ripening by increasing phloem unloading, the low rate of sugar loading for the LSBD treatment was unexpected. Other explanations for the delay in ripening should therefore be explored. Larger leaves in the case of the LSDB treatment could have led to an increased transpiration rate, water loss and water deficit which are also factors known to delay ripening and cause a decrease in sugar loading (Wang *et al*., 2003). Another factor to consider is the well-known phenomenon of Shiraz berries shrinking toward the end of ripening due to an increase in berry transpiration tempos, coinciding with a decrease in phloem sap flow (McCarthy & Coombe, 1999). Lastly, insufficient availability of carbohydrate reserves due to the lower capacity of the low vigour grapevines may also have contributed to this delay in ripening (Parker *et al*., 2014). Increases in TSS values are thus due to a concentration effect, and not due to a further influx of TSS into the berries. The decreased rate of sugar berry evolution proves this fact.

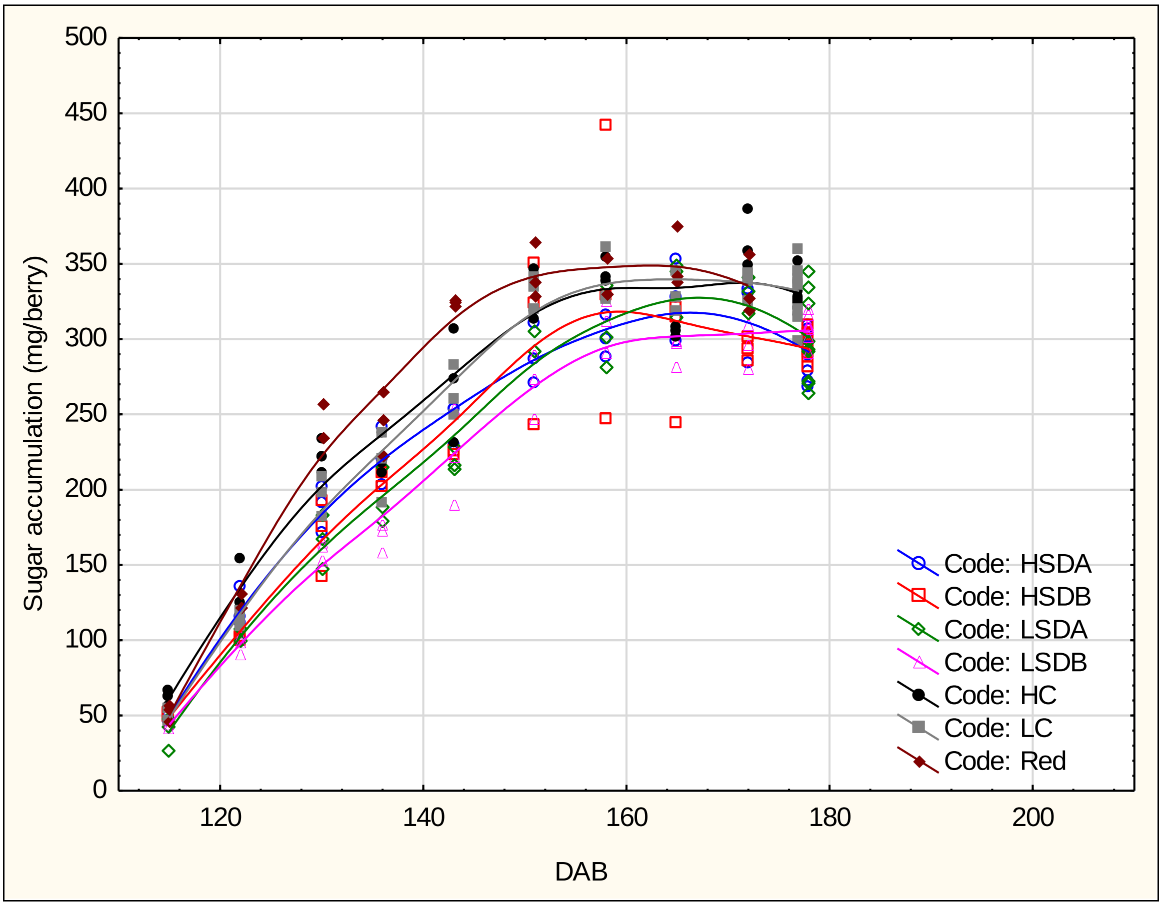

Figure 41 The evolution of berry sugar content relative to days after budburst (DAB) up to harvest for the treatments in season 2011/12 (distance- weighted least- square fits are shown). Red = R

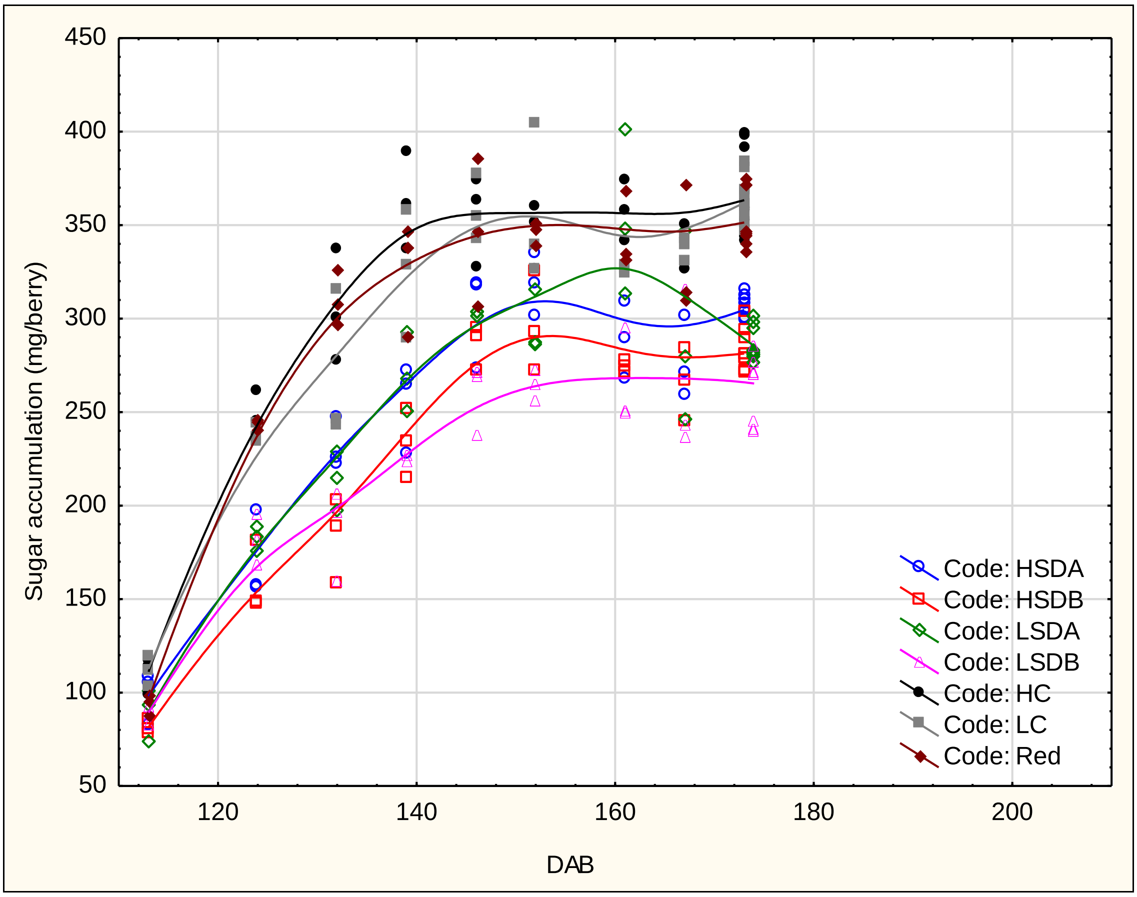

Figure 42 The evolution of berry sugar content relative to days after budburst (DAB) from ±10°B up to harvest for the treatments in season 2012/13 (distance- weighted least- square fits are shown). Red = R

In contrast to the previous two seasons, the initial measurements of TSS during 2013/14 displayed large variations between the seven treatments, ranging between 11.8°B and 14.3°B (Figure 40).

Distinct differences between the ripening progression of the four SD treatments and that of the controls and R treatment became even more apparent in 2013/14, where a deterioration in sugar loading in the four SD treatments occurred (Figure 43). This indicates that these berries indeed reached a stage of over ripeness. Even though sugar accumulation took place at lower rates during 2013/14 for all treatments, values were higher during this final season when compared to that of the previous two seasons. This can be explained by the drier conditions as experienced during the 2013/14 season (refer to section 3.3.1.1) which led to more effective sugar loading as was also noted by Hunter & Deloire (2005). This decreased rate of sugar loading was even more accentuated in the two downward positioned SD treatments. The overall result was limited ripening, and sugar concentration values at the lower end of the range for the SD treatments.

Similar to previous seasons, the lowest rates were measured for the HSDB and LSDB treatments (Figure 43).

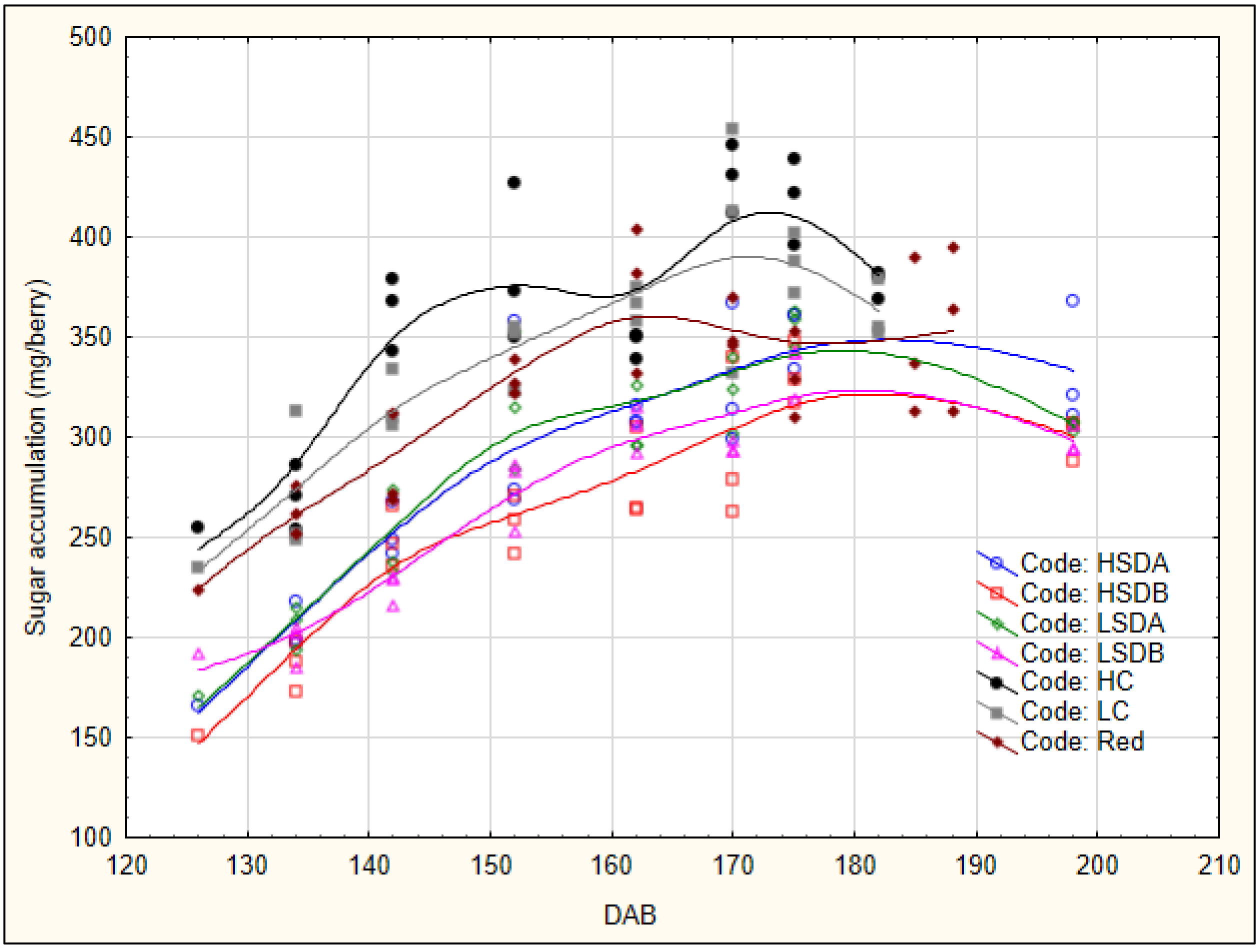

Figure 43 The evolution of berry sugar content relative to days after budburst (DAB) from ±13°B up to harvest for the treatments in season 2013/14 (distance- weighted least- square fits are shown). Red = R

The general decrease in mean lateral leaf areas relative to the mean total leaf areas in the case of the HSDA and HSDB treatments, seemed to have had an impact on the tempo of ripening, and the tempo of sugar loading of these treatments. Where less lateral leaves are present due to practices such as the removal of lateral shoots, or for any other reasons, sugar accumulation may decrease. This can be ascribed to the important role that lateral leaves, especially in the bunch zone, play in phloem unloading into the developing berries (Quinlan & Weaver, 1970; Hunter & Visser, 1988a; Hunter & Visser, 1988b). Even though the LSDB treatment displayed an increase in lateral leaf area, this did not seem to favour ripening, as the same delay in ripening occurred as in the case of the two HSD sub-treatments. In this case the lower vigour and capacity of the low vigour treatment certainly played a role. Where a vine's capacity is limited by an inability to accumulate and mobilize carbohydrate reserves, delayed ripening will be observed (Parker *et al*., 2014).

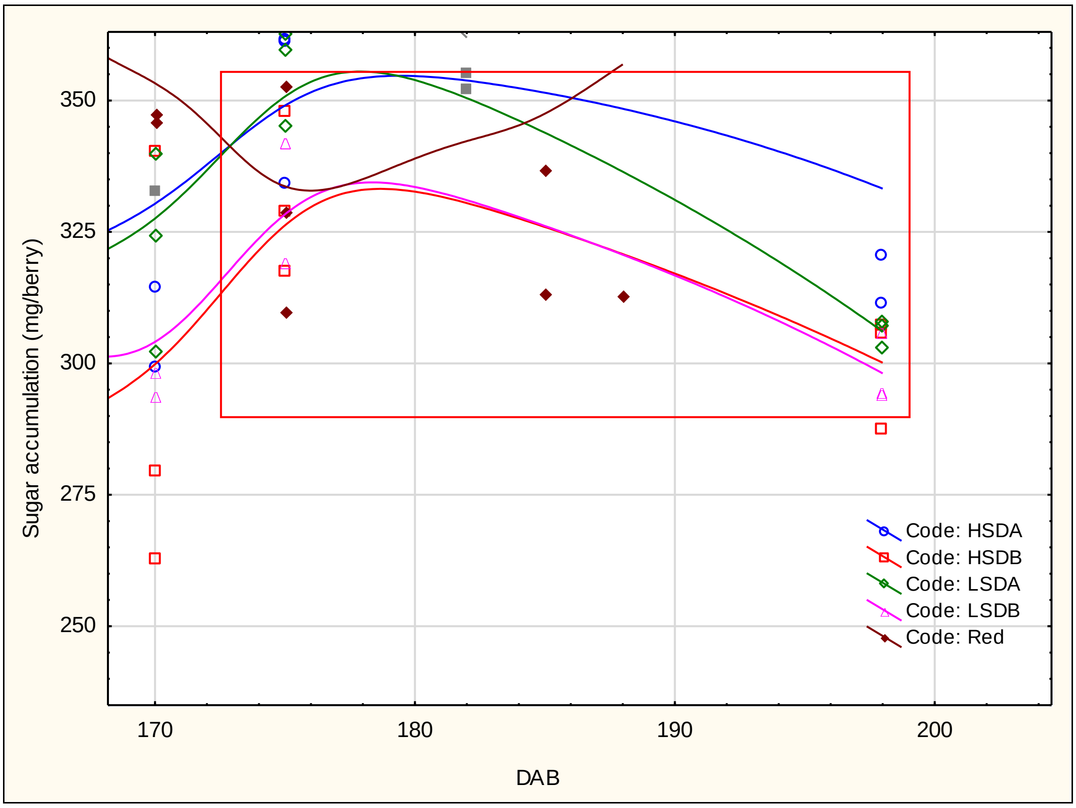

Figure 44 The evolution of berry sugar content in 2013/14, relative to days after budburst (DAB), specifically indicating the deterioration in sugar loading in the HSDB, HSDA, LSDB and LSDA treatments (distance-weighted least- square fits are shown). Red = R

3.3.5.3 TA and pH evolution

Monitoring of the TA content of the berries commenced at +/-6°B (115 DAB) during the 2011/12 season (Figure 45). Certain erratic outlier values for LSDA and HSDA which can be ascribed to a technical fault of the instrument and/or incorrect measurements were recorded between +/- 145 DAB and 165 DAB respectively. This led to a deceptive apparent increase in TA values of these two treatments, which is inaccurate considering that TA values generally decrease during the course of ripening. Apart from these outliers, the other treatments and controls followed a normal pattern of decrease in TA values, as expected.

