UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Effect of shoot removal on bud fruitfulness and yield of *Vitis vinifera* cv. 'Crimson Seedless' in the Western Cape

By

JOHANNES LINKS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
M. INST. AGRAR: HORTICULTURE

IN THE

DEPARTMENT OF PLANT PRODUCTION AND SOIL SCIENCE
FACULTY OF NATURAL AND AGRICULTURAL SCIENCES

AT THE

UNIVERSITY OF PRETORIA
PRETORIA

Supervisor: Dr N.J. Taylor
Co-Supervisors: Mr J.H. Avenant
Mrs E. Avenant

July 2014

DECLARATION

I, Johannes Links, declare that the mini dissertation submitted herewith for the degree Magister Institutionis Agrariae (Horticulture), to the University of Pretoria, contains my own research except where acknowledged. This work has not previously been submitted by me for a degree at this or any other university faculty.

Signed _____

Johannes Links

Date _____

DEDICATION

This document is dedicated to my parents, Johannes and Bettie for believing in me and supporting me throughout my academic career.

ACKNOWLEDGEMENTS

First and foremost, I wish to thank my heavenly Father who has given me the ability to conduct this study. I also want to express my sincere gratitude and appreciation to the individuals and institutions:

- Dr Nicolette Taylor from the University of Pretoria for acting as my supervisor;
- Mr Jan Avenant from the Viticulture Division, ARC Infruitec-Nietvoorbij and Mrs Eunice Avenant from SATI and the University of Stellenbosch for acting as my co-supervisors and for critical evaluation of this document;
- Financial assistance provided by the Western Cape Department of Agriculture in respect of the cost of this study is hereby acknowledged;
- THRIP for partial funding of the project;
- The staff of the Viticultural Division from the ARC Infruitec-Nietvoorbij for their assistance with the measurements and analysis;
- The staff from the Hex River Valley Experiment farm of the ARC Infruitec-Nietvoorbij at De Doorns, especially Tom Stevens for the assistance with treatments and measurements;
- Mrs Mardé Booyse from the Biometric Unit at Infruitec, ARC for statistical analysis and advice;
- My family and friends for always encouraging and supporting me throughout my studies.

ABSTRACT

‘Crimson Seedless’ (*Vitis vinifera* L.) is an attractive, late season, red, seedless cultivar, which is currently a very popular table grape cultivar. It is one of the most planted cultivars in South Africa and third in terms of total area of table grape vineyards in production. Mature ‘Crimson Seedless’ grapes are characterized by outstanding eating quality, good flavour, firm and crisp berries. One of the key factors affecting the yield of table grape cultivars is bud fruitfulness. Low fruitfulness can have a significant effect on the yield of table grape cultivars and ‘Crimson Seedless’ is characterized by a fruitfulness problem. Summer pruning, such as the removal of shoots after harvesting grapes, is a cultivation practice widely used by some table grape producers in the Orange River region of South Africa. The first hypothesis of this study stated that the removal of shoots after harvest will increase the transmitted PAR through the canopy, increase carbohydrate reserve levels in canes and improve bud fruitfulness of ‘Crimson Seedless’. A second hypothesis of this study stated that the cut back of all main shoots and shoots developing from spurs to the nearest lateral shoot and the removal of all unproductive shoots after berry set will result in fruitful shoots the following season. The third and final hypothesis of this study stated that the removal of shoots after harvest and berry set will improve the yield and quality of *Vitis vinifera* cv. ‘Crimson Seedless’.

The study was conducted over three seasons (2010/11 to 2012/13) and aimed at investigating factors, including shoot removal, impacting bud fruitfulness of an 11-year-old commercial *V. vinifera* L. cv. ‘Crimson Seedless’ vineyard, grafted on ‘Ramsey’ (*Vitis champinii*) rootstocks in the Hex River Valley. The treatment design was a complete randomized design and involved five treatments, which included 33% shoot removal (S_{33}) and 66% shoot removal (S_{66}) after harvest, cutting of all main and lateral shoots developing from spurs to the nearest lateral shoot (LS), removal of all unproductive shoots (RSB) which was compared with the control, in which standard pruning practices were performed.

The results obtained in this experiment showed that shoot removal after harvest and after berry set improves PAR transmission into the canopy, but there was no significant impact on bud fruitfulness. In addition, it was found that shoot removal reduced vegetative growth resulting in thinner canes that also led to the improvement in PAR transmission. Furthermore, bunch number per shoot in the LS treated vines was reduced when compared with S_{33} treated vines, illustrating that shoot removal at berry set can reduce bunch number per shoot due to defoliation after berry set. The significant decrease in bud burst in the S_{33} treatments compared with the control was expected due to less shoots, resulting in a reduction in cane mass during the 2010/11 season.

The significant effect of LS treatments after berry set on TSS and total red pigments compared with the S_{66} treatments and the control, respectively, clearly indicates that shoot removal after berry set improves grape colour. The positive effect of LS treatments on colour was supported by the significant improvement in class 4 bunches, representing an improvement in quality. Although shoot removal did not have a significant effect on the bunch mass per vine of 'Crimson Seedless', there was a significant reduction in total bunches for export and mass of the total export bunches in the LS treatments in the 2011/12 season.

A link between carbohydrate concentration in canes and bud fruitfulness was not found in this study, as S_{33} and S_{66} treatments did not have a significant effect on carbohydrate content in canes during the 2011/12 season. The question therefore arises whether the treatments applied during the growing seasons are worthwhile, because there was no significant impact on bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless'. This study illustrates that growers need to decide whether it is worthwhile to utilize labour for this practice and they must manage grapevines not only for the current seasons crop, but also for the next season and this can be accomplished by maintaining sufficient carbohydrates for fruitfulness and yield from season to season.

Key words: bud fruitfulness, carbohydrate reserves, defoliation, inflorescence, yield.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ABA - Abscisic acid

ARC - Agricultural Research Council

et al. - And others

CRD - Complete randomized design

conc - Concentration

EBSN - Early bunch stem necrosis

Fig. - Figure

GA - Gibberellic acid

LS - Lateral shoot removal

LLN - Layer number

LSD - Least significant difference

TA - Titratable acid

PGR - Plant growth regulators

P - Phosphorus

PPFD - Photosynthetic photon flux density

PAR - Photosynthetically active radiation

K - Potassium

PBN - Primary bud necrosis

RSB - Removal of shoots without bunches

Rpm - Revolutions per minute

TSS - Total soluble solids

S33 - 33% shoot removal

S66 - 66% shoot removal

CHAPTER 1

1.1 GENERAL INTRODUCTION AND PROJECT AIMS

'Crimson Seedless' (*Vitis vinifera* L.) is an attractive, late season, red, seedless cultivar, which is currently a very popular table grape cultivar. This cultivar resulted from a cross of 'Emperor' x 'Selection #102-26' and was released to the industry in 1989. Mature 'Crimson Seedless' grapes are characterized by outstanding eating quality, good flavour and firm and crisp berries (Longbottom 2007; Ali 2008; Dokoozlian and Peacock 2012).

One of the key factors affecting the yield of table grape cultivars is bud fruitfulness. Fruitfulness of a cultivar refers to a bud which produces two or more inflorescences per bud (Archer 2011). Low fruitfulness can have a significant effect on the yield of table grape cultivars and 'Crimson Seedless' is characterized by a mild fruitfulness problem (Ali 2008; ABD EL-Razek et al. 2011; Dokoozlian and Peacock 2012). Grapevine cultivars are characterized by their variation in fruitfulness and berry composition (Ali 2008).

Carbohydrates are stored as starch in permanent structures in all temperate woody plants during winter (Hunter et al. 1995; Terence et al. 2002; Lebon et al. 2008; Smith and Holzapfel 2009). These carbohydrate reserves and grapevine bud fruitfulness have a close relationship and adequate levels of carbohydrate reserves determine the formation and development of inflorescences during the bud burst stage (Bennett 2002; Bennett et al. 2005; Lebon et al. 2008). Therefore, carbohydrates in grapevines have been studied in several grape growing countries (Terence et al. 2002) and reports emphasise the importance of source-sink relationship of grapevines in determining bud fruitfulness and the subsequent yield (Lebon et al. 2008; Edwards et al. 2011).

The allocation of photosynthetic products to permanent vine structures during the season is important because it might affect the available carbohydrate levels within the vine and fruit development (Fedelibus and Smart 2004; Lebon et al. 2008). Therefore,

the post-harvest period is crucial for the replenishment of carbohydrates that will have an effect on bud fruitfulness and the subsequent yield (Balasubrahmanyam 1978; Hunter et al. 1995; Smith 2003; Lebon et al. 2008).

The study aimed at investigating bud fruitfulness of 'Crimson Seedless' grapevines. Summer pruning, such as the removal of shoots after harvesting grapes, is a cultivation practice widely used by some table grape producers in the Orange River region. Producers believe that this practice will improve the transmission dynamics of photosynthetically active radiation (PAR) throughout the vine, which will improve bud fruitfulness in the following season. The effect of summer pruning on bud fruitfulness is questioned by several researchers. Mr Jan Avenant, a senior researcher at ARC (Agricultural Research Council: Nietvoorbij), believes that summer pruning after harvest may alter the capacity of the vine to acquire nutrients and replenish storage reserves required for the following season (J. Avenant, 25 January 2011, ARC). It is not assured whether the removal of shoots after harvest and berry set will improve bud fruitfulness in the following season and therefore needs to be investigated.

1.2 HYPOTHESES, AIMS AND OBJECTIVES

Based on the research problem defined above, it was hypothesized that the removal of shoots after harvest will increase the transmitted PAR through the canopy, increase carbohydrate reserve levels in canes and improve bud fruitfulness of 'Crimson Seedless'. It was also hypothesized that the cut back of all main shoots and shoots developing from spurs to the nearest lateral shoot and the removal of all unproductive shoots after berry set will result in fruitful shoots the following season. The third and final hypothesis for this study stated that the removal of shoots after harvest and berry set will improve the yield and quality of 'Crimson Seedless'.

The research aims can therefore be summarized as follows:

- To determine the impact of the removal of shoots after harvest and berry set on bud fruitfulness in the following season;
- To make recommendations for overcoming the bud fruitfulness problem in 'Crimson Seedless'.

The specific objectives were:

- To determine vine fruitfulness, fruit quality and yield;
- To determine the transmitted PAR through the canopy;
- To determine overwintering carbohydrate levels in canes;
- To conduct an anatomical study of fruit bud differentiation in winter.

1.3 BACKGROUND OF THE SOUTH AFRICAN TABLE GRAPE INDUSTRY

Among fruit, grapes are considered as the most valued fruit in the world (Al-Obeed et al. 2010; Fawzi et al. 2010; Rusjan 2010). This statement is based on hectares planted and economical value (Anon. 2012). Grapes are mainly produced for wine, fresh fruit (table grapes) and dried fruit (raisins).

There are five major table grape producing regions in South Africa and the variation in soil and climate in these regions enables producers to supply the international market from November until May. The Hex River Valley region is known as the largest and oldest producer of table grapes in South Africa (Ntombela 2010). The Orange River region is currently the second largest producers of table grapes. The Berg River region is known for its excellent table grape quality (Anon. 2012) and is currently the third largest producer of table grapes (Ntombela 2010). The Northern Province, characterized by high quality grapes, despite the hot and dry conditions in this region, is the fourth largest producer of table grapes in South Africa. The Olifants River region is known for its desert climate and is the smallest producer of table grapes (Ntombela 2010).

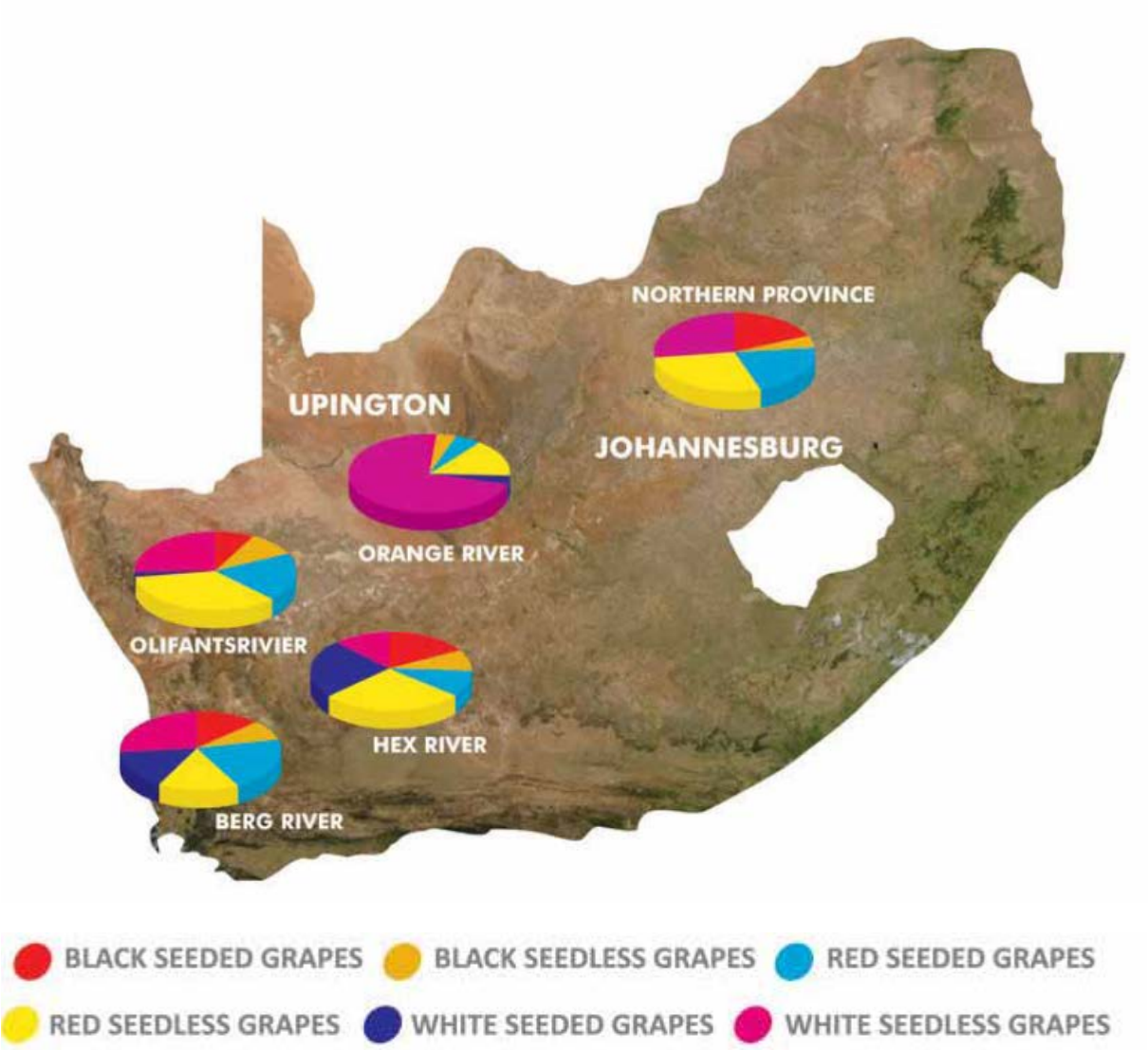

Figure 1.1: The five major table growing regions in South Africa (Anon. 2013).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Vitis vinifera L. cultivar 'Crimson Seedless' is a promising table grape variety developed by scientists of the USDA Fruit Genetics and Breeding Research Unit in California (Ali 2008). The breeding program was initiated in 1926 with 'Thomson Seedless' being the source of seedlessness. The cross was made in 1979 between a late ripening white seedless grape and 'Emperor' (red seeded grape). A total of 85 seedlings were planted and only two red, one white variety and one late variety, now known as 'Crimson Seedless', were selected for further review (Fig. 2.1). The cultivar was selected in 1983, but was only released in California in 1989 (Dokooozlian and Peacock 2001), however, by 2000 it was recognized as one of the important table grape cultivars in the world (Dokooozlian and Peacock 2001; Ali 2008; Human 2010). 'Crimson Seedless' is amongst the most planted table grape cultivars and is currently 3rd in terms of total area under production (Human 2010). The cultivar is characterized by its natural sweet flavour, elongated berries and exceptionally long shelf life (Dokooozlian and Peacock 2001). Therefore, 'Crimson Seedless' holds great promise for commercial farmers and is preferred by supermarkets worldwide (Ali 2008; Anon. 2012).

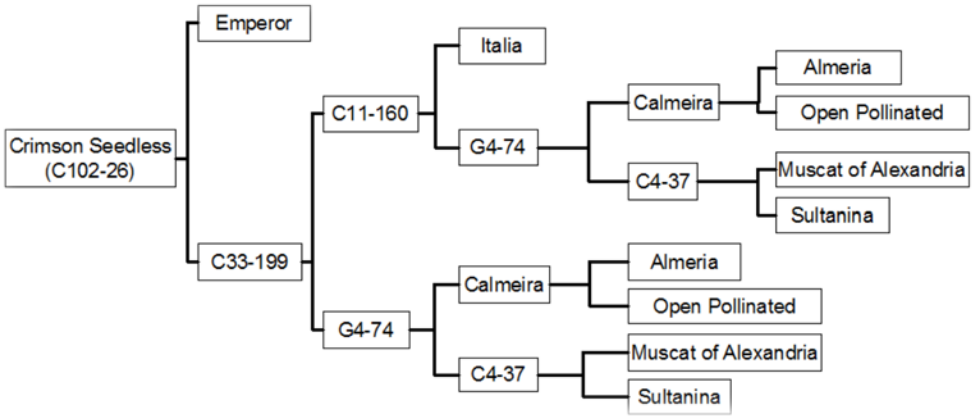

Figure 2.1: A schematic chart of the breeding program for 'Crimson seedless' (Ali 2008).

‘Crimson Seedless’ is head-trained and cane pruned due to the cultivar`s low fruitfulness with spur pruning. During winter, the cultivar is left with up to eight canes to obtain sufficient yield and fruit quality. A large and extensive trellis system, such as the Gable trellis system, should be used to ensure productivity (Abd El-Razek et al. 2011), however, environmental conditions, cultivar selection and the correct trellis system are all factors determining the success of viticulture. That is why fruitfulness and yield assessment of a cultivar are important when deciding which cultivar to establish (Al-Obeed et al. 2010).

The fruitfulness of a vine can also determine its yield (Smith and Holzapfel 2009; Dokaazlian and Peacock 2012) and is influenced by variables such as number of inflorescences per vine, number of flowers per inflorescence, accumulation of photoassimilates, bud development, % fruit set, berry number per cluster and berry and cluster mass (Hunter and Visser 1990). The development of these flower clusters within a grapevine bud and the formation of flower clusters on a newly developed shoot are referred to as potential fruitfulness and actual fruitfulness, respectively (Srinivasan and Mullins 1981; Bennett 2002; Al-Joumayly 2003; Carrol 2011). Furthermore, although the fruitfulness of a grapevine is a genetic characteristic (Al-Joumayly 2003), it is influenced by climate, cultivar and canopy management of the vine (Strydom 2006). Shoot growth and successive fruitfulness is also influenced by grapevine carbohydrate reserves (Bennett 2002; Bennett et al. 2005).

As the yield and quality of table grapes and dried fruit is more important than for wine grapes, it is important to consider how the industry views yield and quality (Carmona et al. 2008). Longbottom (2007) states that grapevine yield is determined over two growing seasons and previous studies found that growers have a problem with obtaining even yield from season to season (Antcliff 1965; Keller et al. 2004; Carmona et al. 2008). This problem is, among other factors, a result of seasonal weather conditions (Clingerleffer 1984; Bennett et al. 2005; Smith and Holzapfel 2009).

2.2 GRAPEVINE PHENOLOGY

A grower needs to have “good” knowledge of grapevine phenology during the growing season in order to achieve the best possible production from a grapevine. A modified system by Eichhol and Lorenz (E-L), developed by Coombe (1995), is used to illustrate the different phenological stages of grapevines (Coombe 1995; Bennett 2002). These stages can be described as follows (Fig. 2.2):

Bud burst: E-L stages two-five illustrate the progressive stages of bud burst. Buds start to burst during spring when a temperature of 10°C is reached. During these stages the vines mainly make use of carbohydrates stored in permanent structures such as roots, trunks and canes, until leaves reach 50% of their final size. Finally, the total number of buds that burst will be determined by the total number of buds on canes (Coombe 1995; Bennett 2002).

Shoot development: E-L stages six-11 describe the appearance of shoots and inflorescences during weeks eight-ten (Coombe 1995). The primary bud of the compound bud will give rise to a shoot. Although secondary and tertiary buds are less fruitful, they can also produce shoots in cases where the primary bud is dead or if vines are pruned severely (Bennett 2002).

Inflorescence development: E-L stages 12-18 show how two-three inflorescences form, starting from node four, as the shoot continues to grow. Due to the rapid formation and differentiation of flowers of inflorescences at stage 15, it takes 10-15 days for flower parts to develop, but the flowers will only be noticeable when shoots have eight leaves (Coombe 1995; Bennett 2002).

Flowering: E-L stages 19-29 are very important stages that are characterized by the formation of 16 leaves and nodes per shoot. Stage 19 is also referred to as the onset of anthesis. Full bloom is reached at 50% caps off (the time of flowering or flower opening) and is completed at stage 26. Stage 27 illustrates fruit set, whereby each flower on an

inflorescence has the potential to produce berries (Coombe 1995), however, due to bad weather conditions, only about 20%-30% of flowers develop berries, which reduces potential crop levels. Vine stress during this stage, as a result of an imbalance between carbohydrates and nitrogen, can lead to early bunch stem necrosis (EBSN) (Bennett 2002).

Berry development: E-L stages 31-34 describe the enlargement of berries and is characterized by three phases namely (1) the fast development of fruitlets into hard berries, (2) reduction in berry growth with the start of seed maturation and (3) softening of berries followed by a change in colour, also known as véraison (E-L stage 34) (Coombe 1995; Bennett 2002).

Harvesting: E-L stages 38-47 refer to the stages from harvest until end of leaf fall. Grapes will be harvested when quality parameters such as sugar, colour, acidity and flavor have reached optimum levels. Just before the vine enters dormancy, leaves change from green to red/yellow (senescence) (Coombe 1995; Bennett 2002).

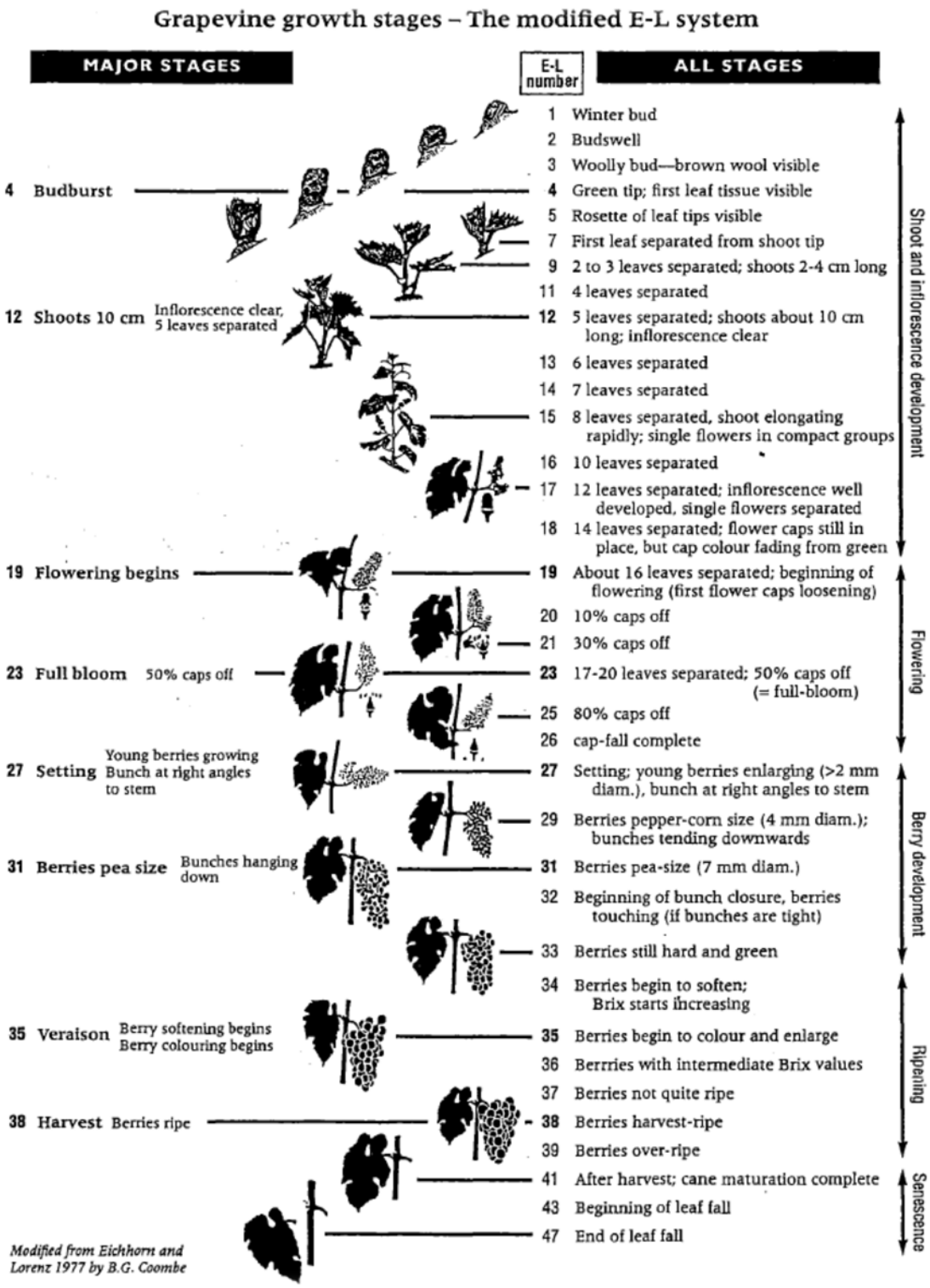

Figure 2.2: The modified E-L system used to illustrate the different phenological stages of grapevines (Coombe 1995; Bennett 2002).

2.3 THE DEVELOPMENT OF COMPOUND LATENT BUDS, INFLORESCENCES AND FLOWERS

2.3.1 Origin of the prompt bud and latent bud

Vitis vinifera L. buds fall into three categories namely the prompt bud, the primary bud and the secondary bud. The prompt bud is the true axillary bud of the subtending leaf and is characterized by its ability to burst and form a shoot during the same season which is then referred to as a summer lateral or it may remain dormant and is then referred to as the lateral bud in the compound bud. However, this shoot can develop into a vigorous fertile shoot if not inhibited by the apex of the main and primary shoot. Prompt buds can also stay dormant until the following season (Bennett 2002).

The primary bud is formed in the axil of a scale-like structure referred to as the prophyll and the secondary and tertiary buds are formed in the prophyll axils of the primary bud. Moreover, the primary bud will give rise to a shoot in spring, whereas secondary and tertiary buds remain vegetative. Depending on the cultivar, the secondary bud might give rise to an inflorescence, if the primary bud is damaged. However, bunches produced by the secondary bud are often small, which will result in a decrease in yield (Rawnsley and Collins 2005).

The primary, secondary and tertiary buds constitute the prominent latent (overwintering) compound bud also referred to as the “eye” on a dormant cane (Fig. 2.3) (Srinivasan and Mullins 1981; Rawnsley 2003; Rawnsley and Collins 2005; Andreini et al. 2009; Archer 2011; Carrol 2011, Sánchez et al. 2015). It takes approximately two-three months for this bud to develop, after the formation of the first node at the tip of a growing point. This bud is fruitful when it produces one or more inflorescence primordia per node. Depending on the cultivar, environmental conditions, shoot orientation and genetically fixed characteristics, fruitfulness of primary buds on main shoots increase up until node 12 and will then decrease (Bennett 2002).

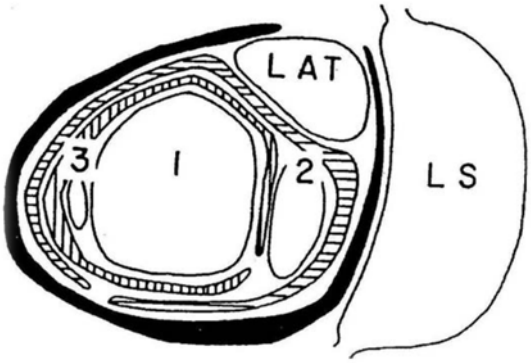

Figure 2.3: A transverse section through a grapevine bud, which consists of the lateral shoot scar (LAT), leaf scar (LS), and three individual buds namely primary (1), secondary (2) and tertiary (3) buds (Rawnsley 2003; Rawnsley and Collins 2005; Archer 2011).

2.3.2 Flower development

There are various factors that influence floral induction in grapevines and there are no definable endogenous or exogenous triggers (Longbottom 2007). The formation of flowers in grapevines is a three-step process and is described below (Pratt 1971; Srinivasan and Mullins 1978; Jones et al. 2009).

The first process is the formation of the anlagen and takes place just before flowering. Anlagen are also referred to as uncommitted primordia and are formed in the axils of the leaf primordial of the primary bud. The anlagen develop after the formation of approximately five leaf primordia on a shoot primordium. In addition, anlagen undergo repeated branching and can produce inflorescence primordia, shoot primordia or tendril primordia (Pratt 1971; Srinivasan and Mullins 1978; 1980; Carrol 2011). Endogenous factors, e.g. nutrients, water and growth substance and exogenous factors, e.g. light and temperature, are all factors that can influence the development of inflorescence primordia, tendril primorida and shoot primordia (Longbottom 2007).

The second process is the formation of the inflorescence primordia. This step takes place during flowering and is characterized by repeated branching. Anlagen that produce two or more branches will produce tendrils, whilst anlagen that undergo repeated branching will give rise to inflorescences (Pratt 1971; Srinivasan and Mullins 1978; 1980; 1981; Carrol 2011).

The third process is the formation of flowers. The previous steps refer to the inflorescence initiation and takes place in the current season, whereas the final step takes place in the following season, just before or during bud burst. This step is also referred to as the differentiation stage and favourable conditions during this stage are critical for bunch size (Pratt 1971; Srinivasan and Mullins 1978; 1981; Carrol 2011).

2.4 GRAPEVINE CARBOHYDRATES RESERVES

The close relationship between carbohydrate reserves and grapevine fruitfulness suggest that adequate levels of carbohydrate reserves determine the formation and development of inflorescences during the bud burst stage (Bennett et al. 2005). The concentrations of these carbohydrates stored in roots range between 10% and 40% depending on the season (Smith and Holzapfel 2002). Both carbohydrate reserves and nutrients are important for early vegetative and reproductive growth, which affects shoot development and therefore canopy size and yield (Caspari et al. 1998; Palliotti et al. 2011). It is therefore the carbohydrates stored in the roots and trunk that are utilized for the development of new shoots and inflorescences in the following season (Bennett et al. 2005).

Furthermore, grapevine leaves import carbohydrates from permanent structures for development until they reach half their final size, after which they will be net exporters of carbohydrates. However, when carbohydrates from photosynthesis are insufficient and when crop load is high or beyond the capacity of the vine, carbohydrates will be mobilized from permanent structures to meet the current demand of the vine. This will continue until photosynthesis becomes the main source of carbohydrates (Bennett

2002; Lebon et al. 2008). The rate of photosynthesis and the allocation of photosynthetic products among shoots, roots and fruits will determine the accumulation of carbohydrate reserves in vines (Bennett et al. 2005; Lebon et al. 2008).

Starch and soluble sugars (sucrose, glucose, fructose and *myo*-inositol) are the two main forms of carbohydrates stored in the grapevine (Sepulveveda and Kliewer 1986; Bates et al. 2002; Rawnsley and Collins 2005; Lebon et al. 2008; Rusjan 2010) and are accumulated in the xylem ray cells of the roots and shoots (Smith and Holzapfel 2002). This sugar content is 5-10% of the dry mass in both the roots and shoots (Smith and Holzapfel 2002) and is mostly located in leaves, shoots and roots.

Fruit of various plants belonging to the genus *Vitis* contain sucrose and this is the main sugar that is mobilized from leaves to the fruit (Sepulveveda and Kliewer 1986). Depending on vine phenology, the concentration of this carbohydrate, within the woody tissue of the grapevine, varies greatly over the growing season (Bennett 2002). Starch reserves in canes, cordons and trunks are at their highest level at the end of the growing season and decrease in winter, while soluble sugars start to increase at this time. The interconversion of this starch to soluble sugars during winter is the result of the development of winter hardiness, where the soluble sugars act as a cryoprotectant against cold (Bennett 2002).

A complex flux of carbohydrates occurs between annual organs (leaves, inflorescence and berries) and perennial organs (roots, trunks and canes) during the annual grapevine cycle (Hunter et al. 1995). Organs which are net importers of carbohydrates are referred to as sinks, due to their requirements for nutrients, and the organs that supply nutrients are referred to as source organs (Lebon et al. 2008). Throughout the development of the vine, vegetative organs will represent both sink and source organs depending on the growth stage of the plant (Lebon et al. 2008).

During spring (bud development) carbohydrates are transported from leaves to buds. These buds are weak sinks compared to flowers and clusters for carbohydrates. At this

stage, growing shoot tips are the strongest sink for carbohydrates (Vasconcelos et al. 2009). The balance between the sink and source organs will therefore influence the development of reproductive organs (Lebon et al. 2008) and it is important to reach a balance between carbon sources (leaves) and sinks (berries) to achieve optimal yield and quality (Carmona et al. 2008). That is why carbohydrates stored in trunks and roots in the previous season act as sources that supply energy to reproductive organs in the current season (Lebon et al. 2008). During the growth of these reproductive organs, bunches become the strongest sinks and carbohydrates are translocated to them (Smith and Holzapfel 2002). However, if the fruit is a weak sink or when the photosynthetic capacity of the vine is low (which results in low reserve restoration) then the removal of leaves after harvest or reducing the crop load would have very little influence on carbohydrate accumulation.