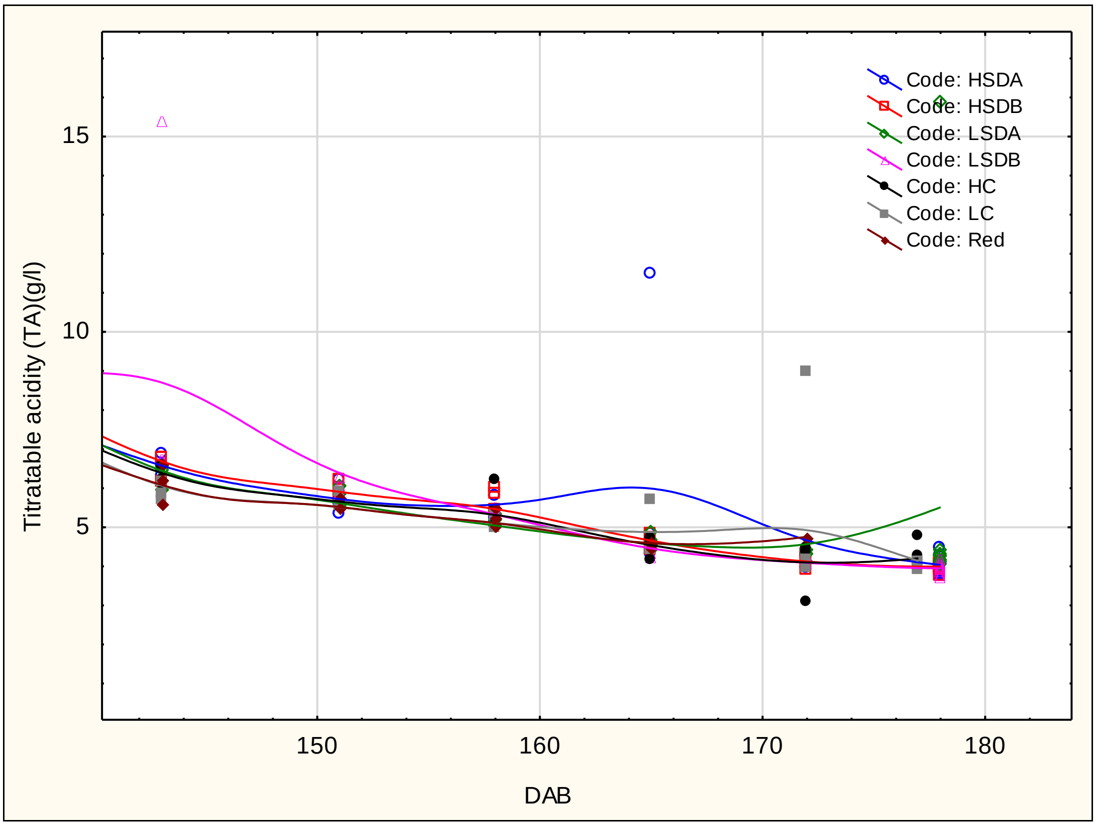

Figure 45 Titratable acidity (TA) relative to days after budburst (DAB) for the treatments from ±6°B up to harvest in season 2011/12 (distance- weighted least- square fits are shown). Red = R

During 2012/13, there were fluctuations in the TA of the HSDA, increasing in concentration from 164 DAB to 166 DAB, and then decreasing again slightly from 168 DAB until the day of harvest at 173 DAB (Figure 46). The TA of the two low vigour SD treatments decreased at a more rapid rate than that of the other treatments and had the lowest concentration of TA of all treatments at the day of harvest (174 DAB). There was a large difference in TA values between the high vigour SD treatments (HSDA and HSDB) and the low vigour SD treatments (LSDA and LSDB), respectively, with the two LSD sub treatments having consistently lower TA's (Figure 46). Under conditions of higher sunlight exposure, the TA concentration regresses at a more rapid rate than when compared to shaded conditions (Smart *et al*., 1985; Bergqvist *et al*., 2001). Therefore, despite the large increase in total leaf area:fruit mass ratios for the LSDA and LSDB treatments during 2012/13, berries were exposed to sunlight to such an extent that it led to a rapid rate in the decrease of TA.

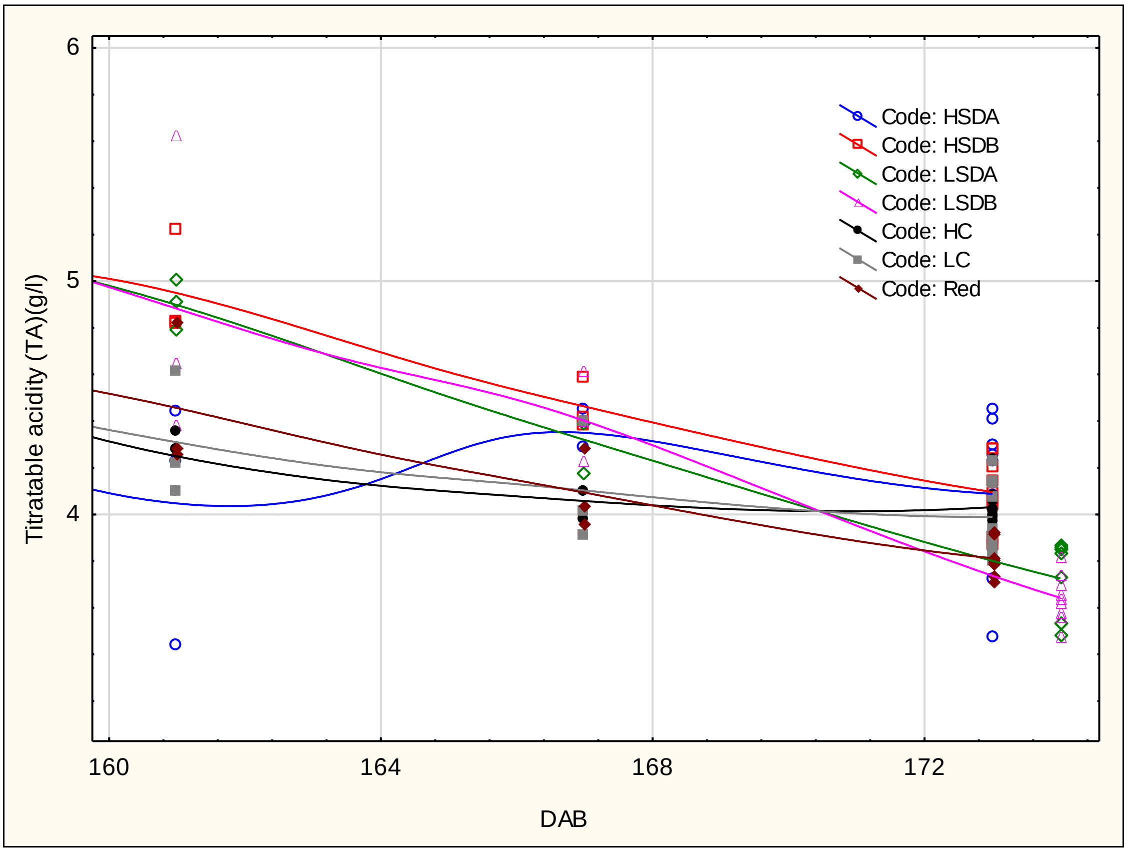

Figure 46 Titratable acidity (TA) relative to days after budburst (DAB) for the treatments from ±10°B up to harvest in season 2012/13 (distance- weighted least- square fits are shown). Red = R

Monitoring of TA regression during the 2013/14 season commenced at 126 DAB. The decline in TA content during 2013/14 followed a curve with a clear distinction between the TA values of the HC, LC and R treatments when compared to that of the four SD treatments, up until +/- 185 DAB, after which the difference between the values of all treatments seemed to have become minimal (Figure 47). The HSDA and HSDB treatments initially had higher TA values when compared to that of the LSDA and LSDB, respectively, but the large difference evened out somewhat as the day of harvest approached, with average TA levels of the HSDB treatment measuring at some of the lowest of all treatments (Figure 47).

During the 2011/12 season, the increase in juice pH was monitored from 115 DAB. Towards the end of ripening (165 to 177 DAB), the range of pH measurements within the HC and LC treatments became much larger (Figure 48). Figure 45 Titratable acidity (TA) relative to days after budburst (DAB) for the treatments from ±6°B up to harvest in season 2011/12 (distance- weighted least- square fits are shown). Red = RFigure 48 Juice pH values relative to days after budburst (DAB) for the treatments up to harvest in season 2011/12 (distance- weighted least- square fits are shown). Red = RThe pH of the four SD treatments and the tempo of increase thereof was distinctly lower when compared to that of the controls and R treatment. The conversion of the existing training system to SD systems created more open canopies, and since increased sunlight exposure is known to decrease juice pH, these lower pH values were expected (Smart, 1985; Smart *et al*., 1985; Bergqvist *et a*l., 2001). Between +/- 165 DAB and 172 DAB (date of harvest), the pH values of the

R treatment did not show the expected increase. This could probably be ascribed to outliers causing a misleading reading (Figure 49). This treatment presented with the lowest eventual pH values of all other treatments, also due to the treatment effect creating an exposed canopy.

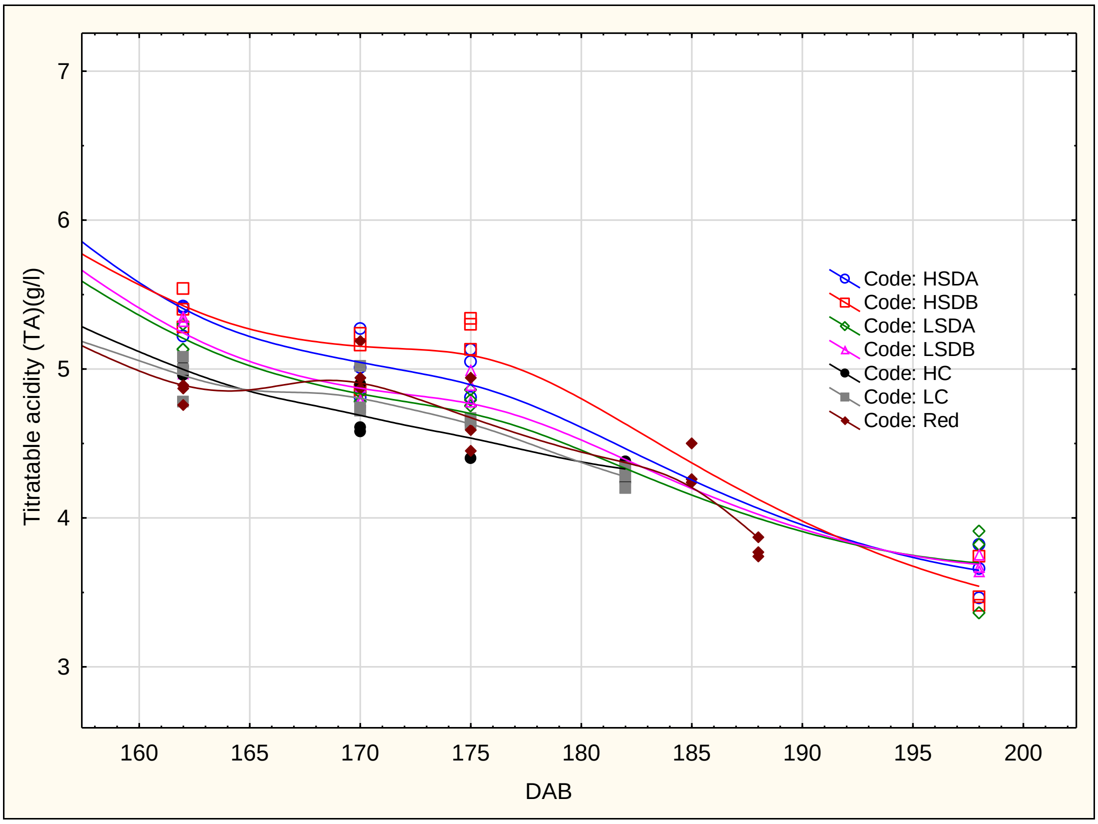

Figure 47 Titratable acidity (TA) relative to days after budburst (DAB) for the treatments from ±13°B up to harvest in season 2013/14 (distance- weighted least- square fits are shown). Red = R

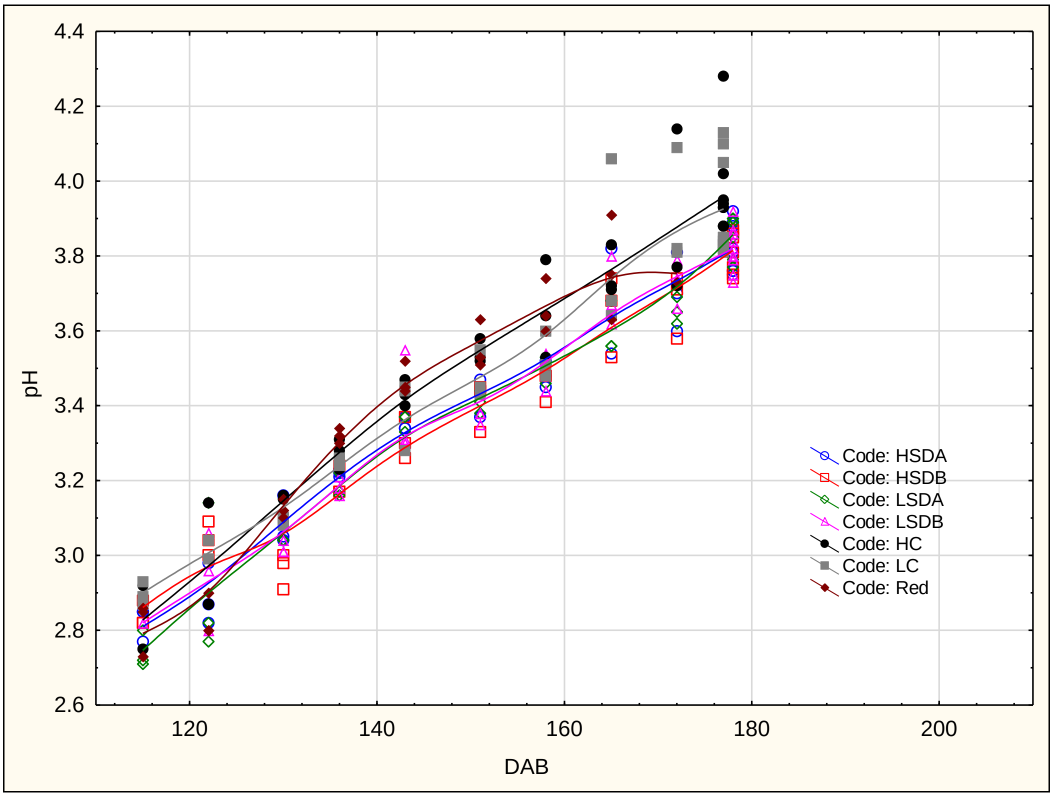

Figure 48 Juice pH values relative to days after budburst (DAB) for the treatments up to harvest in season 2011/12 (distance- weighted least- square fits are shown). Red = R

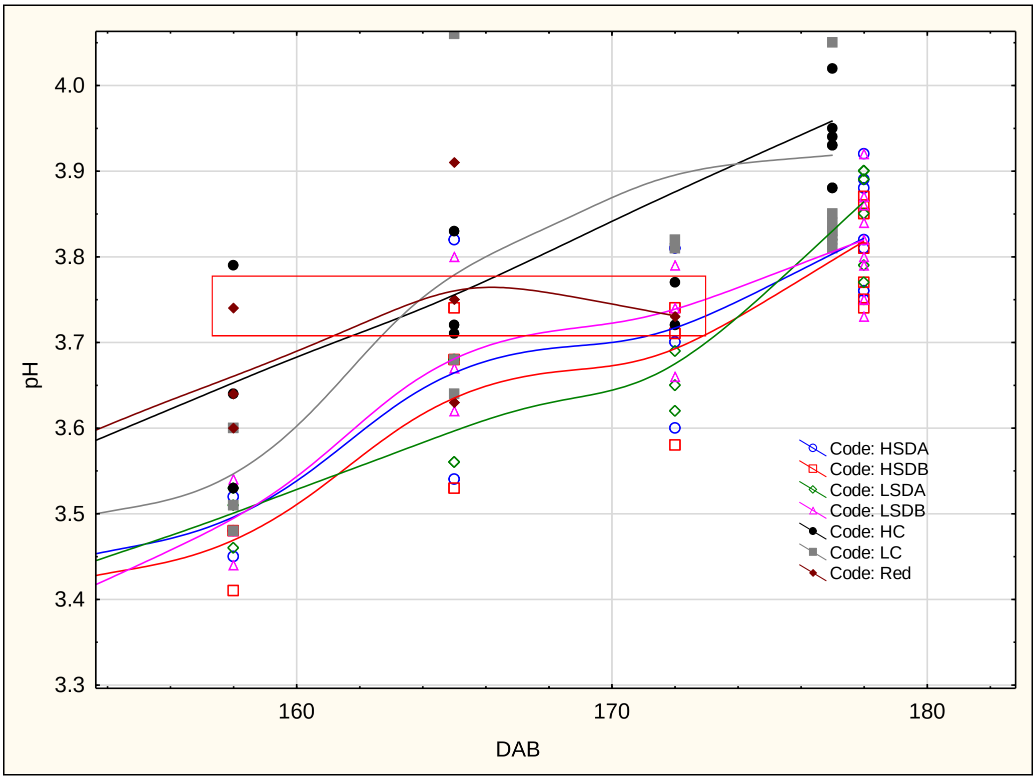

Figure 49 Juice pH values relative to days after budburst (DAB) during season 2011/12, specifically indicating the slight reduction in pH for the R treatment between 165 and 172 DAB. Red = R

The distinction in the increase in pH values were much more pronounced during the 2012/13 season, and the ranges within field replicates of the treatments were also smaller when compared to those during the 2011/12 season (Figure 48 and Figure 50). The pH values of the four SD treatments increased at a similar rate to the controls and the R treatment, but the values of the four SD treatments remained consistently lower when compared to that of the controls and the R treatment.