Carbohydrate reserves can be accumulated before winter by retaining the leaves on the vine after harvest for as long as possible (Bennett et al. 2005). The replenishment of these reserves can be inhibited by crop load before harvest, which will increase the demand for these reserves to ripen the crop (Smith and Holzapfel 2009). In addition, as long as photosynthesis occurs after harvest starch and sugars will accumulate, provided temperatures are sufficiently warm. In contrast, there is limited accumulation of carbohydrates after harvest in cooler areas (Bennett et al. 2005). Carbohydrates produced at this time are continuously transported from basal leaves on shoots to the perennial storage tissue. Injudicious and severe removal of basal leaves will therefore negatively impact the accumulation of reserves and as a result the growth and development of vegetative and reproductive tissue in the following season (Winkler and Williams 1945).

Long postharvest periods allow vines to carry crop loads that many may see as excessive in relation to the amount of leaves and in some grape cultivars high crop loads lead to fluctuations in yield in the subsequent season (Scholefield et al. 1978). Consequently, this may even minimize or limit vine growth in terms of root growth and shoot development (Holzapfel et al. 2006). This statement highlights the importance of

the postharvest period for maintaining the productivity of high-yielding grapevines (Scholefield et al. 1978). However, decreasing the reserve levels in autumn can be used to control vegetative growth during the following spring, whilst this results in a reduction in yield, it does improve grape quality (Smith and Holzapfel 2002).

When the soil reaches 10°C-12°C at the beginning of spring, dormancy is released and plant metabolism is activated. In spring, reserves are also translocated to reproductive organs until flowering when this stops. Often these reserves will accumulate in annual and perennial organs of the vine from the start of bloom to véraison. At the same time photosynthesis in grapevines will increase from bud break until full bloom, from where it will decrease until leaf fall (Fig. 2.4) (Lebon et al. 2008).

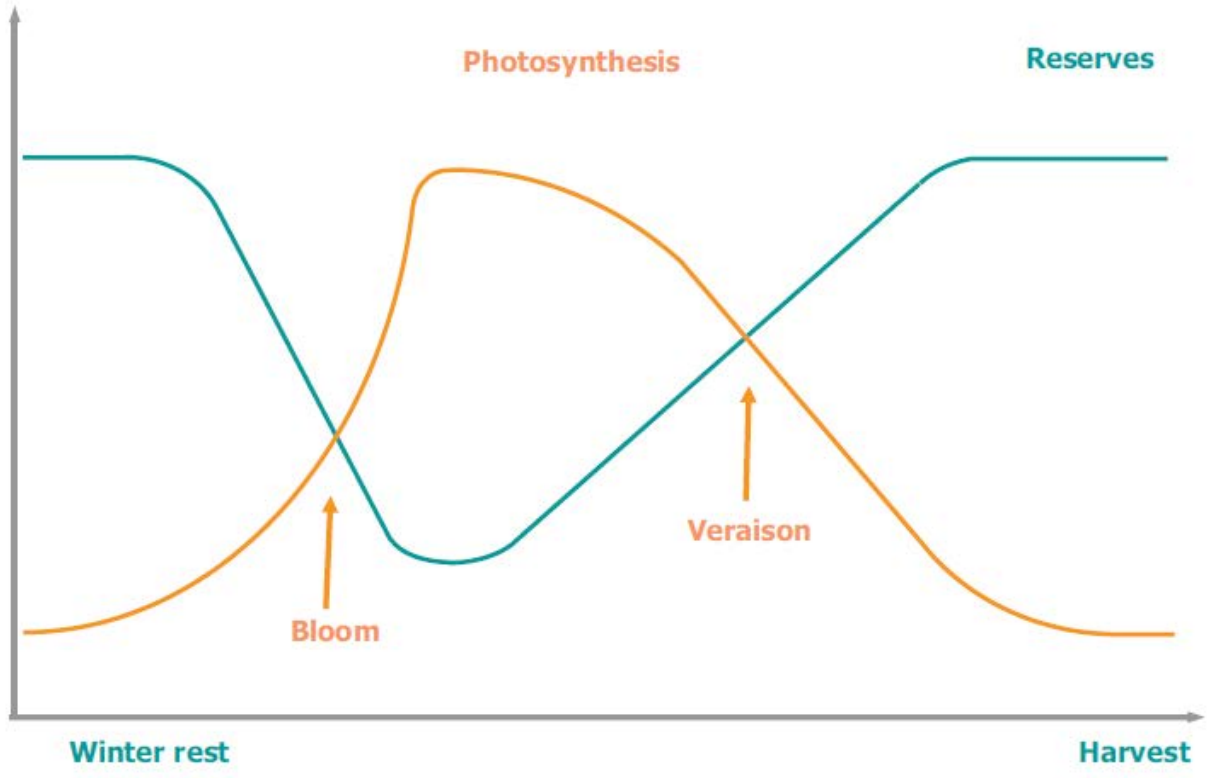

Figure 2.4: Fluctuation of reserves and photosynthesis during the grapevine annual cycle (Lebon et al. 2008).

2.5 ENVIRONMENTAL FACTORS INFLUENCING BUD FRUITFULNESS

2.5.1 Temperature

The climatic conditions of a specific area will determine factors such as temperature and humidity, which will have a direct and indirect influence on the growth and development of grapevines (Human 2010). Grapevines respond differently to different temperature regimes. Temperature can determine whether the energy produced by photosynthesis is stored in leaves as carbohydrates or lipids (Sepulveveda and Kliewer 1986). Although cold temperatures after bud break are a threat, inflorescence development is inhibited by both low and high temperature (Baldwin 1964). According to Buttrose (1970), the formation of anlagen by the shoot apical meristem (SAM) of latent buds is susceptible to high temperatures. Depending on the cultivar and area, it is recommended that temperatures should be above 20°C for best possible floral initiation to occur. Furthermore, in all cultivars, the second and third inflorescences will be initiated by a high temperature pulse, while temperatures below 20°C will give rise to tendrils (Vasconcelos et al. 2009).

Cultivars, such as ‘Sultana’, characterized by low fruitfulness are more responsive to changes in temperature. In addition, there is also a positive relationship between high temperature and fruitfulness in the following season (Srinivasan and Mullins 1981). Orth and Van Rensburg (2012) state that maximum bud fruitfulness can be obtained during bud initiation at a temperature range of 30°C-35°C. A study conducted by Buttrose (1970) demonstrated that ‘Rhine Riesling’ reached sufficient fruitfulness at 30°C, whereas ‘Shiraz’ was less fruitful at temperatures lower than 35°C. In the same experiment it was found that the mass of the primordia was higher at 30°C as compared with 35°C (Buttrose 1970).

Temperature during bud burst may affect flower size and eventual berry mass (Vasconcelos et al. 2009). Bennett (2002) states that during and following bud burst, temperature is critical for the development of flowers in the current season. Depending

on the cultivar and region, flowering in the grapevine is much more favourable at temperatures between 20°C and 30°C, as compared with temperatures between 16°C and 17°C (Srinivasan and Mullins 1981; Vasconcelos et al. 2009; Carrol 2011). Researchers therefore believe that by increasing temperature during flowering and bud burst, as a result of increased interception of incoming radiation, bud fruitfulness can be increased by promoting the initiation and formation of the cluster primordia (Dry 2000).

2.5.2 Solar Radiation

Apart from the effect on temperature, solar radiation plays an important role in photosynthesis and bud fruitfulness. This will have an effect on grapevine yield and quality and as a result knowledge of grapevine cultivation practices, such as pruning, trellis systems, shoot spacing, vine size and cultivar choice, are critical to improve the interception of solar radiation by the vine (Cartechini and Palliotti 1995). Solar radiation has an indirect effect on fruitfulness via temperature and a direct effect on photosynthesis and available carbohydrates in grapevines (Dry 2000; Vasconcelos et al. 2009).

Average bud fruitfulness decreased with an increase in shading, with the highest bud fruitfulness found in unshaded vines (Hunter and Visser 1990). Shading therefore reduces bud fruitfulness by inhibiting the import of nutrients into buds. In addition, transmitted radiation will be reduced by dense canopies that will result in unfruitful buds near the base of the vine (Perez and Kliewer 1990; Howell 1999; Dry 2000; Orth and Van Rensburg 2011). That is why buds on the outside of the canopy are more fruitful then buds in the interior of the canopy (Dry 2000; Vasconcelos et al. 2009). A study that was conducted in New Zealand supported this conclusion, as shoots covered with hessian shade net produced fewer bunches compared to unshaded shoots during summer and autumn (Hunter and Visser 1990). It was also found that shading of the canopy limits the translocation of photosynthates and carbohydrates to inflorescences, which reduces the crop load (Perez and Kliewer 1990) and leads to flower abscission (Lebon et al. 2005). Sommer et al. (2000), concluded that cultivars, such as ‘Sultana’,

grafted on vigorous rootstocks will have lower fruitfulness, due to the characteristic dense canopy.

The amount of intercepted solar radiation by leaves will have an influence on the number of flower clusters per bud. Intercepted radiation also plays an important role in flower induction. Therefore, fruitfulness of latent buds will be most affected during late spring, due to the availability of solar radiation for flower induction (Dry 2000; Vasconcelos et al. 2009).

A study conducted on 'Shiraz' showed that mature leaves intercept more or less 85% of available photosynthetic photon flux density (PPFD), whilst 6% is reflected and 9% is intercepted (Strydom 2006). The intercepted PPFD can influence the rate of photosynthesis, including processes such as stomatal conductance and rate of transpiration (Hunter and Visser 1988). Results obtained by Hunter and Visser (1988) showed the tempo of vine photosynthesis increases with an increase in defoliation. The opposite is also true, with the rate of photosynthesis decreasing as vegetative growth continues and the canopy becomes denser. Therefore, as fruitfulness is correlated to the carbohydrate content of the vine, it is important to allow sufficient PPFD into the canopy for optimal photosynthesis and carbohydrate production (Hunter and Visser 1988).

Furthermore, spacing the shoots before bloom, by moving the cordon wires, creates an open canopy that allows more solar radiation to reach basal buds, which results in more fruitful buds (Perez and Kliewer 1990). Figure 2.5 demonstrates the penetration of the PPFD through different layers of shade cloth and how it influences fruitfulness. The average PPFD, in µmol $m^{-2}s^{-1}$, for the different layers were measured at 09:00, 12:00, 15:00 and 18:00 and the following values were obtained above the canopy, 766 (1^{st} layer), 361 (2^{nd} layer) and 211 (3^{rd} layer). Average PPFD values measured under the foliage were 34, 18, 8 and 5 µmol $m^{-2}s^{-1}$. Average bud fruitfulness decreased with an increase in shading, with the highest bud fruitfulness found in unshaded vines (Perez and Kliewer 1990).

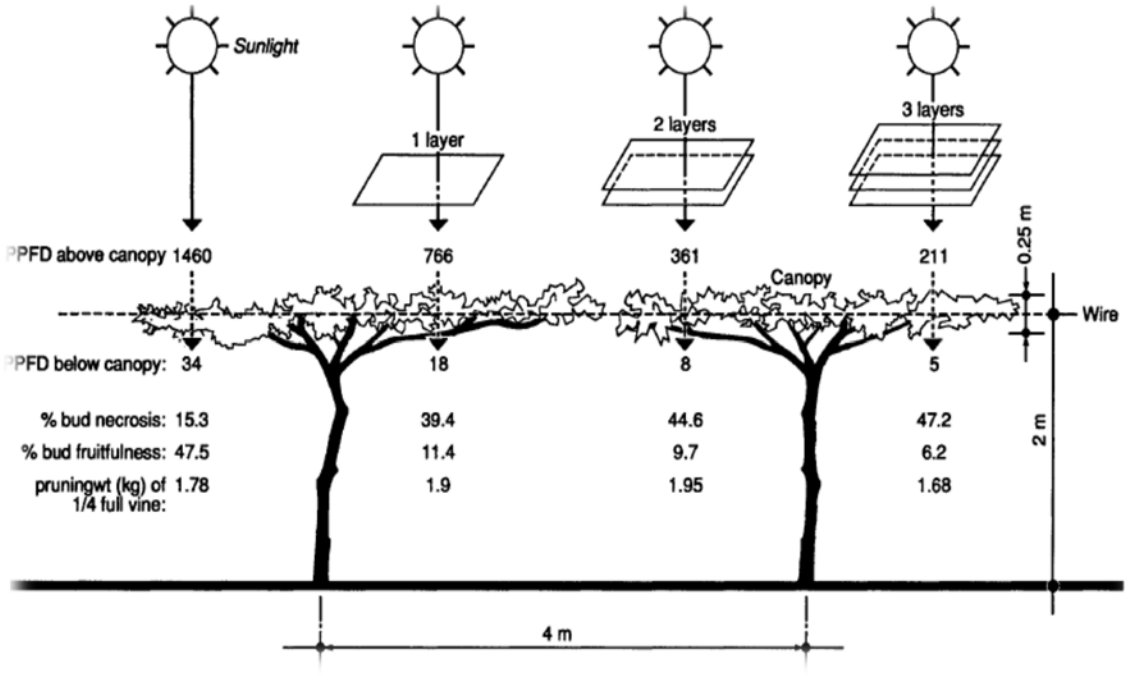

Figure 2.5: Photosynthetic photon flux density (PPFD) above and below 'Thomson Seedless' grapevines under field conditions in Chile (Perez and Kliewer 1990).

Although both temperature and radiation are considered to be important for bud fruitfulness, a combination of the two factors is required for maximum fruitfulness (Srinivasan and Mullins 1981). A study conducted by Carrol (2011) demonstrated that the total amount of radiation is more important than radiation intensity, which means that persistent cloudy days may cause lower bud fruitfulness. That is why different cultivars respond differently to different radiation intensity regimes (Hunter and Visser 1990). Buttrose (1970) also found that among grapevine cultivars, 'Shiraz' requires high radiation intensity for fruitfulness, while cultivars, such as 'Rhine Riesling' are most fruitful under low radiation intensity, and would be more suitable in cloudier regions.

Bledsoe et al. (1988) showed no significant difference between yield components when both the severity and stage of leaf removal was evaluated in order to increase radiation interception by the vines. Studies also illustrated that grape parameters, such as total

soluble solids (TSS), anthocyanins, phenolics and titratable acidity, malate, juice pH, berry mass and yield can be improved when shading in grapevine canopies is prevented (Kliewer and Lider 1968; Kliewer 1970; Hale and Buttrose 1974; Smart et al. 1985; Reynolds et al. 1986; Bloedsoe et al. 1988; Smart et al. 1988; Smart et al. 1990; Zoecklein et al. 1992; Edson et al. 1993; Percival et al. 1994; Cartechini and Palliotti 1995; Dokoozlian and Kliewer 1996; Dry 2000; Hunter 2000; Bergqvist et al. 2001; Volschenk and Hunter 2001; Tardaguila et al. 2008).

2.6 VINEYARD MANAGEMENT PRACTICES

2.6.1 Water stress

Water stress experiments to improve fruitfulness have been conducted by several researchers on grapevines (Williams et al. 1991; Ndung'u et al. 1995; Ndung'u et al. 1996; Ndung'u et al. 1997), whilst other studies have shown how the number of inflorescences decreased as water stress increased (Buttrose 1973; Carbonneau and Casteran 1979). In contrast, some studies have shown that water stress can improve fruitfulness by reducing canopy density, which will allow more solar radiation into the canopy (Srinivasan and Mullins 1981). An experiment conducted by Ndung'u et al. (1997) illustrated that the carbohydrate content in grapevines decreased as water stress increased. The nitrogen content in grapevines also decreases due to water stress, which will increase bud fruitfulness by increasing the solar radiation interception as a result of a reduced vegetative growth (Ndung'u et al. 1997).

A study conducted by Goto-Yamamoto et al. (2010), illustrated that various water applications can have varying effects on flavonoids found in berry pulp, as well as wilted berries, a damaged canopy, diseases, reduction in TSS and lower crop level (Goto-Yamamoto et al. 2010); inadequate water application can cause reduced berry size and delayed ripeness (Christensen 1975). A decrease in yield was also found in a study where irrigation was reduced (Carbonneau and Casteran 1979). Different irrigation

regimes also had different effects on parameters in berry skins (Goto-Yamamoto et al. 2010)

2.6.2 Trellis system

It is important for a grower to choose a trellis system that can accommodate the vegetative growth of a vine so that the vine can utilize the available resources, such as incoming solar radiation. Therefore, factors such as cultivar choice, rootstock, soil potential, vine spacing, cultivation intention and vigour need to be considered before choosing a trellis system. Obtaining a balance between the above factors will contribute to achieving higher yields of the best quality grapes (Strydom 2006).

Shoots which are trained vertically are also more fruitful then shoots which are trained horizontally (Strydom 2006). This is why vines are trained on Geneva Double Curtain trellis systems (Fig. 2.6), to divide the foliage and enable shoots to be trained vertically. In addition, choosing the correct trellis system, which allows shoots to grow vertically and controlling all other factors such as vegetative growth, can improve the radiation interception during the growing season which will increase bud fruitfulness (Cartechini and Palliotti 1995; Al-Joumayly 2003). Experiments conducted on the Geneva Double Curtain trellis system illustrated that bud burst and fruitfulness can be improved and yield can be increased by 44%-90% compared with a non-divided canopy (Cartechini and Palliotti 1995).