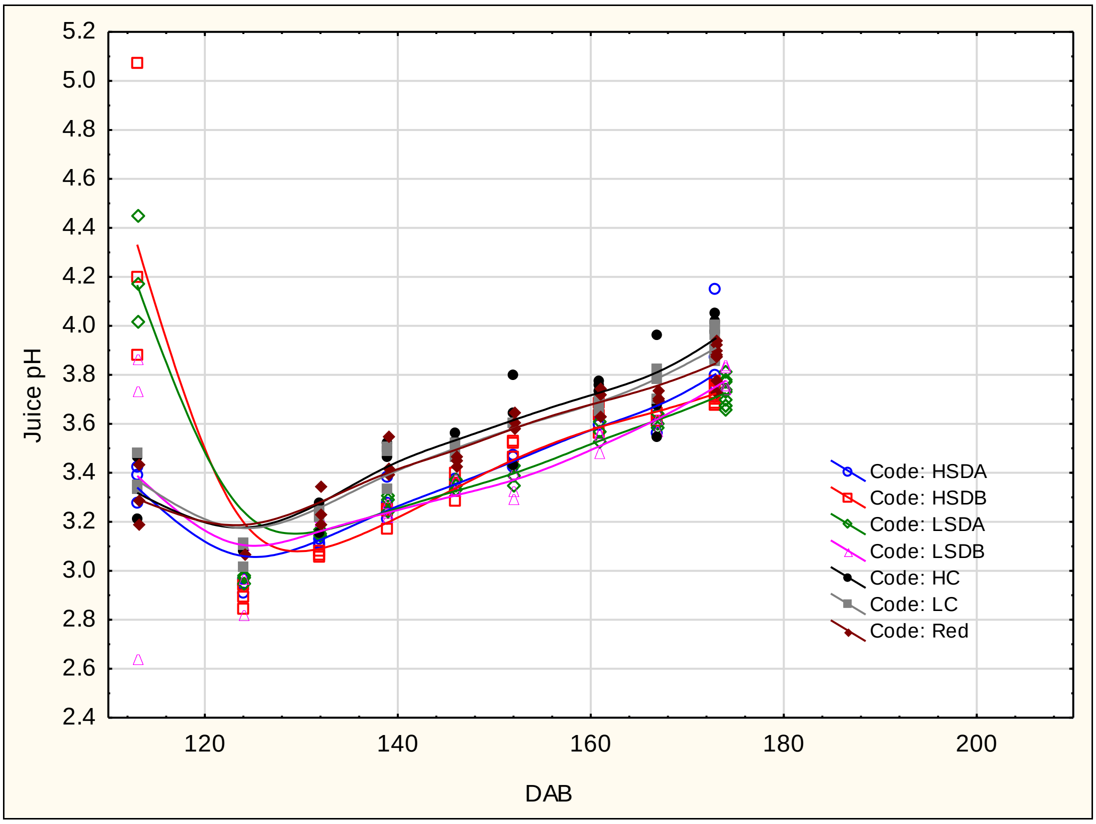

Figure 50 Juice pH values relative to days after budburst (DAB) for the treatments from ±10°B up to harvest in season 2012/13 (distance weighted least square fits are shown). Red = R

Monitoring of pH progression during the 2013/14 season commenced at 126 DAB. Between 130 and 140 DAB, there seem to have been a drastic increase in pH values for all four SD treatments after which the values decreased again to values lower than that of the controls and R treatment. This apparent increase is deceptive, since inconsistent outlier pH values were recorded for these treatments between +/- 142 DAB and 152 DAB. This was due a technical fault and/or inaccurate measurements by the instrument (Figure 51).

After +/- 162 DAB, a steady increase in pH of all four SD treatments occurred until the day of harvest (198 DAB). As in the previous seasons, the pH progression of the four SD treatments was such that values were mostly lower than when compared to that of the controls and R treatment. Since the four SD treatments were harvested later than the controls and the R treatment, the pH values of the SD treatments kept on increasing until the day of harvest, with eventual values of the HSDB being slightly higher than that of all the other treatments and controls (Figure 51).

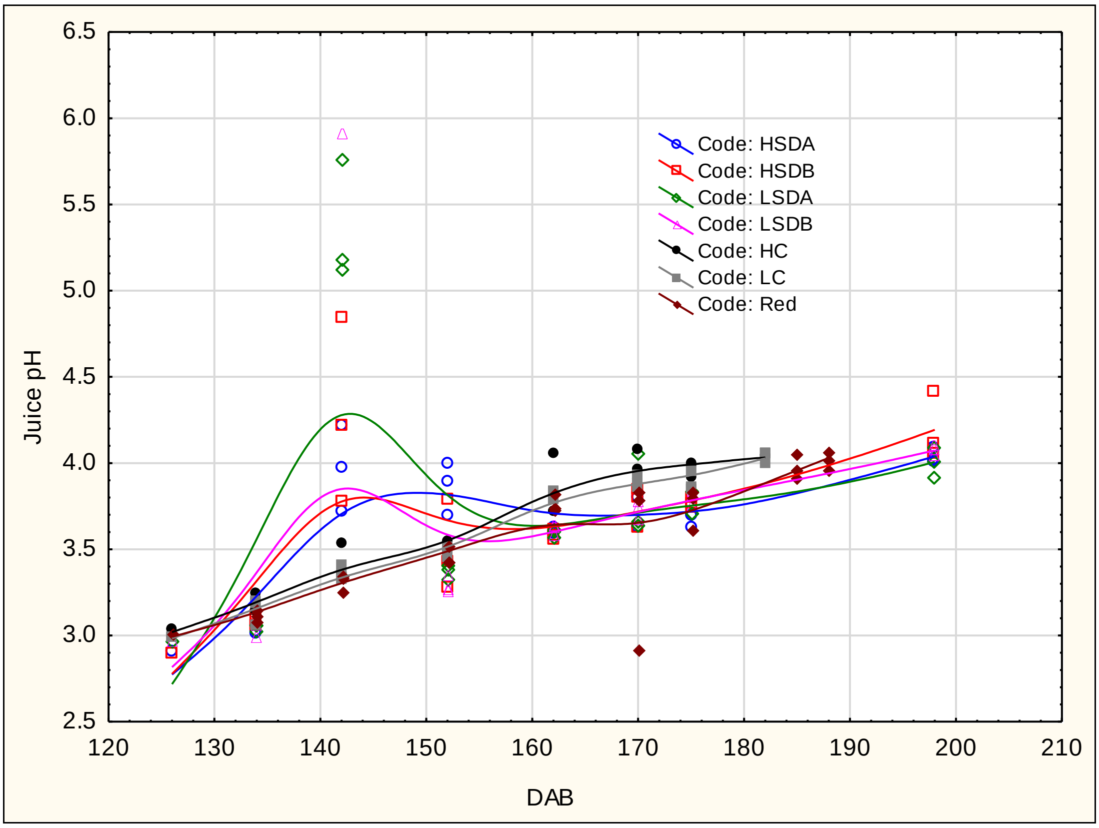

Figure 51 Juice pH values relative to days after budburst (DAB) for the treatments from ±13°B up to harvest in season 2013/14 (distance- weighted least- square fits are shown). Red = R

3.3.5.4 Ratio of total soluble solids to titratable acidity evolution

The ratio of TSS to TA, referred to as the maturity index (Boulton *et al*., 1996), was calculated to determine the level of ripeness of the various treatments. Very high TSS/TA ratios indicate over ripeness and is usually the result in situation associated with overcropping where the rate of TA accumulation remains virtually unchanged with a concomitant increase in TSS accumulation (Winkler, 1954).

During 2011/12, the HSDB, LSDA and LSDB treatments initially displayed a slower progression in the TSS/TA ratio when compared to the HSDA, HC, LC and R treatment (Figure 49). This slower progression was especially apparent in the LSDB treatment, where, since the starting date of measurement up until +/- 150 DAB, it displayed the slowest rate of TSS:TA progression, indicating that ripening was initially delayed. However, after 150 DAB, this rate increased again, with this treatment presenting with TSS:TA ratio values similar to that of the two controls at harvest. After +/- 145 DAB, the HSDA treatment's TSS:TA ratio started to decrease, thereafter displaying the slowest rate of progression of all the other treatments and controls. At 165 DAB, the TSS:TA of the R canopy treatment showed a decline, with the LSDA treatment also displaying a slight decrease after +/- 170 DAB. The TSS:TA ratio of the LSDB treatment and the LC increased between 172 and 177 DAB (date of harvest), ending with average ratios of 5.80 and 5.60 respectively. Even though there was a slight decrease in the TSS:TA progression of HC between +/- 170 DAB and the date of harvest, the eventual ratio was considered to be very high (5.98). It should be noted that all three of these ratios are considered to be at the higher scale of ripeness (Boulton *et al.*, 1996).

The TSS/TA ratio of the R treatment stabilised at a ratio of 4.50 and grapes of this treatment were harvested 177 DAB.

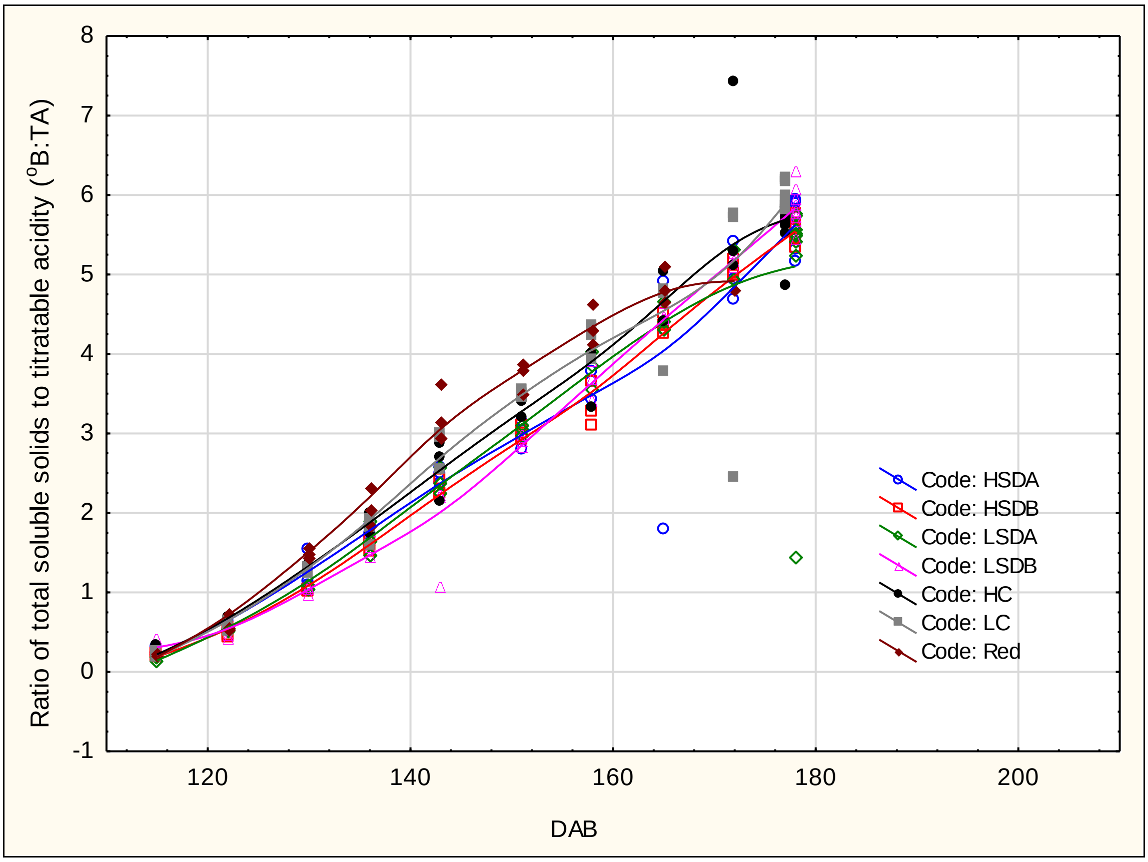

Figure 52 Ratio of total soluble solids to titratable acidity values relative to days after budburst (DAB) for the treatments from ±6°B up to harvest in season 2011/12 (distance- weighted least- square fits are shown). Red = R

During the 2012/13 season, there was a much larger discrepancy between the rate of increase in the TSS:TA ratios of the four SD treatments and that of the two controls and R treatment, when compared to 2011/12. The higher TSS:TA ratios of the HC, LC and R treatment throughout the season when compared to any of the four SD treatments, indicated higher levels of ripeness in the former treatments (Figure 53).

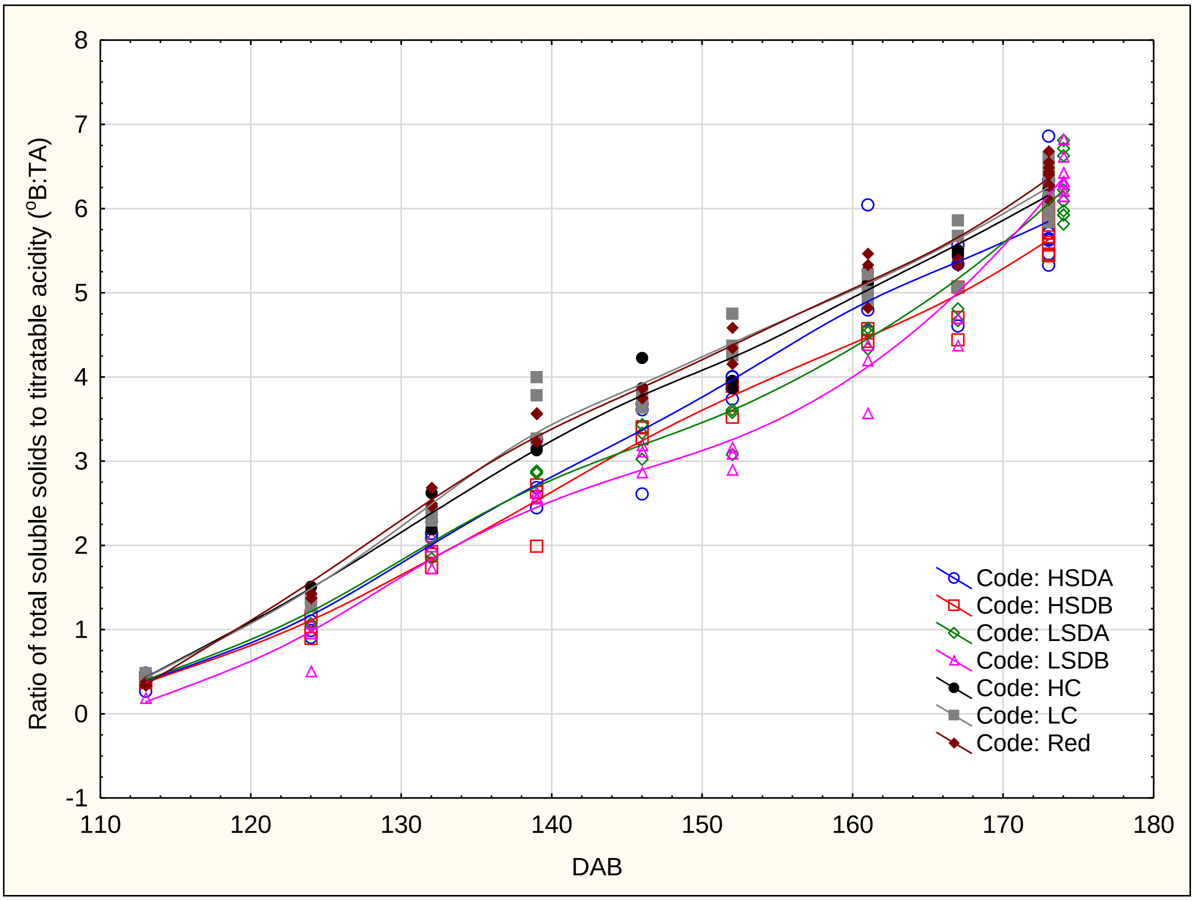

Figure 53 Ratio of total soluble solids to titratable acidity values relative to days after budburst (DAB) for the treatments from ±10°B up to harvest in season 2012/13 (distance- weighted least- square fits are shown). Red = R

The progression of TSS:TA was once again slower for the four SD main treatments during 2013/14 when compared to the controls and R treatment, and the distinction of the TSS:TS ratio between the four SD treatments and the controls and R treatment was especially clear in this season (Figure 54). Towards the end of ripening, both controls exhibited a minimal increase in the TSS:TA ratio, whereas all the TSS:TA ratios of SD treatments and the R treatment increased more rapidly. On the day of harvest, the TSS:TA ratio of the SD treatments ranged between 6.20 and 6.40, which falls into the higher category of ripeness, *i.e.* to overripe (Figure 55).

The higher TSS:TA end values for the four SD treatments during 2013/14 hints at the effect of overcropping (Winkler, 1954). However, when considering the leaf area:fruit mass ratios for these four treatments during 2013/14, none of the values for these ratios were perceived as being sub-optimally low and overcropping didn't seem to be the cause of the delayed ripening (Table 22). The only low ratio that stood out during 2013/14 was that of the HSDB treatment, with a ratio of 5.70 (the lowest of all treatments). Even in this case, this is not necessarily a sub-optimal value, since even though there was a decrease in estimated total leaf area per treatment in relation to an increase in yield, the spatial distribution of the leaves in the open canopy allowed optimal exposure, and the leaves were able to compensate by means of an increase in productivity (Mabrouk *et al*., 1997; Hunter, 2000;). A larger crop could therefore be ripened without any detrimental effect on grape quality.

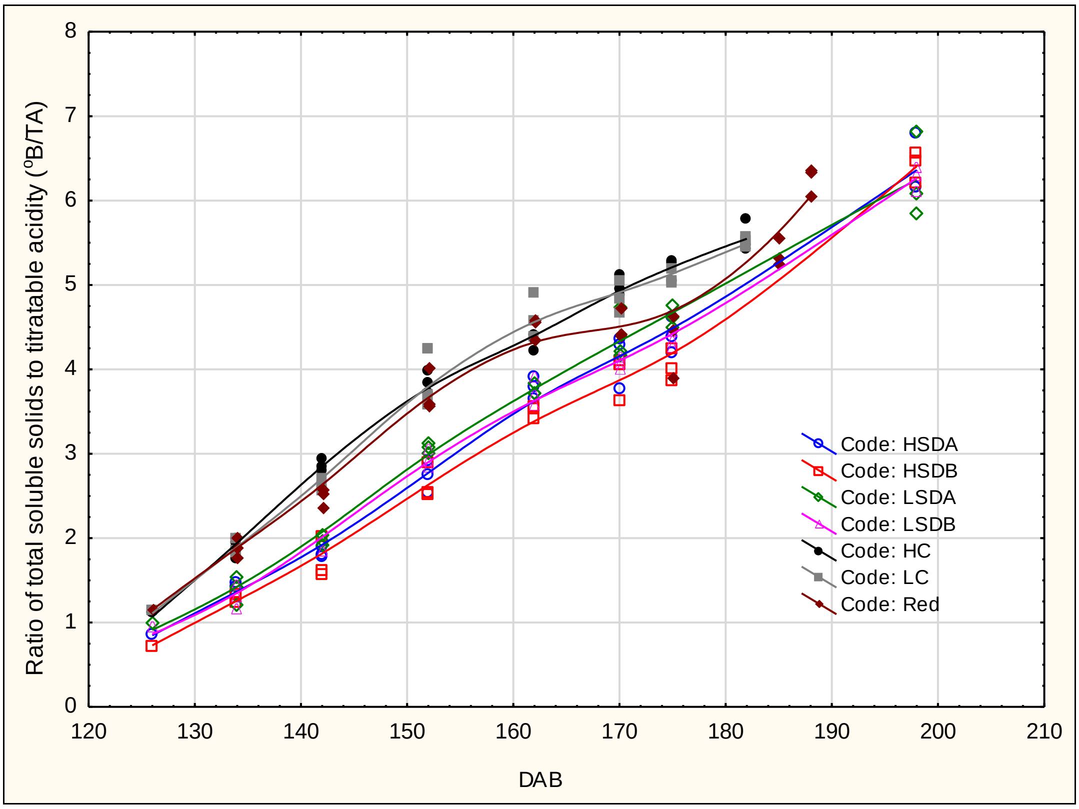

Figure 54 Ratio of total soluble solids to titratable acidity values relative to days after budburst (DAB) for the treatments from ±13°B up to harvest in season 2013/14 (distance- weighted least- square fits are shown). Red = R

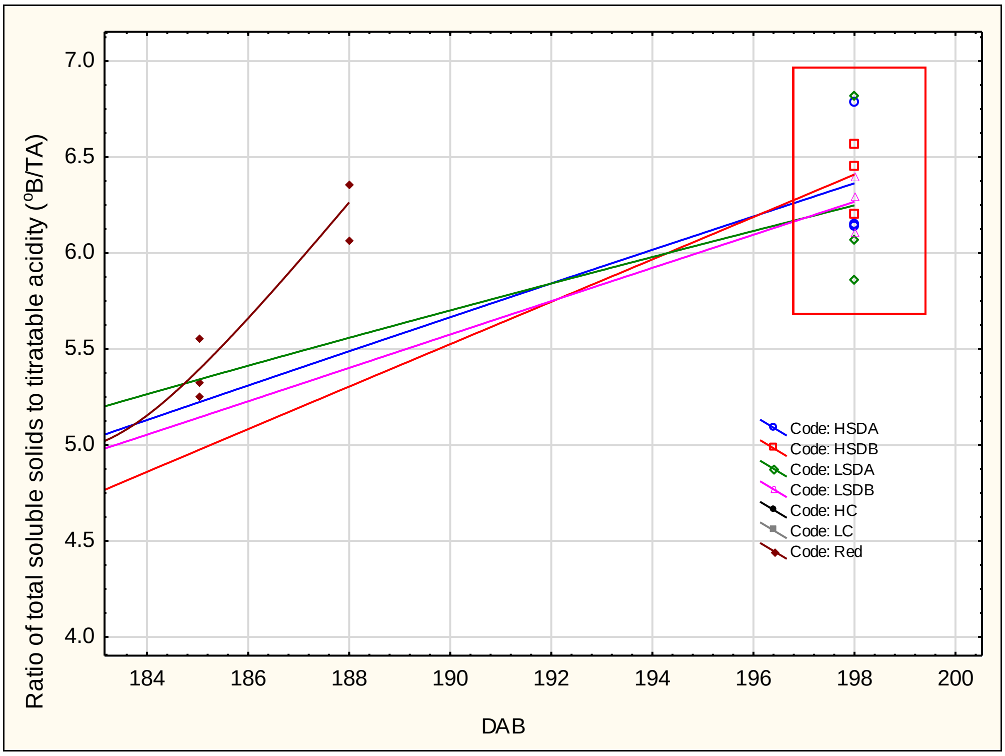

Figure 55 Ratio of total soluble solids to titratable acidity values relative to days after budburst (DAB) for the treatments, indicating specifically the final measurements of all Smart-Dyson (SD) treatments (distance- weighted least- square fits are shown). Red = R

The slow progression in ripening in the four SD treatments during 2012/13 and especially during 2013/14, can be attributed to the higher level of water stress experienced by these four treatments in the last two seasons of the trial. This delay was caused by a decreased rate of sugar loading and a concomitant decreased sugar concentration which corresponds with the findings of Ojeda *et al*. (2002) and Girona *et al*. (2009) that water deficit may delay ripening.

3.3.6 Wine phenolic measurements

3.3.6.1 Total phenolics

Phenolic compounds, including anthocyanins, contribute to colour, mouthfeel and taste of red wines (Gawel, 1998; Ribéreau-Gayon *et al*., 2001). They interact with many factors that will have an influence on canopy microclimate and thus sunlight interception, such as environmental conditions and cultivation practices, to determine to what extent and concentration these components will be formed (Smart *et al*., 1988; Jackson & Lombard, 1993; Downey *et al*, 2006;). Levels can therefore be manipulated to an extent through various viticultural practices that will have an influence on canopy microclimate.

The total phenolic levels for the high vigour SD treatments (HSDA and HSDB) were higher in 2012 wines (2011/12 season) when compared to the 2013 wines (2012/13 season). Unfortunately, there is no data for the low vigour SD treatments during 2011/12, since these samples were lost and therefore not obtainable. The assumption could be made that the wines might have been unbalanced, exhibiting higher tannin levels but lower anthocyanin levels. For the controls and R treatment, it seemed that the 2012 vintage was lower in total phenolics and anthocyanin levels (Figure 56 and Figure 57).

Although there was an increase in total wine phenolic content for both controls as well as the R treatment from 2011/12 to 2012/13, the total wine phenolic content of the two measured HSD treatments decreased from 2011/12 to 2012/13 (Figure 56). All four of the SD sub treatments displayed higher Ravaz indices during 2012/13 when compared to the two controls and R treatment. This was mainly due to higher yields (Figure 27) compared to relatively reduced vigour , as can be seen when considering the decrease in total leaf area:fruit mass ratios of these treatments, from 2011/12 to 2012/13 (Table 22). An increase in yield without a coinciding increase in effective leaf area may actually lead to the decrease in phenolic compounds (Kliewer & Dokoozlian, 2007). The lower vigour in these treatments therefore did not favour ripening, and this may have contributed to the lower phenolic content of the SD treatments (Figure 56).

Research has shown that a converted training system, such as a Smart-Dyson, with a more open canopy may produce berries with higher phenolic concentrations due to the canopy's unique microclimate, architecture and increased sunlight interception (Gladstones, 1992; Dokoozlian & Kliewer, 1996; Bergqvist *et al*., 2001; Cortell & Kennedy, 2006). However, this was not the case in this experiment since the total wine phenolics actually decreased for the two measured HSD treatments between 2011/12 and 2012/13 (Figure 56). For both the controls and the R treatment, however, this parameter increased during this period. There was a very large increase in yield in the two HSD treatments from 2011/12 to 2012/13 relative to the small increase in vegetative growth, leading to large increases in the Ravaz indices during the latter season. Where yield is greatly increased without a proportional increase in leaf area, phenolic synthesis is inhibited (Kliewer & Dokoozlian, 2005). This can be confirmed when considering that the leaf area:fruit mass ratio for the HSDB decreased with 63% from 2011/12 to 2013/14, leading to a scenario that was not favourable for ripening.

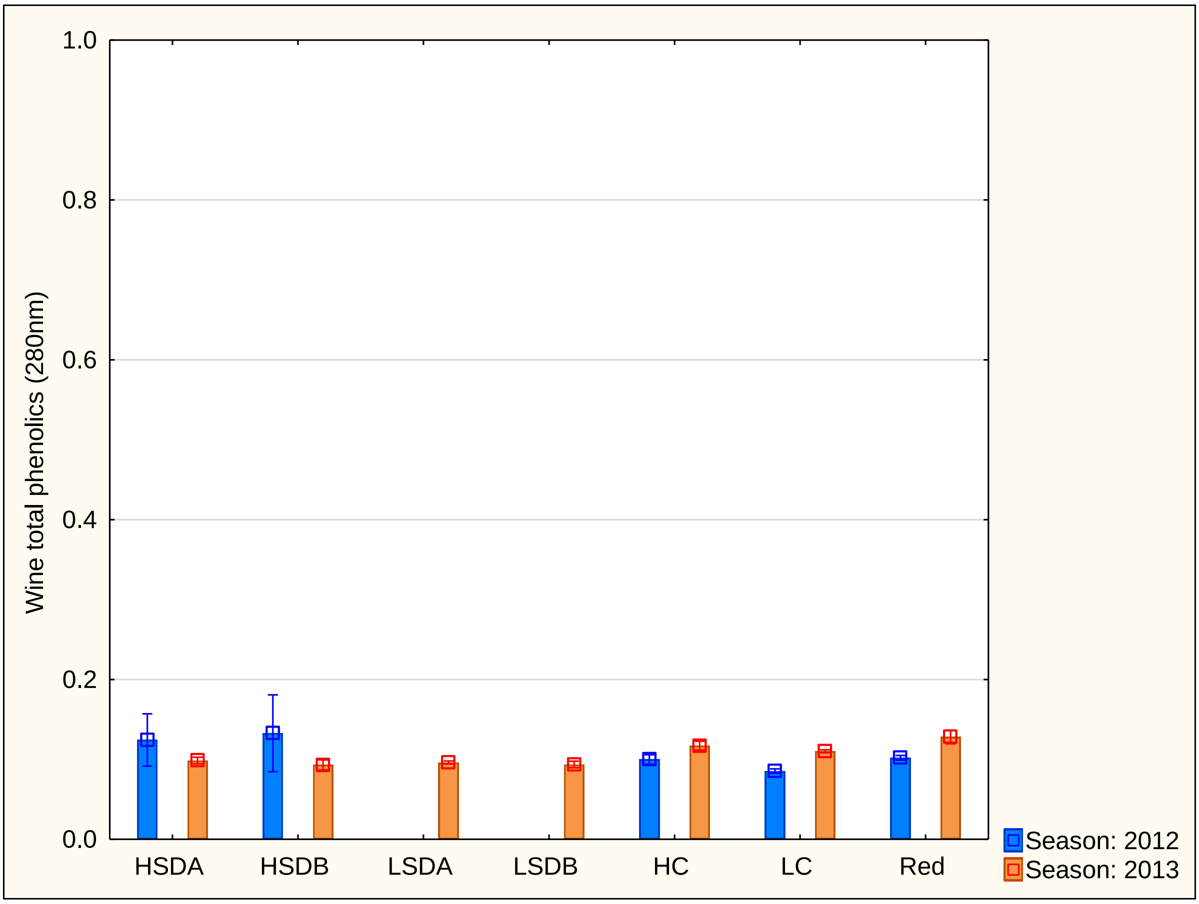

Figure 56 Wine total phenolics for the treatments from seasons 2011/12 and 2012/13 (means with ± standard errors shown). Red = R

3.3.6.2 Anthocyanins

The total anthocyanin reading in absorbance units (A.U.) measures the anthocyanin concentration in a sample. The method used for the anthocyanin quantification uses the effect of an acid (hydrochloric acid) to decrease the pH. At lower pH, the anthocyanins are converted into the red coloured form and can therefore be measured at 520 nm in the spectrophotometer.

Increased light intensities in optimally open canopies favours anthocyanin synthesis, but the over-exposure of berries leads to an increase in temperature, reducing colour and decreasing anthocyanin levels (Kliewer, 1970; Winkler *et al*., 1974; Haselgrove *et al*., 2000; Bergqvist *et al*., 2001). Since anthocyanin synthesis for all treatments increased from 2011/12 to 2012/13 (Figure 57) it can be accepted that the bunches of the HSD treatments were in all likelihood not overexposed or did not become overheated in the latter part of 2012/13. Other factors such as ambient temperature and soil water deficit are also known to have an influence on anthocyanin synthesis (Bergqvist *et al*.,2001; Ojeda *et al*., 2002; Spayd *et al*., 2002; Castellarin *et al*., 2007). The increase in both of these factors during 2012/13 also accounts for the increase in wine anthocyanin content.

There was a substantial increase in the wine anthocyanin content from 2011/12 to 2012/13 in the SD treatments (Figure 57). The fact that the 2012/13 was a much warmer season compared to 2011/12 (Figure 11) and the higher water stress experienced by the SD treatments during the 2012/13 season (Figure 18) could have contributed to the increase in wine anthocyanin content. As mentioned previously, the Ravaz indices of the two HSD treatments were very high during 2012/13 due to reduced vigour relative to larger yields. This probably led to more exposed canopies. Anthocyanin synthesis will be enhanced under conditions where the optimum amount of light can be intercepted, as is the case with more open canopies. However, once berry temperatures become too high due to the effect of overexposure, colour intensity and anthocyanin levels are known to decrease (Kliewer, 1970; Winkler *et al*., 1974; Haselgrove *et al*., 2000; Bergqvist *et al*., 2001). The fact that anthocyanin levels increased rather than decreased, is probably an indication that the berries were in fact not over exposed.