In a study where a standard Vertical Shoot Positioning system was compared to a Ruakura Twin Two Tier (RT2T), shoots per node and cluster per shoot were increased in a ‘Cabernet Franc’ cultivar and yield was increased by 80% when trained on a RT2T trellis system. Other studies with divided trellis systems found similar results in experiments where systems such as U-trellis, V-trellis, and W-trellis were used and yield was 53%-67% higher (Dry 2000).

Figure 2.6: Geneva Double Curtain trellis system (Anon. 2015).

2.6.3 Pruning

The purpose of pruning is to maintain a balance between vegetative and reproductive growth, ensure sufficient radiation penetration into the canopy, develop a favorable structure and obtain a high crop level (Strydom 2006). The pruning method, such as cane or spur pruning, will be determined by the cultivar and cultivation area. The timing of pruning of a specific cultivar will determine the time of ripening of a cultivar. Cultivars with a high fruitfulness are spur pruned, whilst those with a low fruitfulness are cane pruned. Thus, the pruning method used will be determined by the fruitfulness of the cultivar (Cristensen 2013).

Pruning can also be referred to as renewal, whereby the appropriate shoot density is retained, which enhances solar radiation interception that will result in an increase in bud fruitfulness, bud burst and yield (Dry 2000; Reynolds et al. 2005). Higher yield is found in a canopy where it was renewed as opposed to a canopy that was not renewed. In addition, yield increased when the top canopy was renewed as compared with the renewal of the bottom canopy of a single trellis system (Dry 2000).

2.6.4 Canopy management

2.6.4.1 Shoot orientation

Although vertical positioned shoots are more fruitful (Dry 2000), a similar experiment conducted by Kliewer et al. (1989), showed that there was no effect of shoot positioning on the fruitfulness of buds. Shoots should be tightened down on cordon wires to obtain the benefits of trellising, such as efficient solar radiation interception and distribution, effective cluster exposure for colour development and the prevention of dense canopies (Strydom 2006).

2.6.4.2 Removal of leaves and shoots

Viticultural practices, such as shoot thinning, leaf removal and shoot tipping (changes the direction of nutrient translocation, away from the shoot tip towards the bunches), are critical for fruit set (Raath and Du Plessis 2012) and topping can be used to reduce the existing canopy shade (Zoecklein et al. 1992). Applying the above practices will result in an increase in the growth of the remaining shoots and will improve solar radiation interception, pest management and photosynthetic activity (Smart et al. 1985; Hunter and Visser 1988; Perez 1990; Hunter et al. 1995; Poni et al. 2006; Strydom 2006; Human 2010). In addition, cultural practices such as the removal of growing tips can improve fruit set at an early stage (Vasconcelos et al. 2009).

Grapevine leaves absorb solar radiation in the wavelength range between 400 and 700 nm, which is referred to as PAR. It is therefore advantageous to have a leaf area or canopy that can develop rapidly in spring and efficiently intercept sunlight for the purposes of photosynthesis. This can be possible by limiting the density of canopies and by preventing developing canopies from being too close to each other, especially in the cluster or renewal area. By limiting vegetative growth in such a manner, the photosynthetic activity of the vine can be improved (Smart et al. 1990; Percival et al. 1994).

Experiments where shoots and leaves were removed in the canopy zones produced mixed results when researchers investigated at how this action impacted bud fruitfulness. In other studies where shoots were removed in fruiting zones, the number of shoots per node and clusters per node all increased relative to the control treatment (Dry 2000). Research by Hunter and Visser (1990) found that bud fruitfulness of *Vitis vinifera* L. cv. 'Cabernet Sauvignon' was increased when 33% defoliation was applied from bud burst. Defoliation before the berries are pea-sized could also improve the microclimate within the vine, which subsequently improves photosynthetic activity and grape development (Hunter and Visser 1990).

Furthermore, the study showed that 33% leaf removal at pea-size could be used to reduce canopy size. Removing 33% and 66% of the leaves before the berries were pea-sized and at harvest decreased fresh mass per berry and yield at harvest (Hunter and Visser 1990). Results also showed that shoot removal later in a season resulted in an increase in colour development, related to anthocyanin and phenolic concentrations (Ferree et al. 2000). Reynolds et al. (2005) stated that when shoots are removed at harvest, the carbohydrate content of the vine decreases which results in a reduction in crop load, as well as vegetative growth in the following season. In contrast, Palliotti et al. (2011) also conducted a study on defoliation and discovered that by applying defoliation before flowering, node fruitfulness could be increased.

2.6.5 Nutrient reserves

Nutrition is an essential management tool for grape producers (Florin and Blidariu 2012) to ensure a vine with healthy development and performance (Ashley 2012). Grapevines have very few mineral deficiency problems and can adapt to various soil types and fertilities. Vasconcelos et al. (2009) refer to nutrients as having complex interactions, which influence fruitfulness of grapevines. Nitrogen, potassium, zinc and boron are all generally applied in vineyards, with the most essential nutrients being N and K (Ali 2008; Abd El-Razek et al. 2011). The nutritional status of the vine can have an effect on

fruit set, fruit quantity and quality. Thus, in order to ensure continued productivity in a vineyard optimal mineral nutrition should be ensured (Abd El-Razek et al. 2011).

2.7 PHYSIOLOGICAL FACTORS INFLUENCING BUD FRUITFULNESS

2.7.1 Plant growth regulators

Plant growth regulators (PGR`s) occur naturally in plants and can either have a negative or positive effect on grapevines and fruits. Abscisic acid (ABA), auxins, cytokinins, ethylene and gibberellic acids (GA) are the five classical PGR`s that are found in grapevines. These hormones have different functions and affect grapevines according to their growth stages (Human 2010). Internal factors, such as growth regulators, determine the fate of uncommitted primordia with the formation and differentiation of anlagen being the two levels where inflorescence formation is regulated in grapevines by PGR`s (Lebon et al. 2008). The principle regulators of flowering are GAs and cytokinins. It was discovered during a field study conducted by Palma and Jackson (1989) that GA_3 had a negative effect on inflorescence development by decreasing the number of flowers per inflorescence in the following season. In addition, application of GA_3 at a concentration of 31 µmol L^{-1} stimulated bud burst prior to winter and induced the development of tendrils, while inhibiting the development of inflorescences from the anlagen (Srinivasan and Mullins 1980).

Furthermore, root tips produce cytokinins, which are believed to stimulate shoot growth and are assumed to stimulate auxin production. Cytokinins therefore control the root and shoot growth relationship (Kagi 1998). Results showed that fruits with seeds can be produced when cytokinin production is induced in inflorescences (Bennett 2002) and play a role in the formation of uncommitted primordia (Lebon et al. 2008). The growth of early developing flowers and the formation of flowers in the following season are also improved by the presence of cytokinins (Mullins 1967; Longbottom 2007). Cytokinins also control processes, such as the development of inflorescence primordia from anlagen and flower differentiation from inflorescence primordia (Srinivasan and Mullins

1980). Figure 2.7 illustrates how PGR`s can increase, inhibit and promote inflorescences (Vasconcelos et al. 2009).

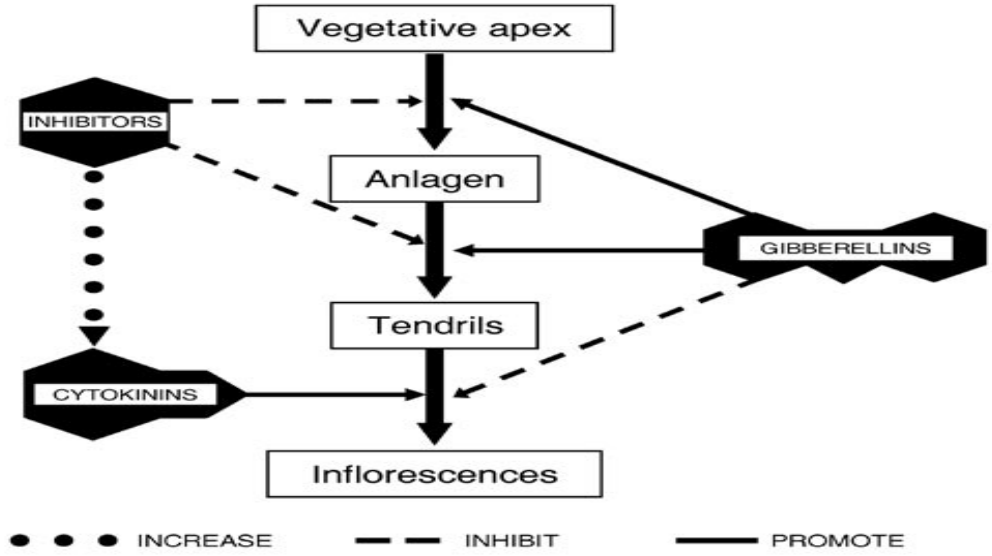

Figure 2.7: The role of plant growth regulators in the formation of inflorescences in grapevines (Vasconcelos et al. 2009).

2.8 PRIMARY BUD NECROSIS

Bud necrosis is a disorder that may result from impaired physiological or developmental processes within the bud (Wolf and Warren 1995) and refers to a condition where the cells of the latent bud in the primary bud die (Bennett 2002). Due to the increase in bud dissection during the dormant stage of the grapevine, researchers became aware of the death of the primary bud; the phenomenon is referred to as primary bud necrosis (PBN). PBN occurs in the current season during bud initiation. If PBN does not develop in primary buds, it can develop in secondary buds that are less fruitful than the primary bud (Wolf and Warren 1995; Vasudevan et al. 1998). As compared with a healthy bud (Fig. 2.8), the primary bud will appear brown and dry if affected by PBN (Fig. 2.9). Vineyards that are affected by PBN can experience a loss in yield. However, the bud dissection method can be used to assess buds for PBN and fruitfulness (Rawnsley and Collins 2005).

Figure 2.8: A grapevine bud not affected by primary bud necrosis (Rawnsley and Collins 2005).

Figure 2.9: A grapevine bud that is affected by primary bud necrosis (Rawnsley and Collins 2005).

Development of PBN depends on factors such as cultivar, excessive vegetative growth, over irrigation, shading, high GA levels and low bud carbohydrates. PBN in vineyards can reduce bud burst, bud fruitfulness and crop levels. The exact cause of PBN remains uncertain, however, studies show that bud necrosis can be promoted when carbohydrate levels in shoots, leaves and buds are reduced due to shading (Wolf and Warren 1995; Rawnsley and Collins 2005).

By applying good canopy management practices, such as shoot removal and positioning to improve PAR transmission through the canopy, the occurrence of PBN could possibly be minimized and bud fruitfulness in ‘Crimson Seedless’ improved.

2.9 CONCLUSIONS

To conclude, the main objective of the research presented in this dissertation is to study the influence of shoot removal on bud fruitfulness, PAR transmission dynamics through the canopy, carbohydrate content in canes and the subsequent yield.

CHAPTER 3

EFFECT OF SHOOT REMOVAL TREATMENTS ON PHOTOSYNTHETICALLY ACTIVE RADIATION, CARBOHYDRATE RESERVES AND BUD FRUITFULNESS

3.1 INTRODUCTION

Partial defoliation is a viticultural practice whereby leaves are removed throughout the vine canopy. The practice has several benefits, such as reducing canopy shade and improving transmitted photosynthetically active radiation (PAR) through the canopy, increasing the growth of remaining shoots, pest management and increased photosynthetic activity that can contribute to an improvement in bud fruitfulness of grapevines (Smart et al. 1985; Hunter and Visser 1988; Hunter et al. 1995; Poni et al. 2006; Strydom 2006; Human 2010). Shoot removal after harvest is commonly used by producers in the Orange River region to improve bud fruitfulness and therefore yield.

Grapevine yield is the final result of a two year reproductive developmental cycle and as a result growers often find it difficult to maintain a constant crop level (Longbottom 2007; Carmona et al. 2008). The seasonal variation in grapevine yield is due to a variation in node fruitfulness, which is a genetic characteristic associated with grape cultivars which affects yield (Bennett 2002). Fruitfulness is also influenced by factors, such as the carbohydrate content in vines, and canopy management practices, such as shoot removal (Bennett et al. 2005).

Defoliation during the growing season results in an increase in the number of inflorescences, the size of the bunch and eventually yield in the following season (Bennett et al. 2005; Holzapfel et al. 2006; Smith and Holzapfel 2009; Lohitnavy et al. 2010). Defoliation during the vine's growing season can also increase photosynthesis and carbohydrate replenishment, which can contribute to the bud fruitfulness of a cultivar (Hunter and Visser 1988; Perez and Kliewer 1990). Carbohydrate reserves play a role in the initiation of inflorescences and thus ensuring sufficient shoot exposure for

leaves to intercept more solar radiation and increasing the photosynthetic capacity is important for promoting bud fruitfulness (Smith and Holzapfel 2009).

According to Candolfi-Vasconcelos and Koblet (1990), defoliation can have a negative effect on carbohydrate reserves by removing a significant source of photosynthates, which limits the accumulation of carbohydrates in woody permanent parts of the vine. These reserves play an important role in ensuring productivity in the following season when they are assembled and collected according to the plants requirements (Candolfi-Vasconcelos and Koblet 1990). During winter dormancy, 90% of the starch is stored in root systems. In most cultivars, dormancy ends when soil temperature reaches 10°C-12°C and plant metabolism is activated. At this time starch is the key source of carbohydrates in vines and is utilised by annual vegetative and reproductive growth. The supply of these reserves to the developing inflorescence ends at flowering (Lebon et al. 2008). In addition, for satisfactory inflorescence initiation and formation, leaves need to produce a certain amount of carbohydrates (Bennett 2002). That is why carbohydrates stored in trunks and roots in the previous season are crucial to act as a source that supplies energy to reproductive organs (Lebon et al. 2008).

The objective of this study was to evaluate the effect of shoot removal treatments on the a) transmitted PAR through the canopy, b) carbohydrate reserves in canes and c) subsequent bud fruitfulness. It was hypothesized that the removal of shoots after harvest will increase the transmitted PAR through the canopy, increase carbohydrate reserve levels in canes and improve bud fruitfulness of ‘Crimson Seedless’. It was also hypothesized that the cut back of all main and shoots developing from spurs to the nearest lateral shoot and the removal of all unproductive shoots after berry set will result in fruitful shoots in the following season.

3.2 MATERIALS AND METHODS

3.2.1 Experimental vineyard

The trial was conducted over the 2010/11-2012/13 growing seasons, in a block located on the Hex River Valley experimental farm of the ARC Infruitec-Nietvoorbij (33°47'S,19°67'E and Alt. 457 m), near De Doorns in the Hex River Valley in the Western Cape, South Africa (Fig. 3.1). The region is classified as a Mediterranean area, with warm dry summers and cold wet winters. The experimental vineyard was a 11-year-old commercial block *Vitis vinifera* L. cv. 'Crimson Seedless' vineyard, grafted on 'Ramsey' (*V. champinii*) rootstock. The vine spacing was 1.8 m in east/west orientated rows, with 2.8 m between rows (~ 1984 vines/ha). 'Crimson Seedless' vines were trained on a Trentina trellising system with a short double split cordon. The Trentina trellis system consists of nine cordon wires, with cordon wires spaced 30 cm apart (Fig. 3.2). Other viticultural practices for the block were according to commercial standards. The vines were pruned with six canes, each containing ten buds and a spur at each cane. The average long-term February temperature in the month in which berries ripen, from 1963 to 2002 was 21.8°C. The Hex River Valley is classified into Region III, which is classified as a moderately warm and suitable region for the production of red and black cultivars (Strydom 2006).

Figure 3.1: The experimental site (highlighted in red) of the shoot removal trial on the Hex River Valley experimental farm of the ARC Infruitec-Nietvoorbij, at De Doorns.

Figure 3.2: Trentina trellis system on which the vines were trained on the Hex River Valley experimental farm of the ARC Infruitec-Nietvoorbij, at De Doorns.

3.2.2 Experimental design

The experimental layout (Fig. 3.3) was a complete randomized design (CRD). Three rows were used, where an experimental plot consisted of four vines, where the two middle vines were used as data vines while the two side vines were used as buffer vines, between treatments. The five treatments were replicated five times.

ROW	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5	PLOT 6	PLOT 7	PLOT 8	PLOT 9	PLOT 10	PLOT 11	PLOT 12
18		RSB	Control	LS	LS	Control						
19		S_{66}	Control	S_{33}	LS	Control	S_{66}	RSB	S_{33}	S_{66}	S_{33}	
20		LS	RSB	LS	S_{33}	RSB	S_{66}	S_{33}	S_{66}	Control	RSB	

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

Figure 3.3: Experimental plot lay-out of the shoot removal trial on ‘Crimson Seedless’ at the Hex River Valley experimental farm of the ARC Infruitec-Nietvoorbij, at De Doorns during the 2010/11–2012/13 growing seasons.

3.2.3 Shoot removal treatments

The five treatments that were applied were as follows: control (no shoot removal), 66% shoot removal ($S_{66,}$ starting at the base and moving up to the end of the cordon arm, two shoots were removed after every shoot), 33% shoot removal ($S_{33,}$ starting at the base and moving up to the end of the cordon arm, one shoot was removed after every two shoots, LS (all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot) and RSB (all unproductive shoots were removed). Suckering was conducted during the 2010/11 season, whereby shoots in unfavourably positions were removed. These missing shoots were taken into consideration when the S_{33} and S_{66} treatments were applied after harvest in the 2010/11 season.

Both the S_{33} and S_{66} treatments were applied after harvest in both the 2010/11 and 2011/12 seasons (Table 3.1). LS and RSB treatments were applied after berry set in both the 2011/12 and 2012/13 seasons (Table 3.1). The lower three shoots or future bearing shoots on each cordon were retained to ensure enough bearing shoots for the following season. The aim of S_{33}, S_{66} and RSB treatments were to improve the transmittance of PAR through the vine and of the S_{33} and S_{66} treatments to improve the carbohydrate reserve levels in canes. The aim of the LS treatment was to obtain new lateral shoots that develop during a later period, which would be exposed to more favourable solar radiation and temperature conditions after berry set, thereby improving bud fruitfulness of ‘Crimson Seedless’ due to the initiation of flower cluster primordia during more favourable solar radiation and temperature conditions.

Table 3.1: Dates when shoot removal treatments were applied on *Vitis vinifera* L. cv. 'Crimson Seedless' vines during the 2010/11-2012/13 growing seasons.

Treatments	**2010/11 season**	**2011/12 season**
Control		
S_{33}	24/03/2011 (after-harvest)	18/03/2012 (after-harvest)
S_{66}	24/03/2011 (after-harvest)	18/03/2012 (after-harvest)
	2011/12 season	**2012/13 season**
LS	31/10/2011 (after berry set)	02/11/2012 (after berry set)
RSB	31/10/2011 (after berry set)	02/11/2012 (after berry set)

3.2.4 Leaf area (LA) measurements

To calculate the leaf area (LA) measurements were taken after harvest in both the S_{33} and S_{66} treatments during the 2010/11 and 2011/12 seasons. These measurements were taken by collecting four main shoots per vine, which consisted of two shoots from each side of the canopy. These shoots were randomly selected, but were representative of each treatment. The leaves of the four shoots were removed and separated into main shoot leaves and lateral shoot leaves. The lengths of the main and lateral shoots were measured before the shoots were discarded. The leaves were stored in brown paper bags at 0°C until the LA was determined with a Li-3000 portable area meter (LI-COR Inc., Lincoln, Nebraska, USA). Additional to the four randomly selected shoots that were measured, the total shoot length of the rest of the shoots that were removed from each data vine (main and lateral shoots) were also measured. The aim of the LA measurements was to determine the LA per vine that remained on vines, as well as the LA per vine removed from vines after the S_{33} and S_{66} treatments were applied.

3.2.5 PAR transmission measurements

PAR measurements were taken in the 2010/11 and 2011/12 growing seasons on cloudless days to compare the transmitted PAR between shoot removal treatments and

control vines. PAR measurements were taken for all treatments from after harvest until before harvest in the following season and were taken in all three vineyard rows. A LI-COR Model LI-250 Line Quantum Sensor (LI-COR Inc., Lincoln, Nebraska, USA) was used and was placed on the 3rd (60 cm from first cordon wire) and 6th (150 cm from first cordon wire) canopy wire in a parallel position to the cordons in the canopy (Fig. 3.4). The transmitted PAR (µmol.m-^{2}.s^{-1}) was expressed as the percentage of the PAR transmitted through the canopy. The average of these two positions was used to calculate percent transmittance by dividing the fruit-zone PAR value by the ambient PAR value (measured above the canopy) * 100.

Figure 3.4: A LI-COR Model LI-250 Line Quantum Sensor was used to determine the % transmitted PAR in the 'Crimson Seedless' fruiting zone during the 2010/11 and 2011/12 seasons.

3.2.6 Carbohydrate reserve measurements

3.2.6.1 Vine material and sampling

One year-old winter shoot material was collected during the dormancy period (August 2012) for analysis of starch and sugar content. The material was stored at 0°C. The material was dried by placing it in an 80°C oven for 72 hours. During September 2012, the samples were then ground to a powder using a ring grinder (Rock labs) and stored at -86°C until analysis.

3.2.6.2 Extraction of total sugars

The dried samples were ground and 0.1 g of sample was placed into Kimix tubes (polystryrene10 x 4 x 45 mm 2 mL) and 5 mL of 80% ethanol (EtOH) was added to the sample. The sample with the 80% EtOH was vortexed three times and placed on a heating block for 60 min at 80°C. Following heating, samples were centrifuged for 10 min at 3500 rpm and the supernatant was decanted into marked glass vials. Another 5 mL of 80% EtOH was added to the same pellet and vortexed three times.

The samples were once again placed on a heating block for 30 min at 80°C, centrifuged for 10 min at 3500 rpm and the supernatant was decanted into the same marked glass vials. A third 5 mL 80% EtOH was added to the centrifuged sample and the heating block was set for 15 min at 80°C. Samples were then centrifuged for 10 min at 3500 rpm. Finally, 5 mL of distilled H_2O (dH_2O) was added to the pellet and it was vortexed three times. Samples were once again centrifuged at 3500 rpm for 10 min and the supernatant was mixed and decanted into empty glass vials. The supernatant samples were then passed through 45 µm filters into 2 mL Eppendorff tubes.

3.2.6.3 Extraction of total starch

The heating block was set to 100°C and 2 mL of acetate buffer (pH 4.8) was added to the pellet, which was placed on the heating block for 60 min to gelatinize. After 60 min, the heating block with the tubes was cooled down to 60°C and after another 60 min, the samples were removed. Amyloglucosidase enzyme (2 mL) was added to the acetate buffer and pellet.

The tubes were then placed on the heating block for 18 h at 60°C. Samples were subsequently boiled for 5 min at 100°C in a water bath and then centrifuged for 12 min at 4000 rpm and 20°C. Samples (4 mL) were decanted into volumetric flasks and 1 mL dH_2O was added and mixed thoroughly. The samples were then filtered through 45 µm filters into newly marked Kimix tubes.

3.2.6.4 Sugar and starch analysis

For sugar and starch analyses, 20 µL of the soluble sugar supernatant and 30 µL of the starch supernatant were pipetted separately into glass tubes. Subsequently, 480 µL and 470 µL of dH_2O were added into the sugar and starch sample glass tubes, respectively, to make up to 500 µL. Before analysis, a glucose concentration range (of 0, 1, 2, 4, 6, 8 $\mu g.mL^{-1}$ glucose concentration) was included to construct a standard curve (Fig. 3.7). The tubes were placed on ice water while 1 mL of Anthrone reagent (1g Anthrone + 500 mL Sulphuric acid [H_2SO_4]) was added into each glass tube. Both the sample and standard tubes were vortexed and placed in a water bath at 100°C for 5 min, while stirring the samples every 30 seconds. After 5 min the samples were placed in ice water and then vortexed. The sample and standard solution were then decanted into newly marked cuvettes.

3.2.6.5 Analysis of sugars and starch

The anthrone method (Windell 2012) was used to determine the soluble sugars from enzyme digested starch. This method does not distinguish between reducing and non-reducing sugars, but is able to determine oligo-, di-and monosaccharides. The absorbance for the sugars and starch solution was measured at 620 nm using a Helios alpha spectrophotometer (Unicam UV-Vis spectrometry). Standards and extracts were analysed in triplicate. The sugar and starch concentration was quantified using the following equation: CONC (µg/mL glucose) = (ABS – b)/a, determined from a calibration curve (Windell 2012).

Where: ABS= Absorbance

a & b= values that are going to change for each spec output

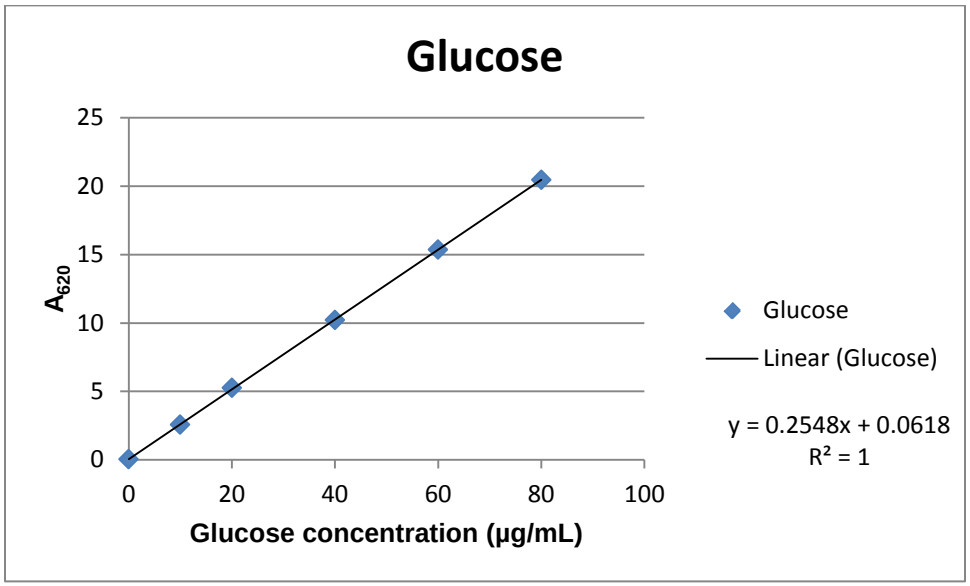

Figure 3.5: A-anthrone reagent glucose standard curve.

3.2.7 Determination of grapevine bud fruitfulness

3.2.7.1 Trial 1: Forcing bud break in glasshouse

Forced budding was used to get an early indication of the number of inflorescences per cane (bud fruitfulness) (Khanduja and Abbas 1973) and to evaluate the effect of defoliation on inflorescence number per cane (Bennett 2002).

Five dormant shoots representative of a typical cane were collected from each repetition during winter pruning (August) in both the 2010/11 and 2011/12 seasons and stored at 0°C until they were put into the glasshouse. These dormant shoots were sectioned into single node cuttings and placed in water trays (Fig. 3.6) in a glasshouse, at 25°C, until the inflorescence was noticeable and then recorded (Fig. 3.7). The number of inflorescences was counted once sufficient shoot growth had occurred. Within two months, the buds on the cuttings burst, but the inflorescences were not visible. This trial was conducted in both the 2010/11 and 2011/12 seasons and power failure in both

seasons resulted in the failure of the air conditioning system resulting in excessively high temperatures in the glasshouse.

Figure 3.6: The single node cuttings of ‘Crimson Seedless’ in water trays in a heated glasshouse in the dormant stage.

Figure 3.7: Single node cuttings of ‘Crimson Seedless’ in water trays after bud burst in a heated glasshouse.

3.2.7.2 Trial 2: Bud dissection analysis

Producers are constantly under pressure to implement precision viticulture to produce grapes with a high quality and therefore bud dissection was introduced (Sanderson 2003). This method provides two types of information, assessing bud fruitfulness and predicting yield of a specific block (Rawnsley and Collins 2005). This information can also be used to estimate the cluster counts, which may develop from each node and to allocate an appropriate number of canes to obtain a desirable yield at harvest (Khanduja and Abbas 1973; Rawnsley and Collins 2005; Orth and Van Rensburg 2011; Vasquez and Fidelibus 2011; Williams 2012). This method can also be used to set pruning objectives during winter and can assist producers to control the variation in fruitfulness amongst cultivars (Sanderson 2003).

Plant material was collected after pruning during the dormant period (August) in both the 2010/11 and 2011/12 growing seasons. Dormant canes were collected according to the following parameters: healthy, fully mature, round and medium size. Two dormant canes from each treatment that contained 10 buds were used for grapevine bud dissection. Canes were marked according to the treatments and replicates. Each bud was dissected individually, with a cross sectional cut, starting at the top and moving to the interior of the compound bud. After the interior of the compound bud was revealed and viewed under a stereo microscope, fruitfulness was determined by counting the flower cluster primordia in the primary bud.

3.2.7.3 Trial 3: Actual bud bursting and fruitfulness in the vineyard

Actual budding was determined by counting the number of buds which burst during spring on each cane that was left following winter pruning. Actual fruitfulness was determined by the number of buds on each cane and identifying how many bunches developed on each shoot. This was considered a more precise method to determine bud fruitfulness, because the actual bunch can be seen and thus, it is possible to

determine potential yield. This evaluation was carried out in both the 2011/12 and 2012/13 growing seasons.

3.3 STATISTICAL ANALYSES

Data collected throughout the seasons were subjected to statistical analyses by means of the SAS program, version 8.2 (SAS Institute Inc., 1999). PAR transmittance was analysed using comparisons within dates/days. The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk 1965). The treatment means were compared by using Student`s t-test for Least Significant Difference (LSD) were calculated at a 5% significant level.

3.4 RESULTS

3.4.1 LA measurements

Table 3.2 details the LA per vine, which remained on vines and was removed from vines by the S_{33} and S_{66} treatments after harvest in both the 2010/11 and 2011/12 seasons. Although the data show no significant differences between the treatments, values for the total % LA/vine removed had a tendency to be lower in both the S_{33} and S_{66} treatments in the 2011/12 season compared with the 2010/11 season.

Table 3.2: Comparison of LA between the S_{33} and S_{66} treated vines of *Vitis vinifera* L. cv. 'Crimson Seedless' after harvest during the 2010/11 and 2011/12 seasons.

	2010/11		2011/12	
Treatments	**S_{33}**	**S_{66}**	**S_{33}**	**S_{66}**
Remaining total LA/vine (cm^2)	* 113192 a	135197 a	* 84068 a	101079 a
Remaining total main shoot LA/vine (cm^2)	55905 a	61833 a	74659 a	93238 a
Remaining total lateral shoot LA/vine (cm^2)	57287 a	73364 a	9409 a	7842 a
Removed total % LA/vine	55.06 a	51.99 a	24.11 a	34.16 a
Removed total main shoot LA/vine (cm^2)	37945 a	41573 a	17259 a	32005 a
Removed total lateral shoot LA/vine (cm^2)	24245 a	24048 a	2767.2 a	3039.6 a

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest

3.4.2 Transmitted PAR measurements

The data collected in both, the 2010/11 and 2011/12 seasons, as measured from after harvest with the LI-COR Model LI-250 Line Quantum Sensor (Li-Cor Inc., Lincoln, Nebraska, USA), show that there was a significant difference between the shoot removal treatments and the control (Table 3.3).

Regarding the S_{33} and S_{66} treatments applied after harvest (24/03/2011) in the 2010/11 season, the transmitted PAR in the S_{66} treated vines was significantly higher compared with the control (28 March 2011). The transmitted PAR was also significantly higher in the S_{33} and S_{66} treated vines relative to the control from 4 April 2011 until 3 June 2011. Compared with the control, LS treated vines showed a significant increase in transmitted PAR during the period from 14 November 2011 (flowering/set) until 27 January 2012 (after berry thinning), while an increase in transmitted PAR was obtained in the RSB treatments for 14 and 25 November 2011 (Table 3.3). LS and RSB treatments were only applied after berry set in the 2011/12 season (31/10/2011).

Table 3.3: Effect of shoot removal treatments on % PAR transmission through the canopy of *Vitis vinifera* L. cv. 'Crimson Seedless' during the 2010/11 and 2011/12 seasons.

Treatments	Control	S_{33}	S_{66}	LS	RSB
28-Mar-11	* 7.29 b	13.72 ab	20.66 a	7.09 b	6.37 b
4-Apr-11	4.41b	13.49 a	18.42 a	4.51 b	4.12 b
10-May-11	6.34 b	16.30 a	21.27 a	5.36 b	6.65 b
3-Jun-11	19.51 c	26.97 b	35.85 a	19.06 c	22.66 bc
14-Nov-11	5.56 b	9.29 ab	10.17 ab	11.60 a	14.06 a
25-Nov-11	4.10 c	7.71 abc	5.85 bc	11.47 a	9.97 ab
27-Jan-12	4.63 b	4.08 b	5.71 ab	9.65 a	7.53 ab
28-Feb-12	4.90 a	8.07 a	7.43 a	6.94 a	7.91 a

*Means with the same letter for each day of measurement (within a row) do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

LS and RSB treatments were only applied after berry set in the 2011/12 season (31/10/2011)

3.4.3 Carbohydrate reserve measurements

Cane carbohydrate analysis revealed that S_{33} and S_{66} treatments applied after harvest in both the 2010/11 and 2011/12 seasons did not have a significant effect on the starch and sugar concentration in canes. However, there was a tendency for decreased carbohydrate concentration in the S_{33} and S_{66} treated vines relative to the control (Table 3.4).

Table 3.4: Effect of S_{33} and S_{66} treatments on the concentration of starch and sugar in canes of *Vitis vinifera* L. cv. 'Crimson Seedless', sampled at pruning, during the 2011/12 season.