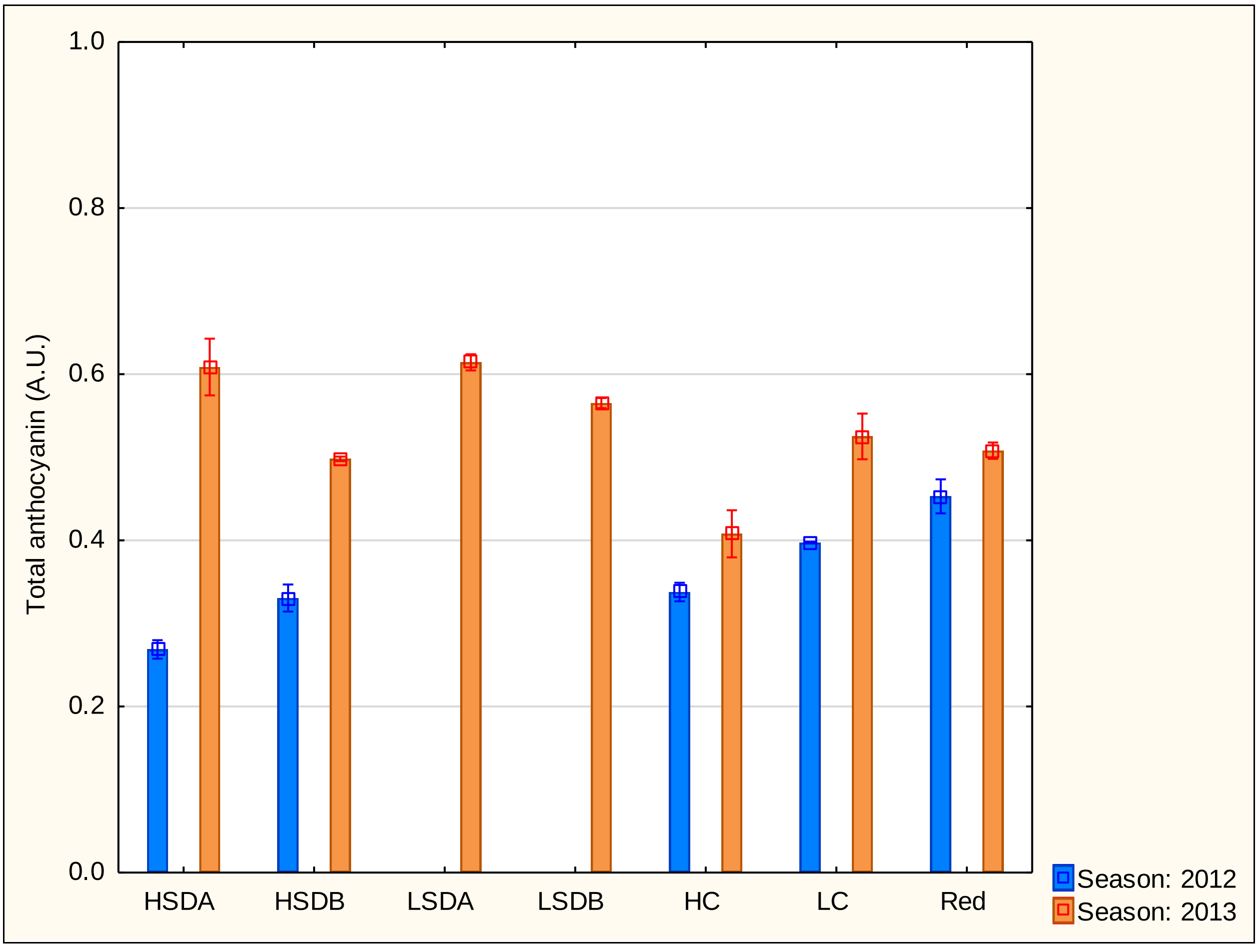

Figure 57 Wine total anthocyanin for the treatments for season 2011/12 and 2012/13 (means with ± standard errors shown). Red = R

3.3.6.3 Wine colour hue and modified colour hue

Wine colour hue expresses the hue (tint or shade) of the colour rather than its intensity, indicating the yellow:red ratio of colour observed in red wines. In cases where wines have been oxidised for example, the ratio will be in favour of the yellowish tint, causing a yellow discolouration to be more noticeable (J. Aleixandre-Tudo, personal communication, 2015). In the analysis of modified wine hue, the pH of the samples was adjusted to a standard value. The absorbance values of all the wines reported for the 2011/12 season were higher than those reported during the 2012/13 season (Figure 58 and Figure 59) This increase is based on the higher expression of a yellowish tint and this suggests that the wines of 2011/12 might have been oxidised (Figure 58). Furthermore, the higher hue values of the 2011/12 wines indicate that there was a larger degradation of anthocyanins, suggesting that the wines may have been out of balance. The anthocyanins in wines that are unbalanced in terms or phenolics degrade faster, resulting in a decrease in anthocyanin concentration and an increase in the hue values of the wine (J. Aleixandre-Tudo, personal communication, 2015). During both seasons, the HC treatment displayed the highest absorbance values of all (Figure 58 and Figure 59).

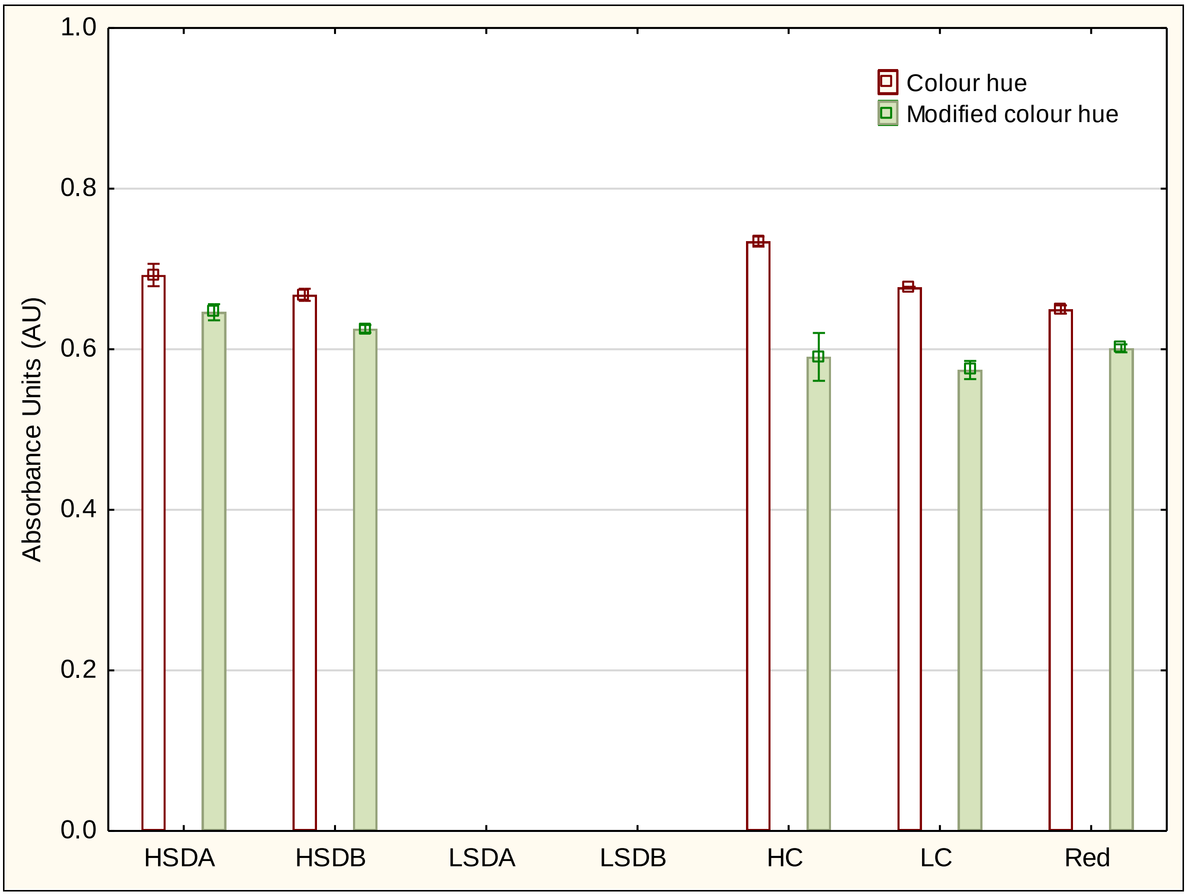

Figure 58 Wine colour hue and modified colour hue for the treatments from season 2011/12 (means with ± standard errors shown). Red = R

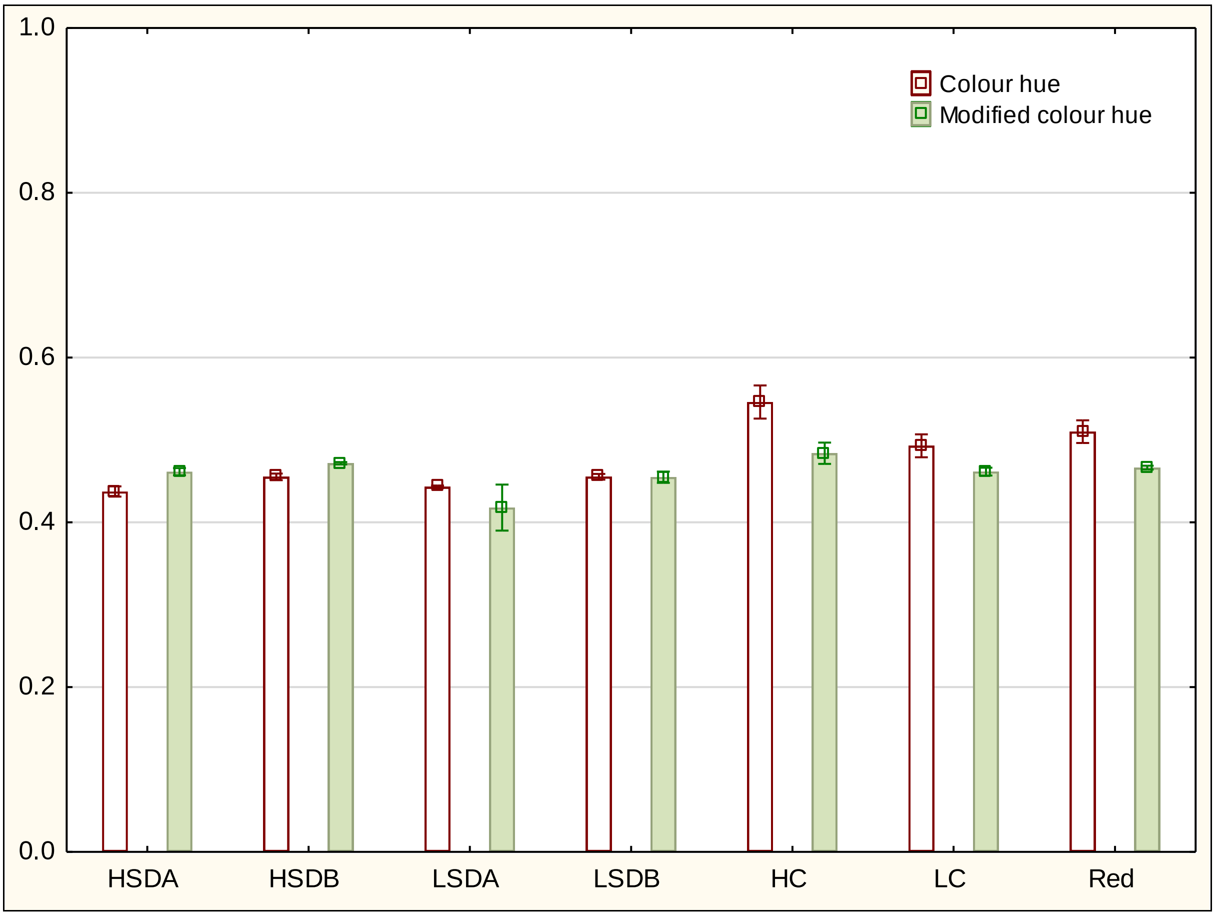

Figure 59 Wine colour hue and modified colour hue for the treatments from season 2012/13 (means with ± standard errors shown). Red = R

Colour intensity (also known as wine colour density) is a measurement of the overall wine colour of a sample by summing the values obtained for the red, blue and yellow tonalities. It is possible that wines with high anthocyanin content may only have moderate colour density, since there is no relation between the two parameters. Initial wine colour in young wines may be attributed mainly to anthocyanins alone (Somers & Evans, 1974).

All treatments exhibited much higher colour intensity at actual wine pH and SO_2 levels during 2012/13 when compared to the 2011/12 season (Figure 60 and Figure 61). This was particularly visible in the high vigour SD treatments, which increased greatly in colour intensity from 2011/12 to 2012/13. On the contrary, the controls and R treatment rather decreased in colour intensity over the two seasons.

As the wine pH was adjusted to 3 in order to standardize the pH of all wines, a higher colour intensity in the wines with the modified, reduced pH was to be expected. The 520 nm absorbance value was probably increased, leading to an increase in the expression of the red colour. At lower pH, the anthocyanins are converted to the red flavylium cation form, which means that some of the anthocyanins that were colourless at wine pH are now red and therefore contribute to the colour density measurement.

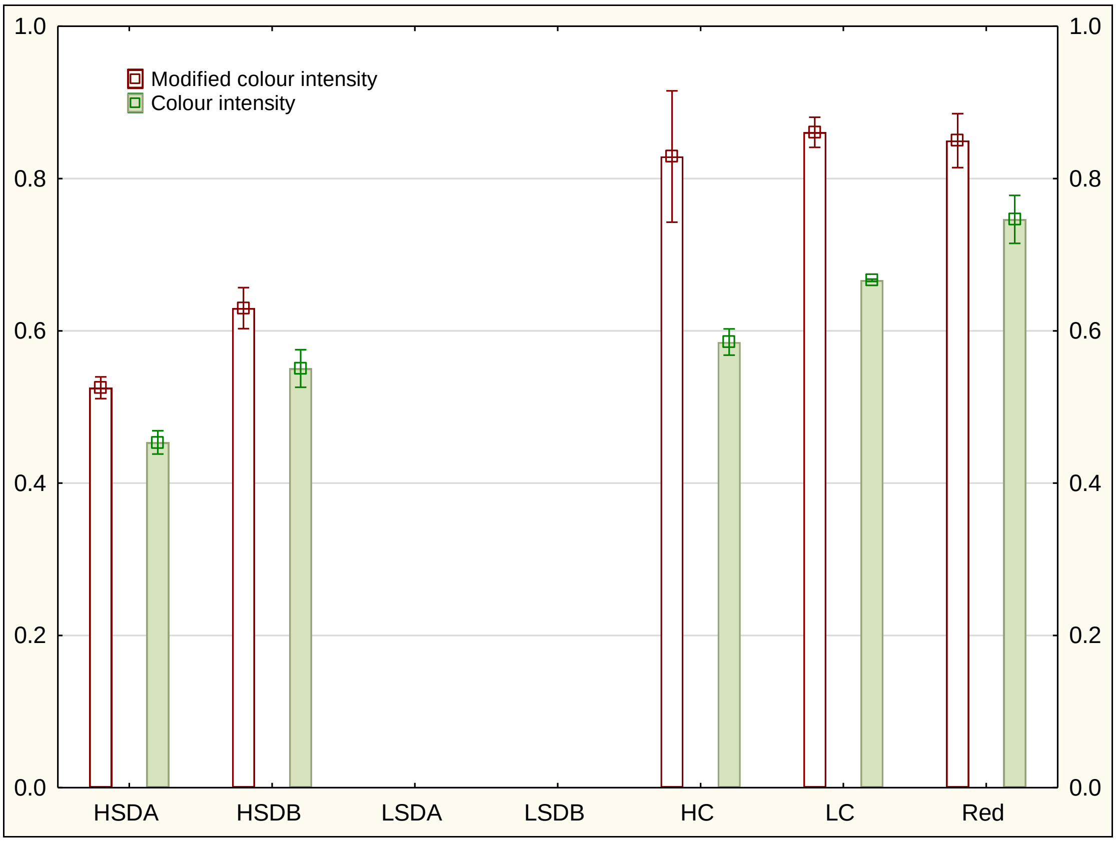

Figure 60 Wine colour intensity and modified colour intensity for the treatments from season 2011/12 (means with ± standard errors shown). Red = R

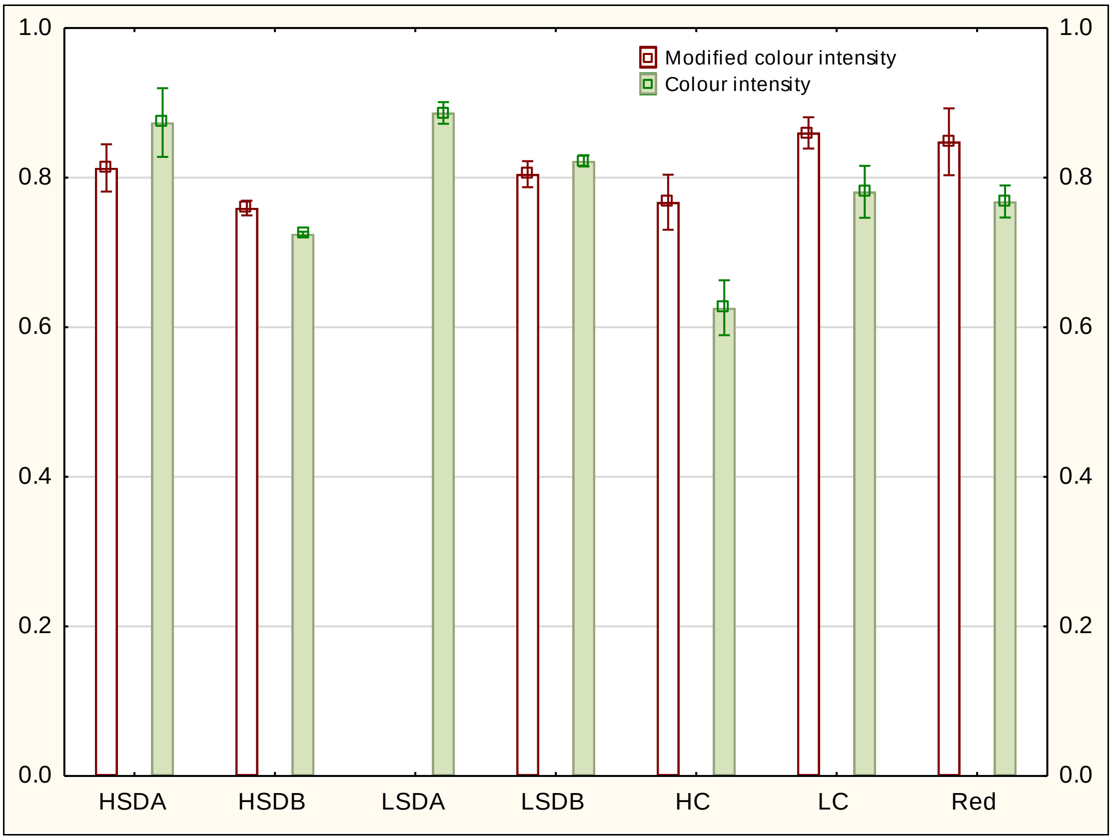

Figure 61 Wine colour intensity and modified colour intensity for the treatments from season 2012/13 (means with ± standard errors shown). Red = R

3.3.7 Sensory evaluation

In studies where various training systems and their microclimates were compared, sensory analysis indicated no difference in wine composition between these systems (Shaulis & May, 1971; Peterlunger *et al*., 2002). In this case, sensory results suggested strong seasonal effects with regard to wine sensory characteristics, even over-powering any possible treatment effects. It can be concluded from detailed sensory results that wine style was impacted more than quality, and that this impact on wine style was more related to seasonal conditions, than to treatment effects.

For the QDA analysis, the ANOVA product effect displaying attribute significance for 2011/12 and 2012/13 are presented in Figure 62 and Figure 63 Figure 62 ANOVA product effect displaying significance among the different sensory attributes for 2011/12.respectively. During 2011/12, the only traits that were prominent and showed significant differences were that of cooked vegetable ($p < 0.01$) and floral aromas ($p < 0.001$), with bitterness ($p < 0.05$) and astringency ($p < 0.01$) as the two mouthfeel components that stood out. The highest significant difference between treatments during 2011/12 was found in the floral aroma (Figure 62). During 2012/13, the only two aromas that were significant were those of caramel ($p < 0.05$) and all spice ($p < 0.05$) (Figure 63).

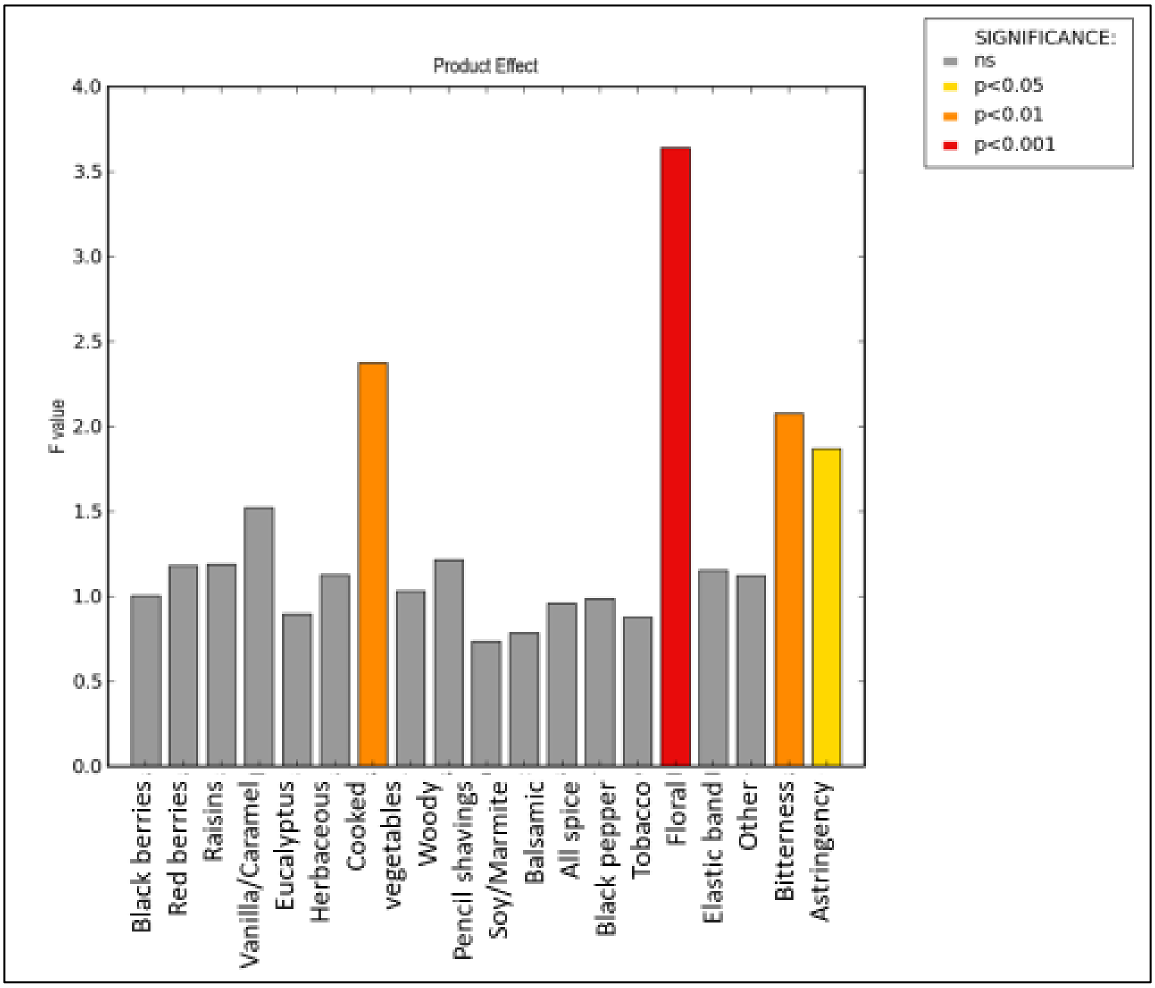

Figure 62 ANOVA product effect displaying significance among the different sensory attributes for 2011/12.

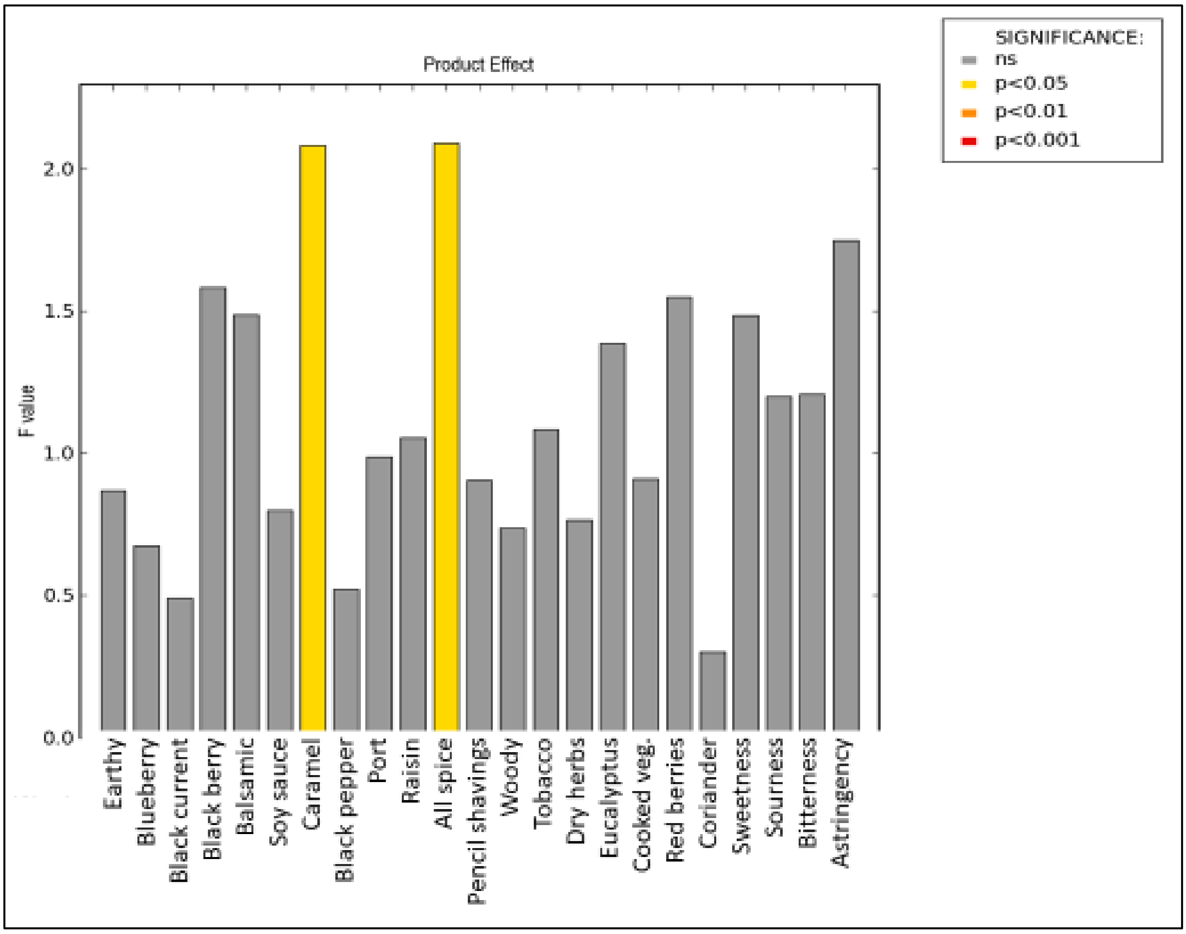

Figure 63 ANOVA product effect displaying significance among the different sensory attributes for 2012/13.

Although no floral aroma was detected in any wines from the 2012/13 season, this aroma was the most significant aroma characteristic of the 2011/12 wines, with the highest ratings being given for the HC and the HSDB treatment (Figure 64). Still, none of the values attained in any of the wines during 2012/13 are regarded high enough to be considered as a negative wine attribute.

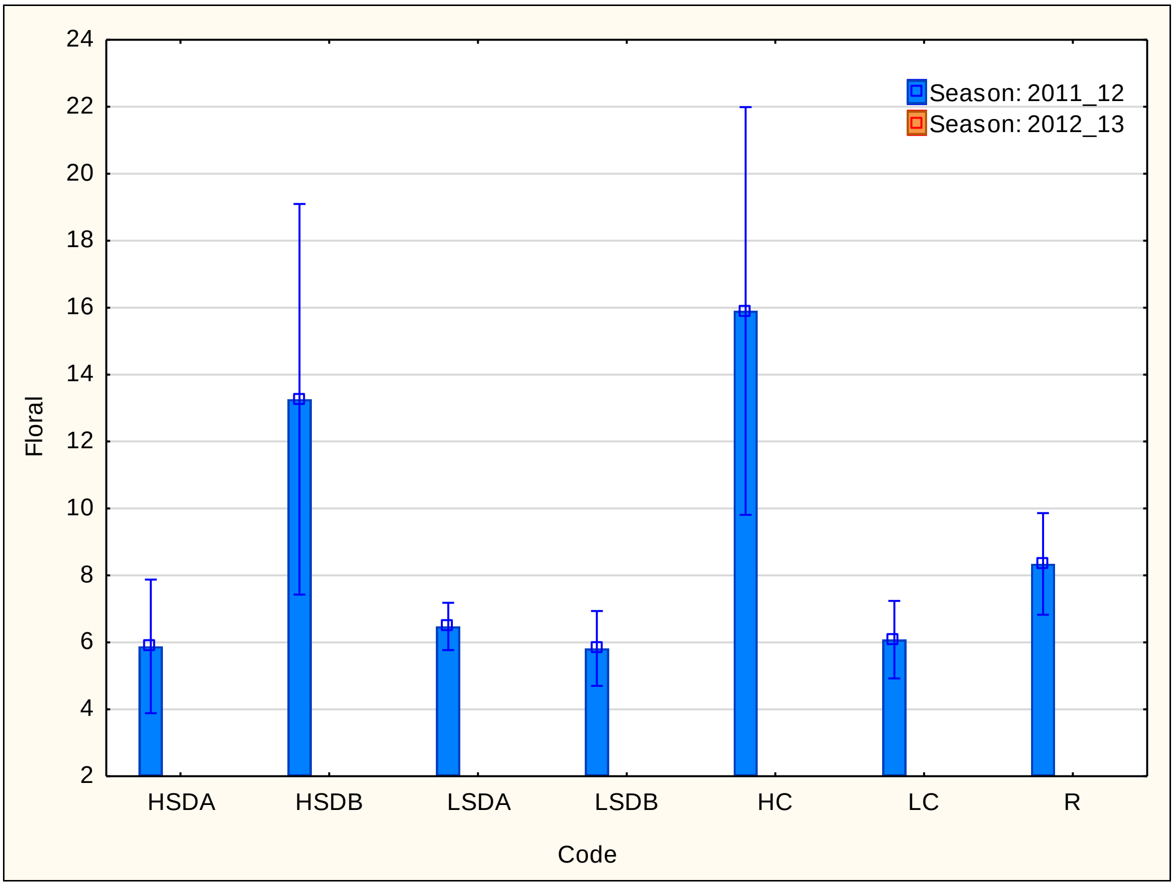

Figure 64 Floral aroma for the different treatments in 2011/12 (means with ± standard errors shown).

During the 2012/13 season, wines from the R treatment seemed to be more astringent than that of the control wines and the four SD treatments (Figure 65). Astringency decreased for the evaluated treatments (HSDA and HSDB) and control (HC) from 2011/12 to 2012/13, apart from the R wines, where levels remained quite similar over the two seasons. The decrease in astringency in the case of the HSDA and HSDB treatments may be associated with more open canopies, as seen by the decrease in estimated total leaf area per treatment from 2011/12 to 2012/13 (Table 22). There were, however, no real clear across-season negative parameters associated with any of the treatments or controls. It was also not evident that higher yield caused any negative effects on wine quality, but rather that it impacted on wine attributes. For the SD treatments it therefore makes sense to apply the treatments even if significant yield increases could not really be attained, since there can be an advantage in terms of wine colour (as seen in the warmer 2012/13 season) rather than for a sensory advantage alone (Figure 60 and Figure 61).

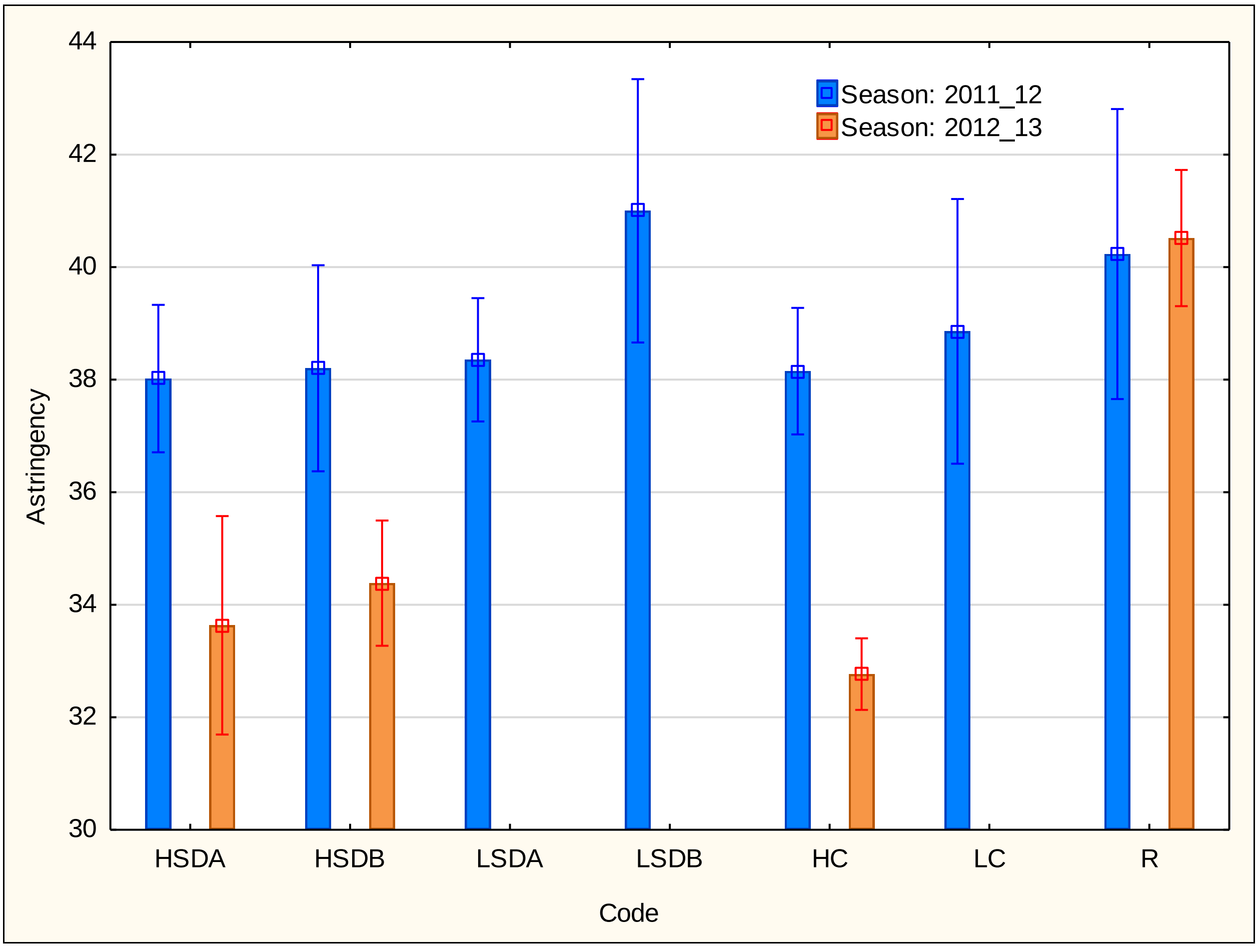

Figure 65 Astringency for the different treatments over both seasons (means with ± standard errors shown).