Treatment	Control	S_{33}	S_{66}
Starch(µg/g DM)	* 3.12 a	2.26 a	2.14 a
Sugar(µg/g DM)	1.15 a	0.5 a	1.01 a

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest

3.4.4 Bud break and actual bud fruitfulness

Although all single node cuttings burst in the heated glasshouse, there was insufficient growth in the canes for inflorescence development. This was due to problems with the functioning of air conditioners inside the glasshouse as a result of constant power failures. During power failures, the air conditioner was unable to start and the temperature in the glasshouse reached 40°C, which led to the scorching of buds and new vine growth. A large number of the single node cuttings (98% in total) were affected (the shoots died before a final assessment of bud fruitfulness could be made).Therefore the data obtained is not a reliable reflection of the actual fruitfulness and is not presented. Regarding the microscopic bud dissection, bud fruitfulness results obtained showed that there were no significant differences between shoot removal treatments when percentage inflorescence per cane was determined (Tables 3.5 & 3.6).

The percentage bud burst was significantly reduced in the S_{33} treated vines compared with the control in the 2011/12 season but it was not significantly different in the following season. However, the percentage bud burst was significantly higher in the LS treatments compared with the S_{33} treated vines in the 2011/12 (Table 3.5) season. Bunch number per shoot in the RSB treated vines were significantly higher compared

with the LS treated vines after berry set during the 2012/13 season. Bud burst percentage was also significantly improved in S_{33} treated vines compared with the S_{66} treated vines in the 2012/13 season (Table 3.6). The bunch number per shoot did not differ significantly between treatments in the 2011/12 season.

Table 3.5: Effect of shoot removal treatments on bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless' during the 2011/12 season.

Treatments	**Control**	**S_{33}**	**S_{66}**	**LS**	**RSB**
% Bud burst (vineyard)	* 95.23 a	86.22 b	89.93 ab	95.51 a	89.29 ab
Inflorescence primordia number per sprouted bud (vineyard)	0.68 a	0.57 a	0.54 a	0.62 a	0.67 a
Inflorescence primordia number per shoot (vineyard)	4.53 a	3.93 a	4.33 a	3.67 a	4.13 a
Number of flower cluster primordia per bud (bud dissection)	0.35 a	0.33 a	0.38 a		

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

LS and RSB treatments were only applied after berry set in the 2011/12 season (31/10/2011)

Table 3.6: Effect of shoot removal treatments on bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless' during the 2012/13 season.

Treatments	Control	S_{33}	S_{66}	LS	RSB
% Bud burst (vineyard)	* 85.40ab	88.72 a	81.82 b	85.57ab	87.56 ab
Inflorescence primordia number per sprouted bud (vineyard)	0.44 a	0.47 a	0.47 a	0.32 a	0.51a
Inflorescence primordia number per shoot (vineyard)	3.10 ab	3.50 a	3.27 ab	2.03 b	3.83 a
Number of flower cluster primordia per bud (bud dissection)	12 a	22.00 a	14 a		

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

LS and RSB treatments were only applied after berry set in the 2011/12 season (31/10/2011)

3.5 DISCUSSION

3.5.1 LA measurements

The non-significant differences between LA parameters were not expected. It was expected that the LA/vine removed would be significantly higher in the S_{66} treated vines compared with the S_{33} treated vines due to more shoots with leaves being removed. It was also expected that the remaining LA/vine would be significantly higher in the S_{33} treated vines relative to the S_{66} treated vines due to less shoots being removed. Although not significant, the remaining total LA per vine (cm^2) in the S_{33} treated vines had a tendency to be lower compared with the S_{66} treated vines in both the 2010/11 and 2011/12 seasons. This is probably due to the severe shoot removal practice in the S_{66}

treated vines. There is little literature available on shoot removal after harvest and its effect on bud fruitfulness, whereas a wide range of research was done on defoliation from bud burst until harvest with the aim to improve fruit set, berry size, fruit maturation and vine yield (Hunter and Visser 1990; Ferree et al. 2000; Bennett 2002; Bennett et al. 2005; Strydom 2006; Vasconcelos et al. 2009; Human 2010; Palliotti et al. 2011). Therefore, no conclusion can be made that shoot removal practices after harvest increase or decrease bud fruitfulness.

3.5.2 Transmission of PAR measurements

Although there were no significant differences between treatments when considering the LA removed, there was a significant increase in PAR transmission in the S_{33} and S_{66} treated vines after harvest compared with the control. The improvement in PAR in the LS and RSB treated vines compared with the control after berry set was also due to defoliation. Shoot removal therefore resulted in more PAR being transmitted through the canopy. The improvement in PAR transmission due to defoliation on its own is in line with previous research as this has been found in other studies (Buttrose and Hale 1973; Smart 1974; Kriedemann 1977; Smart 1982; Smart et al. 1982; Smart 1985; Bledsoe et al. 1988; Hunter and Visser 1988; 1989; 1990; Hunter et al. 1995; Poni et al. 2003; Poni et al. 2006).

Although there was a significant improvement in PAR transmission through the canopies following application of the shoot removal treatments, bud initiation was not affected. The initiation of cluster primordia for the 2011/12 season`s crop occurred during flowering in the 2010/11 season, therefore these treatments could not have affected the initiation process, but could have affected the differentiation process that occurred between November 2010 and May 2011. Canopy shade during the summer can reduce flower initiation and differentiation that can have a negative effect on the yield by decreasing bunch size (Buttrose 1973, Carrol 2011). It is therefore important buds receive sufficient light during flowering to improve the initiation and differentiation of grapevine inflorescence primordia (Sánchez and Dokoozlian 2005). This explanation

is consistent with the timing of inflorescence initiation (period between 12-15 days before bloom to 25 days after bloom) reported by Swanepoel and Archer (1988). Thus, although shoot removal improved PAR transmission through the canopy, bud fruitfulness was not affected in both the 2011/12 and 2012/13 growing seasons.

3.5.3 Carbohydrate reserve measurements

The decline in starch and sugar that was evident in the S_{33} and S_{66} treated vines may be an indication that shoot removal after harvest (early defoliation) lowers the starch and sugar concentration in canes. If the experiment had continued for more seasons it is possible that this decline in sugar and starch may have led to a negative impact on bud fruitfulness. The above statement is supported by previous studies, which found that defoliation removes a significant source of photosynthates for carbohydrate accumulation and therefore bud fruitfulness (Candolfi-Vasconcelos and Koblet 1990; Bennett et al. 2005). A similar study by Koblet (1996) showed that the reduction in photosynthate supply is not the only reason for the reduction in carbohydrate reserves. This can also be due to stress resulting from shoot removal which causes the vine to utilize reserve carbohydrates for fruit maturation (Koblet 1996). Studies therefore confirm that there is a link between carbohydrates, bud fruitfulness and yield (Thomas and Barnard 1937; May 1965; Scholefield et al. 1977; Candolfi-Vasconcelos and Koblet 1990; Hunter et al. 1995; Sommer et al. 2000), but this was not evident in this study.

3.5.4 Determination of grapevine bud fruitfulness

Shoot removal treatments had no effect on Inflorescence primordia number per shoot (bud fruitfulness) in both the 2011/12 and 2012/13 seasons. However, the increase in inflorescence primordia number per shoot in the RSB treated vines in the 2012/13 season may have been the result of the LS treatments where inflorescence primordia were removed that were attached to these shoots. These results are not consistent with other studies, which show that bud fruitfulness is sensitive to a certain degree of defoliation (May et al. 1969; Candolfi-Vasconcelos and Koblet 1990). Hunter and Visser

(1990) also found that 66% defoliation on 'Cabernet Sauvignon' vines reduced inflorescence numbers compared with 33% defoliation at berry set. In addition, May (1969) demonstrated with 'Sultana' vines that full defoliation of shoots resulted in a reduction in inflorescence numbers. The reduction in the percentage bud burst in the S_{33} treated vines in the 2011/12 season can be ascribed to the 33% shoot removal after harvest in the 2010/11 season. May (1969) also found that severe defoliation is the primary cause of the reduction in the percentage bud burst. Results in this study showed that there was no relationship between the reduced bud burst and carbohydrate concentration in canes. This might have been due to a reduction in photosynthesis due to the removal of shoots after harvest. However, Bennett (2002) found that percentage bud burst increased with an increase in starch and a variation in carbohydrate within canes could result in a reduction in bud burst in the following season. Results obtained from the actual budding and fruitfulness evaluations in the vineyard showed that shoot removal treatments did not improve bud fruitfulness.

It was expected that similar results would be obtained from the two methods for accessing bud fruitfulness due to the evaluation of the same cultivar. In this case reliable data could not be obtained with the glasshouse trial, due to the fact that 98% of the single node cuttings died before a final assessment of bud fruitfulness could be made (as describe in 3.4.4). Hunter (2002) used the same glasshouse technique (single node cuttings) and found that an increase in defoliation reduced the number of inflorescences per vine, which will have a negative effect on yield. In addition, Candolfi-Vasconcelos and Koblet (1990) reported that data obtained from single node cuttings in glasshouses may not accurately represent actual fertility in the vineyard. Bennett (2002) also found that results from single node cuttings repetitively under-or-over predict inflorescence number per cane. Forced bud break in glasshouses are recommended to be used to estimate potential fruitfulness of a cultivar. Actual fruitfulness in the vineyard should always be determined, to validate the results obtained in the glasshouse, because various factors may affect the differentiation of flower cluster primordial into flower clusters with completely developed individual flowers (in the period from bud break until flowering).

3.6 CONCLUSIONS

Shoot removal practices performed after harvest and berry set improved PAR transmission throughout the canopy. However, the improvement in PAR transmission through vines did not result in an increase in bud fruitfulness. Whilst previous studies have indicated that bud fruitfulness can increase as a result of shoot removal, it is possible that a fine balance exists between the removal of leaves and an increase in fruitfulness. It is therefore possible that in this study too many leaves were removed which could have impacted the photosynthetic capacity of the vines.

The study also showed that RSB treatments, by only removing unproductive shoots, had the greatest effect on bunch number per shoot when compared with LS treatments. S_{33} and S_{66} treatments did not affect the carbohydrate content in canes and therefore bud fruitfulness. However, the impact of these practices on the carbohydrate content of vines may only become significant after a number of seasons. A longer term experiment, which includes glasshouse evaluation of bud fruitfulness and varying degrees of shoot removal, should allow for a much greater understanding of how these treatments impact bud fruitfulness. Repeating the experiment for at least three seasons in a warmer region and a more vigorous growing “Crimson Seedless” block with a longer growing season, may also contribute to the knowledge and understanding of the effect of shoot removal on overwintering carbohydrate content and actual bud fruitfulness.

The results of this study suggest that shoot removal improve PAR transmission through the vine, but further studies on the effect of shoot removal after harvest on overwintering carbohydrate content in canes and therefore bud fruitfulness is necessary.

CHAPTER 4

EFFECT OF SHOOT REMOVAL TREATMENTS ON GRAPEVINE YIELD AND QUALITY

4.1 INTRODUCTION

Defoliation, involving the removal of shoots and leaves, is a viticultural practice widely used throughout production areas in the world. This practice has several major advantages, such as improving fruit quality, grape composition, disease prevention and bud fruitfulness (Human 2010). It also advances ripening and harvesting time of grapes and contributes to obtaining a beneficial vine structure (Strydom 2006). However, defoliation can have a negative effect on photosynthesis and the replenishment of storage reserves such as carbohydrates (Bennett 2002). This practise should therefore be carefully considered as a canopy management practice (Hunter and Visser 1990). In order to determine the underlying mechanisms for the possible increase in bud fruitfulness as a result of defoliation, the components determining yield were evaluated.

According to Bennett (2002), several factors determine the potential yield of a specific vine. Many of the yield components outlined in Figure 4.1 may be negatively affected by the intensity and timing of shoot removal (Bennett 2002). Firstly, yield is determined by the total number of inflorescence primordia per latent bud formed in a specific season. Secondly, the number of inflorescences per vine is determined by the number of buds, which develop into shoots in the following season. Thirdly, the number of flowers formed on each inflorescence will determine the potential number of berries at fruit set per bunch, but only a certain proportion of these flowers will give rise to berries at fruit set. The yield will be determined by berry size, as berry mass multiplied by the number of berries will determine the bunch mass. Yield per vine is determined by multiplying the mass per bunch by the number of bunches (Bennett 2002).

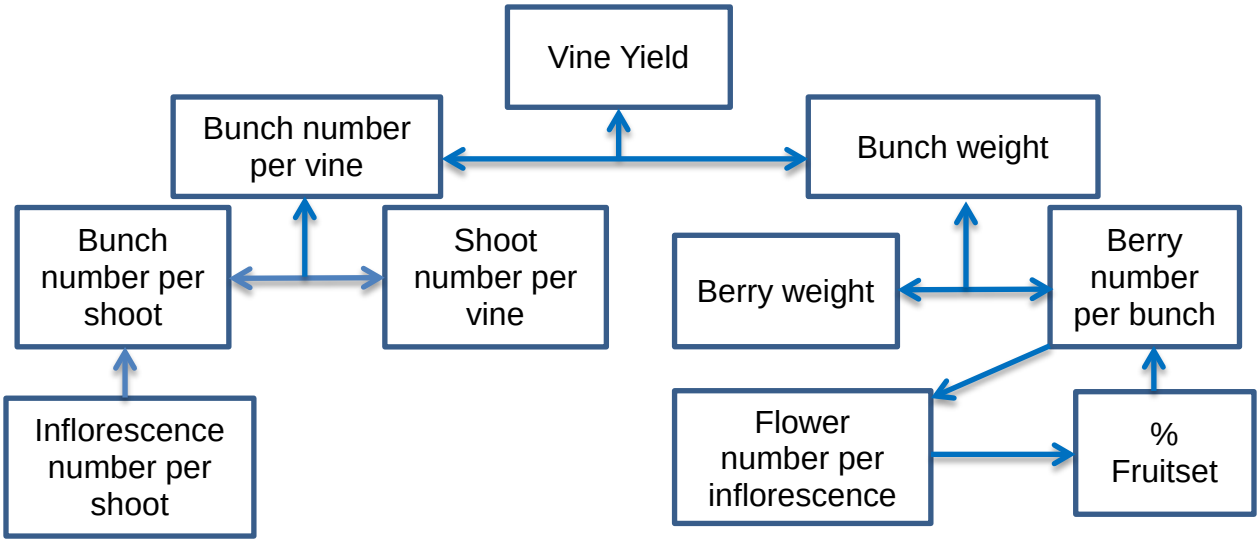

Figure 4.1: The components of grapevine yield (Bennett 2002).

The objective of this study was to evaluate the effect of shoot removal treatments on grapevine yield and quality. It was therefore hypothesized that the removal of shoots after harvest and berry set will improve yield and quality of *Vitis vinifera* cv. 'Crimson Seedless'. To test this hypothesis a series of shoot removal treatments were applied to vines in an attempt to improve yield and quality.

4.2 MATERIALS AND METHODS

4.2.1 Experimental vineyard

The trial was conducted over the 2010/11-2012/13 growing seasons, in a block located on the Hex River Valley experimental farm of the ARC Infruitec-Nietvoorbij (33°47'S,19°67'E and Alt. 457 m), near De Doorns in the Hex River Valley in the Western Cape, South Africa (Fig. 3.1). The region is classified as a Mediterranean area, with warm dry summers and cold wet winters. The experimental vineyard was a 11-year-old commercial block *Vitis vinifera* L. cv. 'Crimson Seedless' vineyard, grafted on 'Ramsey' (*V. champinii*) rootstock. The vine spacing was 1.8 m in east/west orientated rows, with 2.8 m between rows (~ 1984 vines/ha). 'Crimson Seedless' vines were

trained on a Trentina trellising system with a short double split cordon. The Trentina trellis system consists of nine cordon wires, with cordon wires spaced 30 cm apart (Fig. 3.2). Other viticultural practices for the block were according to commercial standards. The vines were pruned with six canes, selected as fruit bearers, each containing ten buds and a spur at each cane. The average long-term February temperature in the month in which berries ripen, from 1963 to 2002 was 21.8°C. The Hex River Valley is classified as Region III, which is classified as a moderately warm and suitable region for the production of red and black cultivars (Strydom 2006).

4.2.2 Experimental design

Details of the experimental design are given in Chapter 3, section 3.2.2.

4.2.3 Shoot removal treatments

Shoot removal after harvest is commonly used by producers in the Orange River region to improve bud fruitfulness and therefore yield. Five treatments were applied: Control (no shoot removal), 66% shoot removal ($S_{66,}$ starting at the base and moving up to the end of the cordon arm, two shoots were removed after every shoot), 33% shoot removal ($S_{33,}$ starting at the base and moving up to the end of the cordon arm, one shoot was removed after every two shoots, LS (all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot) and RSB (all unproductive shoots were removed). Sucker removal was conducted during the 2010/11 season, whereby shoots in unfavourably positions were removed before the treatments after harvest were applied. These missing shoots were included in the S_{33} and S_{66} treatments.

Both the S_{33} and S_{66} treatments were applied after harvest in both the 2010/11 and 2011/12 seasons (Table 3.1). LS and RSB treatments were applied after berry set in both the 2011/12 and 2012/13 seasons (Table 3.1). The basal three shoots or future bearing shoots on each cordon were retained to ensure enough bearing shoots for the following season. The aim of S_{33}, S_{66} and RSB treatments were to improve the

transmittance of PAR through the vine and for the S_{33} and S_{66} treatments to improve the carbohydrate reserve levels in canes. The aim of the LS treatment was to obtain new lateral shoots that develop during a later period, which would be exposed to more favourable solar radiation after berry set thereby improving bud fruitfulness of 'Crimson Seedless'.