There were significant differences in cooked vegetable aromas between the treatments during 2011/12. The most intense cooked vegetable aroma during this season was measured for the LC and HSDA treatments. The lowest value was measured for the HSDB treatment (Figure 66). These differences were substantial. In the 2012/13 season, the values of the cooked vegetable aroma were higher for all treatments measured during this season when compared to their respective values measured in 2011/12. Among the treatments themselves, there were no significant differences in cooked vegetable aroma for the 2012/13 season. Even though there was an increase in the cooked vegetable aroma in the second season, obtained values are still considered below the threshold value where this aroma is perceived as a negative attribute. Even though cooked vegetable aroma is associated with negative wine attributes, the low levels measured for all treatments over both seasons therefore did not seem to have had a negative impact on perceived wine quality.

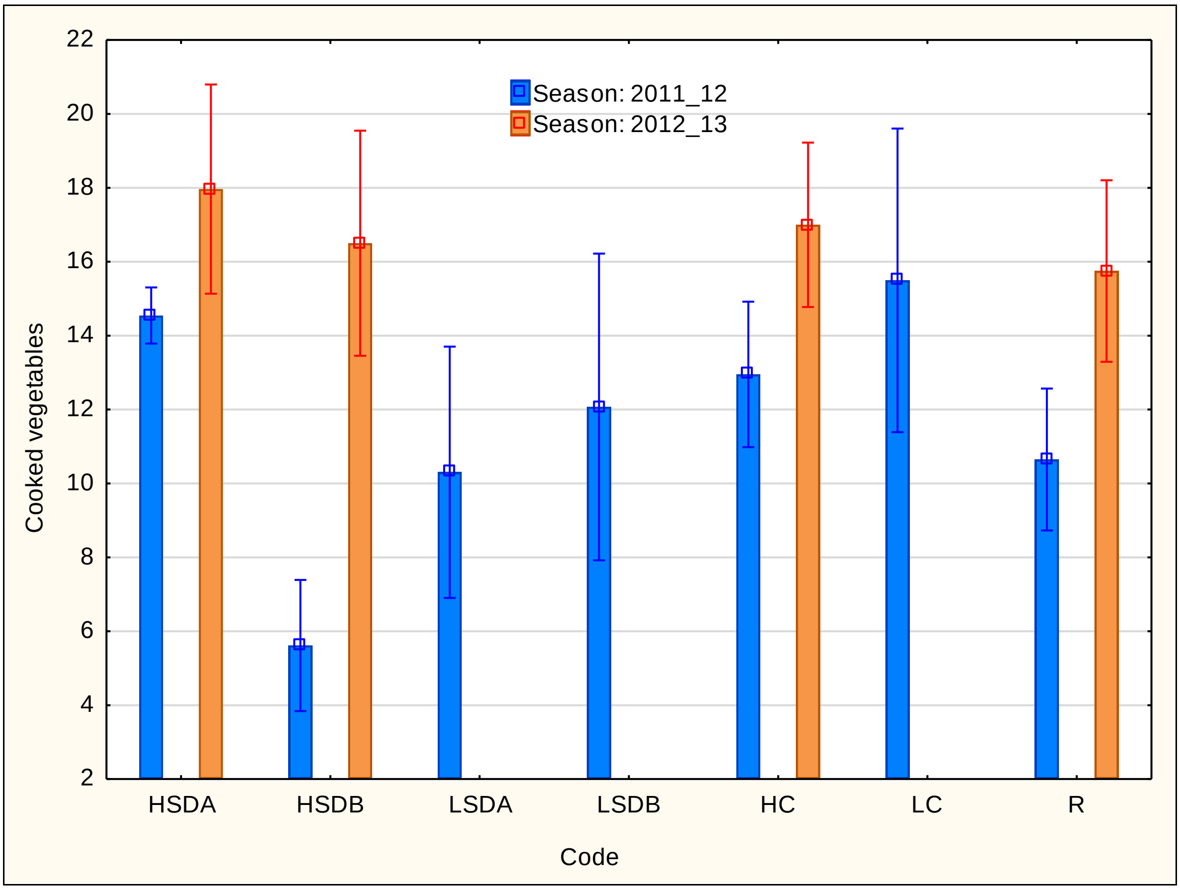

Figure 66 Cooked vegetable aroma for the different treatments of both seasons (means with ± standard errors shown).

During the 2012/13 season there were significant differences in vanilla/caramel aroma and all spice aroma. The lowest value of vanilla/caramel aroma was detected in the HSDA treatment, while the HSDB and HC had similar values (Figure 67). The HSDA also displayed the lowest value in all spice aroma during 2012/13, while the HSDB and R treatments, and the HC had similar values of this aroma (Figure 68).

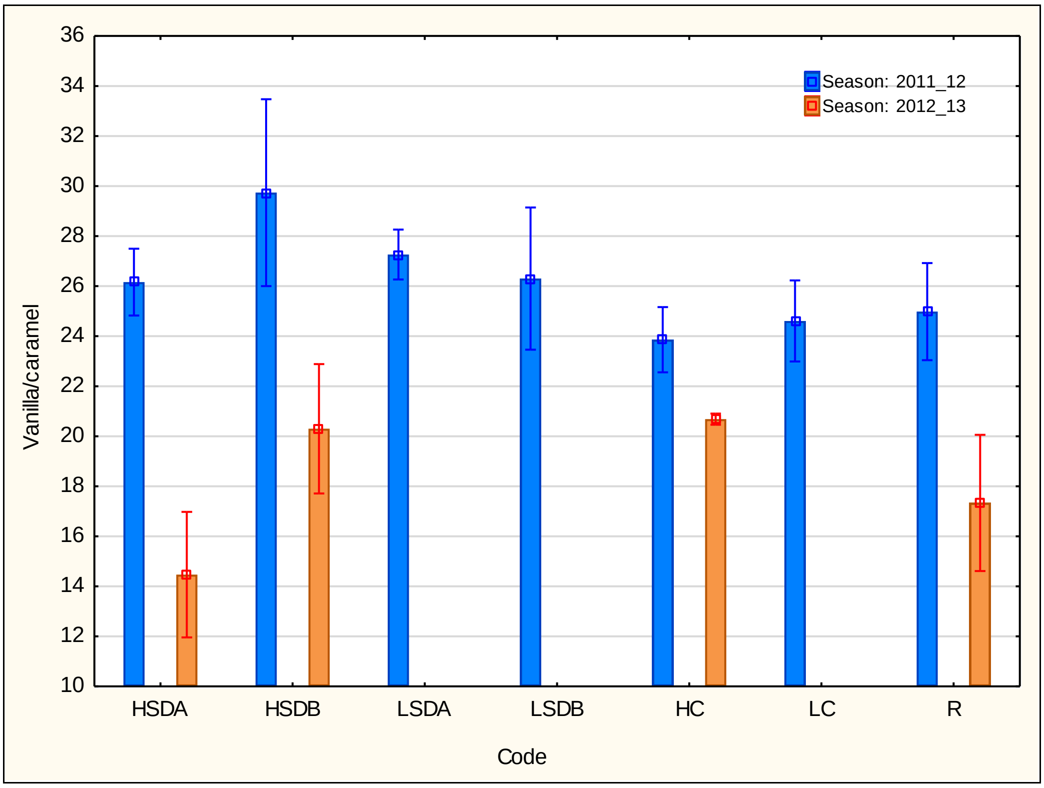

Figure 67 Vanilla/caramel aroma for the different treatments of both seasons (means with ± standard errors shown).

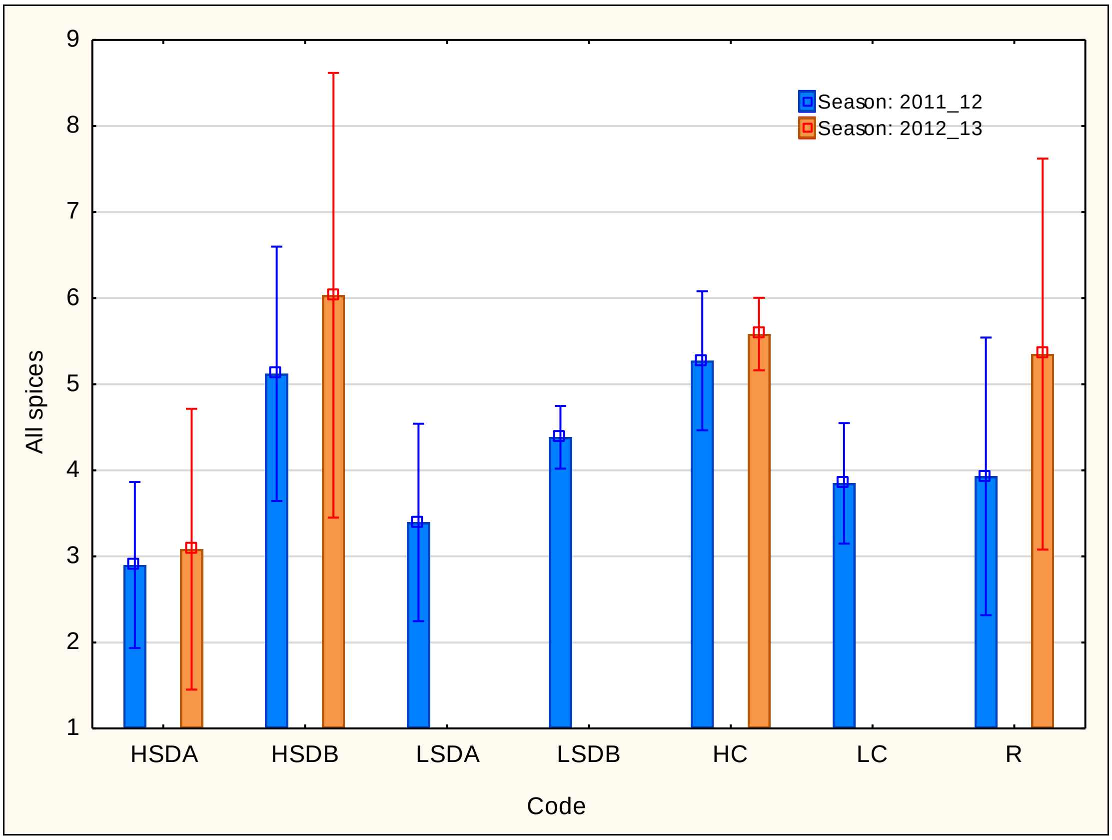

Figure 68 All spices aroma for the different treatments of both seasons (means with ± standard errors shown).

During 2011/12, bitterness was found to be more pronounced in all treatments and the controls when compared to the 2012/13 season (Figure 69). In 2011/12, the R treatment had the highest level of bitterness, but this perceived bitterness also decreased more drastically in 2012/13 when compared to the other treatments.

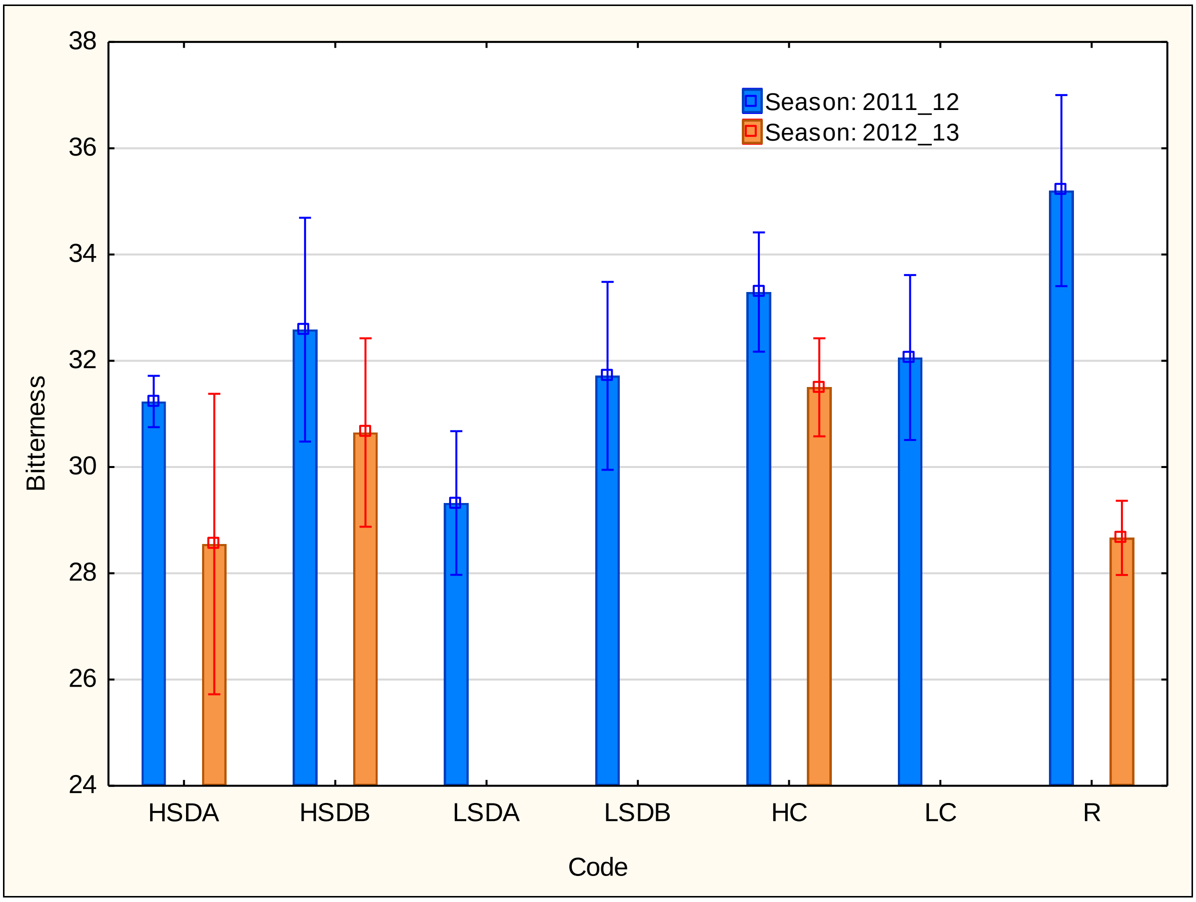

Figure 69 Wine bitterness for the different treatments over both seasons (means with ± standard errors shown).

There was no indication of any negative impact on wine quality by the parameters (such as bitterness & vegetative aromas) associated with the SD and R treatments when compared to the controls. Since the increased yield of the SD treatments did not have any detrimental effects on the quality of the wines, it can be concluded that modifying a grapevine's balance to produce a higher yield may be a viable and sustainable option for producers.

3.4 Conclusions

Over the course of the three seasons, there was a progressive increase in total rainfall and temperatures, which led to a general increase in vegetative growth. Even though the highest rainfall of all seasons was recorded during 2013/14, water deficit levels also reached a maximum during this season, causing vines to consistently experience high levels of water stress. It is evident that factors other than soil water content and climatic conditions contributed to this situation. Increased estimated total leaf areas of specifically the four SD treatment vines in reaction to the modification of balance, as well as more exposed canopies in the case of these treatments, probably contributed to increased transpiration rates and thus greater water loss. These treatment effects became more evident as the seasons progressed and the treatments became more established.

Ripening progressed faster in the controls and R treatment compared to the four SD treatments. The latter displayed slower ripening progressions with regard to rates of TSS accumulation, regression in sugar loading and slower TSS/TA progression which might partly be ascribed to higher water stress levels experienced by the main SD treatments. This delay in ripening was even more accentuated in the two downward positioned SD treatments, and especially distinctive during 2013/14. Although ripening progressed slower for the four SD treatments, this was not necessarily negative, since the treatments eventually still achieved similar levels of ripeness compared to the controls and R treatment. The modified, divided canopy structures in the case of the four SD treatments allowed for an increase in optimally exposed leaf surface, thus increasing the productivity of the existing leaves. Secondly, compensatory behaviour on a whole-vine basis was observed where the leaves borne on the upward positioned shoots compensated to an extent for the limitations in the downward positioned shoots. This compensation presented by spreading exposure over a larger area, increasing the potentially effective leaf area. The result was an increased carbohydrate supply to the berries of the downward positioned treatments in order to satisfy the demand of those sinks. These compensatory responses allowed for the downward positioned treatments' grapes to ripen as well, albeit at a slower tempo than that of the upward positioned shoots, the controls and the R treatment.

No concrete correlation could be drawn between the leaf area:fruit mass ratios of the four SD treatments and their rate and extent of ripening, since there was an inconsistency in these ratio values for these treatments over the seasons(both high and low values for the same treatment observed). Despite this wide range in leaf area:fruit mass ratios, progression in ripening for these four treatments was quite similar. It can therefore not be argued that delays of ripening were due to either decreased leaf areas or increased yield alone.