4.2.4 Pruning mass measurements

After winter pruning, the length of each of the six canes (ten nodes each) that were selected as fruit bearers and their accompanying spurs, as well as the length and mass of removed canes of the data vines were measured. The winter pruning data was used to determine the leaf area (LA) parameters in both the 2010/11 and 2011/12 seasons.

4.2.5 Grape collection, measurement and analyses

Grapes from the 'Crimson Seedless' block were harvested when quality parameters, such as sugar, colour, acidity and flavor have reached optimal levels during March in both the 2011/12 and 2012/13 seasons. At harvest, 50 berries were randomly selected from each treatment replicate for berry mass and juice analyses. These berries were placed in plastic bags and stored at -0.5°C until further use. Total soluble solids (TSS) were determined by crushing these berries and using a digital Atago abx-30 refractometer (Palette 101; Atago, Farmingdale, NY) and expressed as °Brix. The total titratable acidity (TA) and pH were determined from the same extract using a Mettler DL21 titrator (Mettler Toledo, Swizerland).

The method described by Strydom (2006) was used to determine grape skin anthocyanins and phenolics. The skins of the collected berries were removed from the flesh, after which it was freeze-dried and finally grounded. A solution (50% methanol: water; pH 2 with HCl) of ten mL of an acidified hydro-alcohol was added to 500 mg of the berry skin. The extract was centrifuged (1300 rpm, 5 min) and supernatant retained. A Helios alpha spectrophotometer (Unicam UV-Vis spectrometry) was used to

determine the absorbance for the extracts from the crushed berries at A520 nm, A420 nm and A280 nm. Measurements at A520 nm represent anthocyanins, A420 nm represent total yellow brown pigments and A280 nm represents compounds such as flavonols, tannins and other simple phenolics.

Only bunches from data vines were harvested, counted and weighed to determine the total yield per vine (kg/vine) during both the 2011/12 and 2012/13 seasons. Bunches were classified in four classes according to the total amount of fully coloured berries (Table 4.1), ranging from 0%-25% (class 1), 25%-50% (class 2), 50%-75% (class 3) and 75%-100% (class 4), with class 1 being bunches that are poorly coloured (Fig. 4.2) and class 4 being fully coloured (Fig. 4.3). After these measurements were collected, bunches preferable for the export markets were sent to the packing facility for further packing and exporting (class 4).

Table 4.1: Classes and description of bunches of *Vitis vinifera* L. cv. 'Crimson Seedless' according to the amount of fully coloured berries in both the 2011/12 and 2012/13 seasons.

Classes	**Description**
75%-100% (class 4)	Between 75% & 100% of total berries on bunches were fully coloured (good quality, most desired colour development for export)
50%-75% (class 3)	Between 50% & 75% of berries on bunches were fully coloured
25%-50% (class 2)	Between 25% & 50% of berries on bunches were fully coloured
0%-25% (class 1)	Between 0% & 25% of total berries on bunches were fully coloured (poor quality, less desired colour for export)

Figure 4.2: A typical class 1 (0%-25%) ‘Crimson Seedless’ bunch with poor colour development (Anon. 2015).

Figure 4.3: A typical class 4 (75%-100%) ‘Crimson Seedless’ bunch with full colour development, preferable for export market (Anon. 2015).

4.3 STATISTICAL ANALYSES

The data collected throughout the seasons were subjected to statistical analyses by means of the SAS program, version 8.2 (SAS Institute Inc., 1999). The Shapiro-Wilk test was performed to test for non-normality (Shapiro and Wilk 1965). The treatment means were compared by using Student`s t-test for Least Significant Difference (LSD) were calculated at a 5% significant level.

4.4 RESULTS

4.4.1 Pruning measurements

The pruning data (Table 4.2) collected after pruning (August 2011 & 2012), showed that cane mass in the S_{33} and S_{66} treatments were significantly decreased compared with the control treatments during the 2010/11 growing season. In addition, there were no significant differences in cane mass amongst all shoot removal treated vines compared with the control in the 2011/12 season. However, cane mass was significantly increased in the LS treated vines compared with the S_{66} treated vines in the 2011/12 season. The length of the rest of the main canes (m) in the S_{66} treated vines was significantly reduced compared with the control in the 2011/12 season.

4.4.2 Yield and quality measurements

At harvest there were no significant differences in bunch mass per vine between the control and various shoot removal treatments applied throughout the growing seasons. However, in the 2011/12 season total bunches for export and mass of export bunches were significantly lower in the LS treatments compared with the control (Table 4.3).

The study also showed that class 1 (poorly colour) bunches were significantly lower in LS treated vines compared with the control in both seasons. In addition, LS treated vines had a significant increase in class 4 bunches relative to the control in the 2012/13 season (Table 4.3).

Table 4.2: The effect of shoot removal treatments on pruned off material of *Vitis vinifera* L. cv. 'Crimson Seedless' during the 2010/11 and 2011/12 seasons.

	TREATMENTS	Control	S_{33}	S_{66}	LS	RSB
2010/11	Length of the rest of the main canes (m)	* 6.36 b	6.82 b	6.57 b	15.05 a	#
	Length of lateral canes on the rest of the main canes (m)	20.75 a	14.24 a	14.69 a	20.07 a	#
	Cane mass (kg)	1.98 b	1.44 c	1.57 c	2.45 a	#
	Length of new canes (m)	4.54 ab	4.21 b	5.63 a	3.98 b	#
2011/12	Length of the rest of the main canes (m)	* 34.09 a	27.94 bc	26.51 c	31.85 ab	27.77 bc
	Length of lateral canes on the rest of the main canes (m)	2.03 a	2.69 a	2.11 a	3.45 a	2.34 a
	Cane mass (kg)	1.43 ab	1.33 ab	1.08 b	1.75 a	1.38 ab
	Length of new canes (m)	4.85 ab	4.86 ab	4.93 ab	5.38 a	4.45 b

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

LS and RSB treatments were only applied after berry set from the 2011/12 season (31/10/2011)

#Pruning data for the RSB treatments was only collected from after berry set in the 2011/12 season

Table 4.3: Effect of shoot removal treatments on grape yield and ripening parameters of *Vitis vinifera* L. cv. 'Crimson Seedless' after harvest during the 2011/12 and 2012/13 growing seasons.

	2011/12						2012/13				
Treatments	**Control**	**S_{33}**	**S_{66}**	**LS**	**RSB**		**Control**	**S_{33}**	**S_{66}**	**LS**	**RSB**
Bunch mass per vine (g)	* 428.03 a	417.22 a	422.4 a	431.21 a	454.13 a		228.24 a	225.23 a	222.35 a	255.40 a	217.80 a
Total bunches for export	36.1 a	31.4 ab	33.6 a	26.7 b	31.8 ab		20.4 a	20.3 a	16.7 a	17.5 a	21.3 a
Total mass of export bunches (kg)	15.21 a	13.08 ab	14.06 ab	11.25 b	14.22 ab		9.17 a	9.02 a	7.74 a	7.43 a	10.49 a
Mean berry mass (g)	4.00 a	4.10 a	4.14 a	4.25 a	3.89 a		4.75 a	5.13 a	4.92 a	4.93 a	4.70 a
CLASS 1 (%)	1.63 a	0.31 ab	1.44 ab	0 b	0.57 ab		6.36 a	0.89 ab	1.03 ab	0 b	3.25 ab
CLASS 2 (%)	3.13 a	3.37 a	1.57 a	0.70 a	1.64 a		1.20 a	0.40 a	0 a	0 a	0 a
CLASS 3 (%)	25.34 a	29.33 a	29.13 a	15.64 a	30.32 a		0.80 a	0 a	0 a	0 a	0 a
CLASS 4 (%)	60.44 a	66.99 a	67.87 a	83.66 a	67.47 a		91.64 b	98.71 ab	98.97 ab	100 a	96.75 ab

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

Class 1: 0%-25% berries fully coloured, class 2: 25%-50% of berries fully coloured, Class 3: 50%-75% of berries fully coloured, Class 4: 75%-100% of berries fully coloured

4.4.3 Berry composition measurements

There were no significant differences in pH and TA between the control and various shoot removal treatments in both the 2011/12 and 2012/13 seasons. TSS was significantly higher in LS treated vines compared to S_{66} treated vines in the 2011/12 season. The total red pigments were also significantly higher in LS treated vines compared to the control in the 2011/12 season. Data show that there were no significant differences between shoot removal treatments and the control when total phenolics were determined. However, total phenolics were significantly higher in the LS treated vines compared to the RSB treated vines during the 2011/12 season (Table 4.4).

Table 4.4: Effect of shoot removal treatments on fruit quality parameters of *Vitis vinifera* L. cv. 'Crimson Seedless' after harvest during the 2011/12 and 2012/13 growing seasons.

	2011/12						2012/13				
Treatments	**Control**	**S_{33}**	**S_{66}**	**LS**	**RSB**		**Control**	**S_{33}**	**S_{66}**	**LS**	**RSB**
pH	3.62 a	3.65 a	3.66 a	3.71 a	3.65 a		3.64 a	3.74 a	3.55 a	3.55 a	3.50 a
TA (g/L)	4.01 a	4.05 a	3.92 a	3.82 a	3.96 a		4.54 a	4.61 a	4.53 a	4.59 a	4.55 a
TSS (°Brix)	47.16 ab	46.86 ab	45.88 b	52.13 a	47.06 ab		45.00 a	44.31 a	45.82 a	45.27 a	43.64 a
Total red pigments (A520)	1.40 b	1.49 ab	1.58 ab	1.68 a	1.62 ab		1.17 a	1.18 a	1.23 a	1.27 a	1.26 a
Total yellow brown pigments (A420)	1.07 a	1.11 a	1.14 a	1.31 a	1.03 a		1.12 a	1.13 a	1.17 a	1.12 a	1.17 a
Total phenolics (A280)	0.95 ab	0.98 ab	0.95 ab	1.03 a	0.88 b		0 a	0 a	0.21 a	0.07 a	0.07 a

*Means with the same letter do not differ significantly from each other at the 5% significant level

S_{33} - 33% shoot removal after harvest; S_{66} - 66% shoot removal after harvest; LS - all main and lateral shoots developing from spurs were cut back to the nearest lateral shoot after berry set; RSB - all unproductive shoots were removed after berry set

4.5 DISCUSSION

4.5.1 Pruning measurements

Shoot removal after harvest was the primary cause of the reduction in cane mass in the S_{33} and S_{66} treated vines. These canes were also thinner compared to control vines (visual observation, data not presented). The higher cane mass in the LS treated vines compared to the S_{66} treated vines in the 2011/12 season, may be due to more shoots being removed after harvest in the S_{66} treated vines. In addition, the significant reduction in the length of the rest of the main canes in the S_{66} treatments relative to the control in the 2011/12 season may also be due to shoot removal earlier in the season (after harvest). The above results are supported by Longbottom (2007) and May (1969), who found a reduction in vegetative growth due to defoliation. Reynolds et al. (2005) also found a reduction in vegetative growth due to defoliation. The significant increase in PAR transmission in S_{33} and S_{66} treated vines during the 2010/11 and 2011/12 seasons can be related with the reduced cane mass in these treatments, allowing more PAR transmission through the canopy, as also found in other studies (Bennett et al. 2005; Strydom 2006; Human 2010). Therefore, no conclusions in this study can be made on the effect of shoot removal on pruning measurements and the subsequent yield.

4.5.2 Yield and quality measurements

Data from this study indicate that shoot removal treatments did not result in a significant difference in bunch mass per vine relative to the control. However, results do show a reduction in bunch mass per vine in all treatments from one season to the next and therefore it is unlikely to be the result of shoot removal in the previous season. The significant reduction in total bunches for export and mass of export bunches in the LS treated vines is also probably due to the removal of shoots after berry set, which might have contained bunches. Although the yield results in this study are not supported by May et al. (1996), who found that a reduction in yield as a result of the impact of

defoliation on vegetative growth (cane mass), this could be attributed to the differences in treatments between the two studies. Reynolds et al. (2005) also state that when shoots were removed at harvest, the carbohydrate content of the vine decreased which resulted in a reduction in crop load as well as vegetative growth in the following season. However, these findings are contradictory to a study conducted by Zoecklein et al. (1992) and Reynolds et al. (1996) who found that the removal of basal leaves did not influence yield.

Class 4 bunches was significantly increased by LS treatments in the 2012/13 season. This improvement can be related to an increase in PAR transmission through the canopy after berry set. These results are consistent with the findings of Hunter et al. (1995), Bennett (2002), Strydom (2006) and Human (2010) in studies where grape colour was improved due to an improvement in solar radiation as a result of defoliation. Therefore although shoot removal (LS) reduced the total bunches for export and mass of export bunches, colour of 'Crimson Seedless' grapes was improved.

4.5.3 Berry composition measurements

The increase in TSS in LS treatments compared to the S_{66} treatment might have been due to an improvement in PAR transmission. This supports the proposition that an increase in TSS is the result of the effect of shoot removal enhancing PAR transmitted through the canopy (Kliewer and Lider 1968; Bledsoe et al. 1988; Poni et al. 2006). These findings are contradictory to a study conducted by Andrade et al. (2005), who showed that the removal of basal leaves had no influence on TSS. The improvement in PAR transmission can also be linked to the increase in red pigments (anthocyanin), which can also be correlated with an increase in class 4 grapes (fully coloured). It was found by Kataoka et al. (2004), that an increase in light intensity due to defoliation can be beneficial for colour development, as increased light intensity results in an increase in anthocyanins. Hunter et al. (1991) also found an increase in anthocyanin in the berry skins of defoliated 'Cabernet Sauvignon' grapes. The above results show that applying defoliation at a specific development stage is important to improve various physiological

aspects, such as colour development (Human 2010). The amount of red pigments obtained in the 2011/12 season, in contrast to previous experiments, demonstrated that LS treatments late in the season can lead to an improvement in the colour of 'Crimson Seedless' grapes.

4.6 CONCLUSIONS

The results of this trial have shown that shoot removal after harvest and after berry set in the previous season does not improve bunch number per cane (bud fruitfulness) and hence vine yields. In addition, this trial has shown that although bud fruitfulness was not improved, grape quality such as colour was significantly improved by the LS treatments after berry set in the 2011/12 season.

Furthermore, vegetative growth was also shown to be reduced by defoliation early in the season and the primary factor responsible for this is shoot removal. Results in this study support previous studies that defoliation later in the season improves PAR transmission through the canopy, which leads to the improvement in grape colour and hence quality. In future studies, it should be investigated what effect shoot removal has on overwintering carbohydrate content and next season`s bud fruitfulness, when this experiment is repeated. These results may also contribute to the knowledge and understanding on how to improve bud fruitfulness and hence yield of "Crimson Seedless".

CHAPTER 5

GENERAL DISCUSSION AND RECOMMENDATIONS

'Crimson Seedless' is an important late season red table grape cultivar for the South African industry which fills a niche. Producers compete with other southern hemisphere countries such as Australia and Chile and producers need to produce a consistant yield, season after season, to be competitive. One of the key factors affecting the consistent yield of table grape cultivars is bud fruitfulness. Low bud fruitfulness can have a significant effect on table grape cultivars and 'Crimson Seedless' is characterized by a fruitfulness problem. Furthermore, in the table grape industry, yield, as well as fruit quality, are important to generate income. It is therefore important to apply practices to improve bud fruitfulness, yield and quality season after season to be competitive in the industry.

The general aim of this study was to evaluate the impact and usefulness of S_{33}, S_{66} treatments after harvest, and LS and RSB treatments after berry set on bud fruitfulness and yield of 'Crimson Seedless' grapes. The focus was firstly to investigate the effect of shoot removal on PAR transmission, carbohydrate content in canes and the subsequent bud fruitfulness, and secondly, to investigate the effect of shoot removal on grapevine yield and quality of 'Crimson Seedless'.

The first hypothesis of this study stated that the removal of shoots after harvest will increase the transmitted PAR through the canopy, increase carbohydrate reserve levels in canes and improve bud fruitfulness of 'Crimson Seedless'. The results obtained in this study showed that whilst shoot removal after harvest and berry set improve PAR transmission through the canopy, it did not have a significant effect on the carbohydrate concentration in canes and hence bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless'.

A second hypothesis of this study stated that the cut back of all main and shoots developing from spurs to the nearest lateral shoot and the removal of all unproductive

shoots after berry set will result in fruitful shoots the following season. It was shown in this study that there was not a significant increase in fruitful shoots and hence bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless' as a result of LS and RSB treatments after berry set.

The third and final hypothesis of this study stated that the removal of shoots after harvest and berry set will improve the yield and quality of *Vitis vinifera* L. cv. 'Crimson Seedless'. Bunch mass per vine results show a reduction in bunch mass per vine in all the treatments from one season to the next and therefore it is unlikely to be the result of shoot removal in the previous season. However, quality parameters such as colour was significantly improved by the LS treatments after berry set, which can be correlated with the improvement in PAR through the canopies.