As expected, the low vigour treatments and their control consistently exhibited less vegetative growth relative to that of the high vigour treatments and their control. The four SD treatments displayed compensation reactions to the modification of their structure, but the levels of compensation differed between the high vigour and low vigour treatments, and also between the upward positioned and downward positioned treatments. However, the differences between the vegetative components of the high and low vigour SD treatments, as well as between the upward and downward positioned SD treatments, became less pronounced over the duration of the trial. This leads to the conclusion that compensation took place progressively as the treatments became more established. The low vigour main SD treatment seemed to have had more challenges than the main HSD treatment in establishing and compensating in response to the altered balance, over compensating by increasing vegetative growth to the detriment of reproductive growth. The high vigour main SD treatment seemed to have had the opposite reaction when considering the large increases in yield relative to smaller increases in vegetative growth. Be as it may, both levels of compensation led to similar rates of ripening with no distinctive difference in grape composition or wine quality.

The main HSD treatment seemed to have compensated in favour of reproductive growth to the detriment of vegetative growth, leading to overcropping and a possible over exposure of berries to sunlight. It was due to this great increase in yield without the concomitant increase in effective leaf area that phenolic levels in the main HSD berries decreased rather than increased. The increase in anthocyanin levels in the main HSD treatment can be attributed to a concentration effect due the decrease in berry sizes, rather than effects of optimal sunlight exposure, since all indications were that the berries of the main HSD treatment were in fact over exposed. In this case where over exposure occurred, anthocyanin levels were actually expected to decrease. The over exposure effect was thus counteracted by the concentration effect as noticed in the decreased berry sizes, mainly due to increases in both ambient temperature and water deficit.

Results showed that there were consistent berry size restrictions for the four SD treatments, and even more specifically so in the downward positioned SD treatments. The limitation in berry sizes in specifically the HSDB treatment cannot be ascribed to the effect of overcropping alone, although it no doubt did have a notable detrimental influence on the reproductive growth of the berries. The same berry size limitations were noted for the LSDB treatment, leading to the conclusion that factors other than crop load played a role in the reduction of berry sizes. Apart from the obvious physiological limitations in the downward positioned shoots, the more open canopies enhanced berry exposure to sunlight, leading to increased berry transpiration tempos, dehydration and thus a reduction in berry size.

Sensory analysis indicated no negative wine attributes or differences in quality between the four SD wines, when compared to controls and R, but rather only a difference in wine style. Strong seasonal effects may even have overpowered the treatment effects.

When the yield component effects in the trial are considered, both the main SD treatments increased in productivity over the course of the trial. This increase was even more apparent in the main HSD treatment. As both the downward positioned treatments became more established, contribution to the total yield on a per vine basis for the main SD treatments increased. The fact that productivity of the two main SD treatments increased without any negative wine attributes associated with it, can lead to the conclusion that modification of a grapevine's balance by means of a training system conversion is indeed a sustainable and economically viable option for producers.

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Chapter 4

GENERAL CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 4: GENERAL CONCLUSIONS AND RECOMMENDATIONS.

4.1 Introduction

The aim of this study was to provide insights into the concept of vine balance, and to investigate the credibility of the popular belief that only small yielding vines are able to produce a crop for premium wine quality. The main purpose of this study was to increase the effective canopy surface area of an existing Shiraz vineyard by means of training system conversions, and to investigate the effect of a grapevine's compensation reaction to a modification in its balance. Taking historical vigour into account, the various levels on which a grapevine can compensate in reaction to an altered balance were investigated. In cases where trellising or training systems are found to be limiting, the conversion of such systems needs to be considered. Where existing, limiting, vertically shoot positioned canopies (VSP) are therefore divided leading to higher levels of sunlight interception, it has been found that grape composition can be improved, alongside an increase in production capacity (Reynolds & Vanden Heuvel, 2009; Smart *et al*., 1985a; Smart *et al*, 1985b). Higher levels of sunlight interception lead to an increased ability of the vine to fix photosynthates, and as a result increasing the capacity of the vine.

This study was undertaken in order to determine at which point that decision, which should be economically justified, viable and sustainable, needs to be taken. Three training system adaptations were investigated in order to determine to what extent, and in which ways a grapevine will compensate, and what the consequences will be on productivity, grape composition and wine quality. The results will be beneficial to serve as a guideline to producers in order to make informed decisions regarding trellis/training system conversions based on historical within-block information.

4.2 Outcomes of the study

4.2.1 Objective I: to modify grapevine balance in a field trial and study the effects of the modification on yield components as well as grape and wine composition.

A thorough understanding of the concept of vine balance is needed before a decision can be made on whether or not a training system conversion can be considered. Much research has been done on this concept, and many authors have attempted to define it (Ravaz, 1911; Partridge, 1925; Archer & Strauss, 1991; Brase, 2004). Although their definitions and approaches varied, there are clear cut similarities between all. A concise and summative definition is that a vine can be considered to be in balance if it is able to sustain controllable vegetative growth without experiencing any plastic stress, while ripening its crop optimally in order to produce the desirable quality grapes for production of a specific wine style and purpose. Vine balance is thus a subjective concept, and should be viewed in a context where all external and internal factors that can possibly influence it, are considered. The all-important consideration is that any approach in grapevine cultivation should be aimed at meeting the expectation of the production goal, whether it is to produce premium quality wine, or with the intention to produce base wine for distilling purposes.

By altering the existing balance by means of a training system conversion, as was conducted during the study, bud load was increased, leading to an increase in cane numbers, larger leaf areas and a general increase in above-ground growth. This study has proven that converted systems were able to compensate and ripen increased yields and optimize productivity without having any detrimental influences on wine quality. The outcome was differences in wine styles, rather than differences in wine quality as such. It is therefore a viable option to consider converting existing training systems in order to optimize productivity and ensure sustainable production in the uncertain current economic context of the South African wine industry.

The converted grapevines all compensated in response to the modified balance, but the levels and extent to which these reactions occurred varied depending on vigour and shoot orientation. Once converted, the high vigour vines displayed compensation in favour of reproductive growth to the point of overcropping, and to the detriment of vegetative growth. The low vigour vines experienced more challenges in establishing a balance, and exhibited the opposite reaction to that of the high vigour vines, rather compensating by increasing vegetative components. Regardless of the way in which compensation manifested in the various vigour classes, similar rates of ripening were recorded with no distinctive difference in grape composition and wine quality.

In the converted vertically divided Smart-Dyson (SD) canopies, the downward orientated shoots continuously exhibited lower vigour than the upward orientated shoots due to lower levels of exposure creating physiological constraints (Schubert *et al*., 1995). However, compensation and a reinstatement in balance on a whole-vine basis was observed as the treatments became more established. In order to achieve this, the downward positioned treatments increased in vigour over time with a concomitant reduction in vigour of the upward positioned treatments. The upward positioned canopies were able to compensate for the limitations in the downward positioned treatments by increasing total exposed leaf area on a per-vine basis. This led to an increase in effective leaf surface, and thus the ability of the upward positioned canopies to allocate more photosynthetic product to the downward positioned shoots that acted as sinks.

As both the high and low vigour downward positioned treatments became more established, their contribution to the total yield on a per vine basis for the main SD treatments increased. By dividing existing canopies bud load is increased, canopy microclimate is improved and productivity is optimised, leading to a general increase in yield. The fact that productivity of the converted SD treatments increased without any associated negative wine attributes arising from the conversion can lead to the conclusion that modification of a grapevine's balance by means of a training system conversion is indeed a sustainable and economically viable option for producers.

This study has proven that the increased total leaf area which results from the conversion of an existing training system, can be accommodated better in the case of high vigour vines, and the devigorating effect leads to a generally more balanced grapevine (Coombe & McCarthy, 2000).This further leads to an improved microclimate with a larger effective leaf area and ultimately an increase in photosynthetic activity and therefore the export of photosynthetic products as well (Hunter & Visser 1988; Candolfi-Vasconcelos & Koblet, 1990).

4.2.2 Objective II: to use the within-block information on grapevine performance variability and yield components as a means to study grapevine balance, in order to guide decision making in a vineyard.

Many producers worldwide are unaware of the impact that grapevine variability can have on the resource efficiency of the grapevine (Zerihum, 2010). This lack of information led to the creation of a broad viewpoint on the general vineyard management of a specific block as a whole, that is also followed widely in the South African wine industry. In the past, all vineyard management practices were applied with the same approach and intensity on the trial block as a whole, disregarding any spatial variation in the block.

Variations in soil and climatic conditions are known to cause variation in grapevine growth and development with regard to canopy structure, physiology and grape composition (Smart, 1985). The vineyard studied in this field trial was characterized by highly variable vigour, capacity and non-uniform growth caused by heterogeneous soil conditions in the field. Historical within-block information on grapevine performance variability as used in this study to identify different vigour classes, can be a useful tool for producers to identify variability in a block, and to guide decision making in the vineyard.

Based on historical total pruning mass, mean cane mass and yield data, a clear picture of variability and differences between vigour classes in a block can be attained. Using this information, management practices can be adapted in order to accommodate this variability. In the wine industry, it is not practically possible to convert only parts of a row or single vines within a block to alternative training systems. However, as this study has proven, conversion can be successful on both high and low vigour class vines, even though the levels of adaptation differ, and low vigour vines tend to struggle somewhat in achieving a full compensatory reaction. Due to these reasons, converted vines should be managed according to their individual vigour status once conversion has been applied.

4.2.3 Objective III: study the effects of initial vigour on the training conversion.

The modification of the grapevines' balances led to compensation reactions as expected. As was anticipated, there were some differences in the extent to which the high vigour versus the low vigour classed vines responded to the modification. Evaluating the responses of the main SD treatments were also somewhat complicated since vines were evaluated on sub treatment levels (upward and downward positioned shoots) within the main SD treatments as well. These evaluations, however complicated, were used to eventually determine the collective response of the whole vine to the alteration of its balance, indicating the success with which this balance was re-established. The low vigour converted vines seemed to have had more challenges with the compensatory response than the high vigour vines. In the case of low vigour converted vines, overcompensation by increasing vegetative growth to the detriment of reproductive growth and development resulted. Large increases in yield were recorded for the converted high vigour class vines, with a relatively small concomitant increase in vegetative growth. This all points to the latter exhibiting a vegetative response in favour or reproductive growth to the level of overcropping. Interestingly enough, these vastly different responses seem to have no concrete negative effect on wine quality as such, instead producing wines of different wine styles.

4.3 Limitations and shortcomings of the study

This study was limiting in the sense that the trial was conducted in a very specific and narrow context, not taking into account the influence and interaction of factors such as the differences between various viticultural areas, the possible difference in responses of cultivars and the influence that a rootstock may have on the compensation ability of a grapevine. It is a well-known fact that there exists a close relationship between above-ground and subterranean growth, and once a modification to either of these components take place, the other will react in a compensatory way (Richards, 1983; Archer & Strauss, 1985; Archer & Strauss, 1991). In reaction to an alteration in above-ground growth, the root system is expected to respond by developing more fine roots and utilizing the available soil volume more efficiently by means of an increase in absorption capacity (Richards, 1983; Hunter & Volschenk, 2001). Not only will such a more efficient root system be able to support the increase in above-ground growth and yield, but it has been found that grape quality can also remain consistent pre- and post-alteration (Hunter & Volschenk, 2001). To gain more insight into the intricate interaction regarding the relationship between above-ground and subterranean growth that took place in this study, and the compensation on a whole-vine level, it is recommended that root studies in this block should be conducted during future studies.

Monitoring of the soil water content by means of neutron probes was not done in a way which was treatment specific. Therefore, a clear picture regarding the water usage of treatments, and how it may have differed between treatments, could not be obtained. This resulted in inadequate irrigation that contributed to increased water stress. It is recommended that additional neutron probes be installed in a treatment specific way in order to get a better understanding of the actual water usage of the different grapevine vigour classes and treatments. Furthermore, the increased canopy sizes after the conversion of the training systems were not considered, whereas irrigation scheduling should have been adapted in order to accommodate and support the larger canopies with suspected concomitant higher transpiration rates and higher levels of water usage.

Probably the biggest shortcoming is that light interception in the canopies was not monitored in order to determine to what extent sunlight was intercepted in the altered canopies. It is a well-known and proven fact that more exposed canopies intercept sunlight more efficiently (Gladstone & Dokoozlian, 2003). Confirmation of this would have strengthened the arguments presented in this research.

4.4 Perspectives for future research

The discussed trial can successfully be repeated and refined by following different and more extended methodologies to those followed in this trial. Taking into account the shortcomings as discussed above, different approaches towards irrigations scheduling should be evaluated and incorporated, soil water monitoring should be revised, root studies should be executed and sunlight interception should be monitored by means of a sunlight ceptometer.

An addition to the improvements as mentioned above that will provide valuable insights into the intricate concept of the vine's compensation ability, may be repeating this trial for different scenarios, including various soil types and viticultural areas. The fact that Shiraz, which is known to be a vigorous variety, was the cultivar used in this trial, limits the results somewhat in the sense that the same results will not necessarily be obtained when considering other cultivars - especially those which commonly display poorer growth. Trials with different cultivars are therefore crucial in order to confirm or disprove certain observations that were made during this trial outside of its very specific context. From the results obtained from trials like these, the most important impacts on the grapevine's regulatory response can be determined, leading to even further and more insightful studies.

Since climate change is a reality, the training system investigated in the trial might not be the solution under all climatic conditions. The north-south row direction might prove to create canopy conditions that are too warm for certain viticultural areas, leading to overheating and possible sunburn of the berries. It is recommended that this trial should be repeated, exploring the effect that different row directions might have on the microclimatic and environmental conditions under which grapes will ripen with this training system.

4.5 General recommendations to the industry

One of the most important outcomes of this study is that regardless of the altered balance in grapevines due to training system conversion or the variability of vigour, no negative effects associated with the increased vigour were discernible in the wines that were evaluated. Due to this reason, it can be recommended that producers seriously consider training system conversions in cases under conditions related to limited vigour or production. It is possible to consistently produce the same quality of wine without having to sacrifice production. Not only is a conversion of an existing, limiting VSP system viable, but it is also simple and cost effective. This option may just be the solution to ensure sustainable and economically viable production of grapes in the current harsh economic conditions.

This conversion, however, cannot be executed with success unless the increased bud load and increased canopy size is taken into consideration and suitable adjustments are made. Larger effective leaf surfaces will inevitably lead to higher transpiration rates, demanding re-evaluation of current irrigation systems. New irrigation regimes with increased water supply is a necessity to gain the benefits of the conversion to the full extent. Soil and leaf samples should be taken annually to determine the exact nutritional requirements of the vines in their altered state of balance, and fertilization should be applied judiciously and timeously.

Although both high and low vigour grapevines were able to compensate, albeit in different ways, the low vigour vines displayed some difficulty adapting to the conversion and ripening was slightly delayed. The insufficient reserve status in the case of low vigour vines caused this effect. It has to be kept in mind that the conversion of the low vigour vines was extreme in the sense that the downward positioned shoots were bent downward to both sides of the cordon. In practice, conversion can be executed less drastically in the case of low vigour vines by, for instance, only applying the modification to one side of the cordon *i.e.* positioning shoots downward to one side of the cordon only. Regarding management practices post conversion, balanced pruning and different levels of canopy management should be applied. These actions should be suited to accommodate each individual grapevine according to its vigour status, and to maximize its productivity to contribute to the block as a whole.

It is recommended that producers rather consider implementing an alternative training system such as the Smart-Dyson system from establishment, since it will prevent the decrease in production which is evident in the year of conversion if such an adaptation is made to an older, established vineyard. The yield produced by the reduced canopy treatment was very low relative to the main SD treatments and controls, and this treatment can therefore not be recommended due to its lack in economic viability.

4.6 Literature cited

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ADDENDUM

Table 1 Days after budburst (DAB) corresponding with the ripening measurement dates during season 2011/12 for the different treatments.

2011/12	
Date	**DAB for all treatments**
12/01/2012	114
19/01/2012	121
27/01/2012	129
02/02/2012	135
09/02/2012	142
17/02/2012	150
24/02/2012	157
02/03/2012	164
09/03/2012	171
14/03/2012	176 (Only SD and VSP)
15/03/2012	177 (Only SD)

Table 2 Days after budburst (DAB) corresponding with the ripening measurement dates during season 2012/13 for the different treatments.

2012/13	
Date	**DAB for all treatments**
17/01/2013	113
28/01/2013	124
05/02/2013	132
12/02/2013	139
19/02/2013	146
25/02/2013	152
06/03/2013	161
12/03/2013	167
18/03/2013	173
19/03/2013	174 (only LSD)

Table 3 Days after budburst (DAB) corresponding with the ripening measurement dates during season 2013/14 for the different treatments.

2013/14	
Date	**DAB-HSD**
28/01/2014	126
05/02/2014	134
13/02/2014	142
23/02/2014	152
05/03/2014	162
13/03/2014	170
18/03/2014	175 (only for HC, LC)
28/03/2014	185 (Only for Red)
31/03/2014	188 (Only for Red)
10/04/2014	198 (Only for SD)