A link between carbohydrate content and bud fruitfulness was not found in this study as S_{33} and S_{66} treatments did not have a significant effect on carbohydrate content in canes during the 2011/12 season. However, if the carbohydrate content in this trial did not have a tendency to be lower, treatments may have become significant, but after two seasons there were no significant changes in carbohydrate status in response to shoot removal treatments. Therefore, results in this study do not support the findings from other studies that shoot removal reduce the carbohydrate content in canes resulting in a decrease in bud fruitfulness and hence yield.

A reduction in bunch mass per vine was evident in all treatments including the control during the 2012/13 season and therefore no conclusions can be made regarding the impact of shoot removal treatments in the previous season on yield in the subsequent season. However, the significant reduction in total bunches for export and mass of total export bunches showed that the LS treatments after berry set can have a negative effect on the export total.

Considering the positive effect of LS treatments after berry set on total red pigments, it is clear that shoot removal, for the purpose of better colour development can be

conducted after berry set. In addition, the positive effect of LS treatments on quality parameters, such as colour, can be supported by the significant decrease in class 1 bunches (poorly coloured) in both the 2011/12 and 2012/13 seasons, representing an improvement in grape colour of 'Crimson Seedless'.

Thus, it is important to consider the amount of shoots being removed, as well as the reserve status of the vine if the producer wishes to avoid possible reduction in yield in the following season. This study illustrates that growers need to decide whether it is worthwhile to utilize labour for this practice and they must manage grapevines not only for the current seasons crop, but also for the next season and this can be accomplished by maintaining sufficient carbohydrates for fruitfulness and yield from season to season. Therefore, it is recommended that further studies on the effect of shoot removal after harvest and berry set on bud fruitfulness of *Vitis vinifera* L. cv. 'Crimson Seedless' should be continued.

6. REFERENCES

Abd E-razek E, Treutter D, Saleh MMS, El-Shammaa M, Amera A, Fouad, Abdel-Hamid N. 2011. Effect of nitrogen and potassium fertilizers on productivity and fruit quality of 'Crimson Seedless' grape. *Agriculture and Biology Journal of North America* 2 (2): 330-340.

Ali E. 2008. Effect of horticultural practices on improving productivity and fruit quality of 'Crimson Seedless' grapes. PhD Thesis, Technischen Universität München, Germany.

Al-Joumayly A. 2003. Fertility and flower cluster position of two grape cultivars (*Vitis vinifera*) in South Jordan. *Pakistan Journal of Biological Sciences* 6 (23): 1956-1960.

Al-Obeed RS, Kassem HA, Ahmed MA. 2010. Effect of grapevine varietal difference on bud fertility, yield and fruit quality under arid environments and domestic wastewater irrigation. *American-Eurasian Journal of Agricultural and Environmental Science* 9 (3): 248-255.

Andreini L, Viti R, Scaalabrelli G. 2009. Study on the morphological evolution of bud break in *Vitis vinifera* L. *Vitis* 48 (4): 153-158.

Anon. 2012. South African table grape industry trade newsletter. Available at [accessed 20 March 2012].

Anon. 2013. South African table grape industry. Available at http://satgi.co.za/pages/Production-Regions [accessed 25 June 2013].

Anon. 2015. Free grape growing tips and help to grow your own grapes. Available at http://www.my-grape-vine.com/blog/ [accessed 5 January 2015].

Antcliff AJ. 1965. A Comparison of cropping levels in the 'Sultana'. *Vitis* 5: 1-9.

Archer E. 2011. Verhoging van opbrengs by wyndruiwe1: Inleiding en die rol van effektiewe oë (deel 1). *Wynboer* 259: 69-71.

Ashley R. 2012. Grapevine nutrition- An Australian perspective. Available at http://ucanr.org/sites/nm/files/76731.pdf [access 3 April 2012].

Balasubrahmanyam VR, Eifert J, Diofasi l. 1978. Nutrient reserves in grapevine cane as influence by cropping levels. *Vitis* 17: 23-29.

Baldwin JG. 1964. The relation between weather and fruitfulness of the 'Sultana' vine. *Australian Journal of Agricultural Research 15: 920-928.*

Bates TR, Dunst RM, Joy P. 2002. Seasonal dry matter, starch, and nutrient distribution in 'Concord' grapevine roots*. HortScience* 37: 313-316.

Bennett JS. 2002. Relationships between carbohydrate supply and reserves and the reproductive growth of grapevines (*Vitis vinifera* L.). PhD thesis, Lincoln University, New Zealand.

Bennett J, Jarvis P, Creasy GL, Trought CT. 2005. Influence of defoliation on carbohydrate reserves, return on bloom, and yield of mature 'Chardonnay' grapevines. *American Journal of Enology and Viticulture* 56 (4): 386-393.

Bergqvist J, Dokoozlian N, Ebisuda N. 2001. Sunlight exposure and temperature effects on berry growth and composition of 'Cabernet Sauvignon' and 'Grenache' in the Central San Joaquin Valley of California. *American Journal of Enology and Viticulture* 52 (1): 1-7.

Bledsoe AM, Kliewer WM, Marois JJ. 1988. Effects of timing and severity of leaf removal on yield and fruit composition of 'Sauvignon Blanc' grapevines. *American Journal of Enology and Viticulture* 39 (1): 49-54.

Buttrose MS. 1970. Fruitfulness in grape-vines: The responds of different cultivars to light, temperature and day length. *Vitis* 9: 121-125.

Buttrose MS, Hale CR. 1973. Effect of temperature on development of the grapevine inflorescence after bud burst. *American Journal of Enology and Viticulture* 24 (1): 14-16.

Candolfi-Vasconcelos MC, Koblet W. 1990. Yield, fruit quality, bud fertility and starch reserves of the wood as a function of leaf removal in *Vitis vinifera*- Evidence of compensation and stress recovering. *Vitis* 29: 199-221.

Carbonneau A, Casteran P. 1979. Irrigation- depressing effect on floral initiation of 'Cabernet Sauvignon' grapevines in Bordeaux area. *American Journal of Enology and Viticulture* 30 (1): 3-7.

Carmona MJ, Chaïb J, Martinez-Zapater JM, Thomas MR. 2008. A molecular perspective of reproductive development in grapevine. *Journal of Experimental Botany* 59 (10): 2579-2596.

Carrol D. 2011. Grape bud fruitfulness. Available at http://aaie.net/wp-content/uploads/2012/10/Grape-fruitfulness-factors-12-9-2011.pdf [accessed 21 February 2011].

Cartechini A, Palliotti A. 1995. Effect of shading on vine morphology and productivity and leaf gas exchange characteristics in grapevines in the field. *American Journal of Enology and Viticulture* 46 (2): 227-234.

Caspari HW, Lang A, Alspach P. 1998. Effects of girdling and leaf removal on fruitset and vegetative growth in grape. *American Journal of Enology and Viticulture* 49 (4): 359-366.

Christensen P. 1975. Response of 'Thomson Seedless' grapevines to the timing of pre harvest irrigation cut-off. *American Journal of Enology and Viticulture* 26 (4): 188-194.

Christensen LP. 2013. Vine pruning. Available at http://iv.ucdavis.edu/files/24432.pdf [accessed 20 June 2013].

Clingerleffer PR. 1984. Production and growth of minimal pruned Sultana vines. *Vitis* 23: 42-54.

Coombe BG. 1995. Adoption of a system for identifying grapevine growth stages. *Australian Journal of Grape and Wine Research* 1 (2): 100-110.

Dokoozlian NK, Kliewer WM. 1996. Influence of light on grape berry growth and composition varies during fruit development. *Journal of the American Society for Horticultural Science* 121 (5): 869-874.

Dokoozlian NK, Peacock WL. 2001. Gibberellic acid applied at bloom reduce fruit set and improves size of 'Crimson Seedless' table grapes. *HortScience 3*6 (4): 706-709.

Dokoozlian N, Peacock B. 2012. Cultural practices for 'Crimson Seedless' table grapes. Available at http://cetulare.ucanr.edu/files/73923.pdf [accessed 15 July 2012].

Dry P. 2000. Canopy management for fruitfulness. *Australian Journal of Grape and Wine Research* 6: 109-115.

Edson CE, Howel GS, Flore JA. 1993. Influence of crop load on photosynthesis and dry matter partitioning of 'Seyval' grapevines I. Single leaf and whole vine response pre and post- harvest. *American Journal of Enology and Viticulture* 44 (2): 139-147.

Edwards EJ, Downie AF, Clingeleffer PR. 2011. Technical brief: A simple microplate assay to quantify nonstructural carbohydrates of grapevine tissues. *American Journal of Enology and Viticulture* 62 (1): 133-137.

Fawzi MIF, Shahin MFM, Kandil EA. 2010. Effect of bud load on bud behaviour, yield, cluster characteristics and some biochemical contents of the cane of 'Crimson Seedless' grapevines. *Journal of American Science* 6 (12): 187-194.

Fidelibus M, Smart D. 2004. Effects of harvest pruning on 'Thomson Seedless' grapevines. *HortScience* 39 (4): 827.

Ferree DC, McArtney SJ, Scurlock DM. 2000. Influence of irradiance and period of exposure on fruit set of French-American hybrid grapes. *Journal of the American Society for Horticultural Science* 126 (3): 283-290.

Florin S, Blidariu C. 2012. Macro- and micronutrient content in grapevine cordons under the Influence of organic and mineral fertilization. *Bulletin UASVM Horticulture* 69 (1): 1843-5394.

Goto-Yamamoto N, Mori K, Numata M, Kitayama M. 2010. Effect of temperature and water regimes on flavonoid content and composition in the skin of red- wine grapes. *Journal International des Sciences de la Vigne et du Vin* : 75-80.

Hale CR, Buttrose MS. 1974. Effect of temperature on ontogeny of berries of *Vitis vinifera* L. cv. 'Cabernet Sauvignon'. *Journal of the American Society for Horticultural Science* 99 (5): 390-394.

Holzapfel BP, Smith JP, Mandel RM, Keller M. 2006. Manipulating the postharvest period and its impact on vine productivity of 'Semillon' grapevines. *American Journal of Enology and Viticulture* 57 (2): 148-157.

Howell GS. 1999. Sustainable grape productivity and the growth-yield relationship: A review. *American Journal of Enology and Viticulture* 52 (3): 165-174.

Human MA. 2010. Effect of shading and ethephon on the anthocyanin composition of 'Crimson Seedless' (*Vitis vinifera* L.). MSc Thesis, University of Stellenbosch, South Africa.

Hunter JJ, Visser JH. 1988. The effect of partial defoliation, Leaf position and developmental stage of the vine on the photosynthetic activity of *Vitis vinifera* L. cv. 'Cabernet Sauvignon'. *South African Journal for Enology and Viticulture* 9 (2): 9-15.

Hunter JJ, Visser JH. 1989. The effect of partial defoliation, leaf position and developmental stage of the vine on leaf chlorophyll concentration in relation to the photosynthetic activity and light intensity in the canopy of *Vitis vinifera* L. cv. 'Cabernet Sauvignon'. *South African Journal for Enology and Viticulture* 10: 67-73.

Hunter JJ, Visser JH. 1990. The effect of partial defoliation on growth characteristics of *Vitis vinifera* L. cv. 'Cabernet Sauvignon' II Reproductive growth. *South African Journal for Enology and Viticulture* 11 (1): 26-32.

Hunter JJ, Riffner HP, Volschenk GG. 1995. Starch concentration in grapevine leaves, berries and roots and the effect of canopy management. *South African Journal for Enology and Viticulture* 16 (2): 35-40.

Hunter JJ. 2000. Implication of seasonal canopy management and growth compensation in grapevine. *South African Journal for Enology and Viticulture* 21 (2): 81-91.

Jones JE, Menary RC, Wilson SJ. 2009. Continued development of *V. vinifera* inflorescence primordial in winter dormant buds. *Vitis* 48 (3): 103-105.

Kagi BF. 1998. Vigour control in grapevines for wine production: The effects of root restriction on the vegetative growth, fruitfulness and fruit maturity of *Vitis vinifera* L. cv. 'Cabernet Sauvignon'. MSc thesis, Lincoln University, New Zealand.

Katoaka I, Beppu K, Yanagi T, Okamoto K. 2004. Light components contributing to accumulation of anthocyanins in 'Gros Colam' grape berries. *Acta Hort*. 640: 333-339.

Keller MK, Mills IJ, Wample RL, Spayd SE. 2004. Crop load management in 'Concord' grapes using different pruning techniques. *American Journal of Enology and Viticulture* 55 (1): 35-49.

Khanduja SD, Abbas S. 1973. Estimating fruitfulness of grapevine buds by forced bursting in summer in the tropics of India. *Vitis* 12: 23-25.

Kliewer WM, Lider LA. 1968. Influence of cluster exposure to the sun on the composition of 'Thompson Seedless' fruit. *American Journal of Enology and Viticulture* 19: 175-184.

Kliewer W. 1970. Effect of day temperature and light intensity on coloration of *Vitis vinifera* L. grapes. *Journal of the American Society for Horticultural Science* 95 (6): 693-697.

Kliewer WM. 1977. Effect of high temperature during the bloom-set period on fruit-set, ovule fertility and berry growth of several grape cultivars. *American Journal of Enology and Viticulture* 28 (4): 215-222.

Kliewer WM, Bowen P, Benz M. 1989. Influence of shoot orientation on growth and yield development in 'Cabernet Sauvignon'. *American Journal of Enology and Viticulture* 40: 259-264.

Koblet W. 1996. How do grapevines respond to altered source/sink ratio and unfavourable environmental conditions? II-Vine Stress Physiology, *Proceedings for the 4th International Symposium on Cool Climate Viticulture and Enology* pp.1-8.

Kriedemann PE. 1977. Vine leaf photosynthesis. In: Proc. International Symposium on The Quality of the Vintage. 14-21 Feb. 1977, Cape Town. pp 67-87.

Lebon G, Duchene E, Brun O, Clement C. 2005. Phenology of flowering and starch accumulation grape (*Vitis vinifera* L.) cuttings and vines. *Annals of Botany* 95: 943-948.

Lebon G, Wojnarowiez G, Holzapfel F, Viallant-Gaveau N, Clement C. 2008. Sugars and flowering in the grapevine (*Vitis vinifera* L.). *Journal of Experimental Botany* 59 (10): 2565-2578.

Lohitnavy N, Bastian S, Collins C. 2010. Early leaf removal increase flower abscission in *Vitis vinifera* 'Semillon'. *Vitis* 49 (2): 51-53.

Longbottom ML. 2007. The reproductive development of grapevines – factors that affect flowering and fruitset. MSc Thesis, University of Adelaide, Australia.

May P. 1965. Reducing inflorescence formation by shading individual 'Sultana' buds. *Australian Journal of Biological Sciences* 18: 463-473.

May P, Shaulis NJ, Antcliff AJ. 1969. The effect of controlled defoliation in the 'Sultana' vine. *American Journal of Enology and Viticulture* 20: 237-250.

Mullins MO. 1967. Morphogenetic effects of roots and of some synthetic cytokinins in *Vitis vinifera* L. *Journal of Experimental Botany* 18: 206-214.

Ndung'u CK, Okamoto G, Hirano K. 1995. Budbreak induction in dormant cuttings of 'Kyoho' grape by use of water stress. *Environment Control in Biology* 33: 269-275.

Ndung'u CK, Okamoto G, Hirano K. 1996. Use of water stress in forcing 'Kyoho' grapevines to produce two crops per year. *American Journal of Enology and Viticulture* 47: 157-162.

Ndung'u CK, Shimizu M, Okamoto G, Hirano K. 1997. Abscisic acid, carbohydrates, and nitrogen contents of 'Kyoho' grapevines in relation to bud break induction by water stress. *American Journal of Enology and Viticulture* 48 (1): 115-303.

Ntombela S. 2010. Scenario development to support strategic planning in the South African table grape industry. MSc thesis, University of Stellenbosch, South Africa.

Orth CHF, Van Rensburg K. 2011. Oogvrugbaarheid by tafeldruiwe. Available at http://www.gwrdc.com.au/wp-content/uploads/2012/09/Final-Reportgwr0202h.pdf [accessed 15 July 2011].

Palliotti A, Gatti M, Poni S. 2011. Early leaf removal to improve vineyard efficiency: gas exchange, source-to-sink balance, and reserves storage responses. *American Journal of Enology and Viticulture* 62 (2): 219-228.

Palma BA, Jackson DI. 1989. Inflorescence initiation in grapes - response to plant growth regulators. *Vitis* 28: 1-12.

Perez J, Kliewer WM. 1990. Effect of shading on bud necrosis and bud fruitfulness of 'Thomson Seedless' grapevines. *American Journal of Enology and Viticulture* 41 (2): 168-175.

Percival DC, Fisher KH, Sullivan JA. 1994. Use of fruit zone leaf removal with *Vitis vinifera* L. cv. 'Riesling' grapevines. I. Effects on canopy structure, microclimate, bud survival, shoot density, and vine vigor. *American Journal of Enology and Viticulture* 45 (2): 123-132.

Poni S, Magnanini E, Bernizzoni F. 2003. Degree of correlation between total light interception and whole-canopy net CO_2 exchange rate in two grapevine growth systems. *Australian Journal of Grape and Wine Research* 9: 2-11.

Poni S, Casalini I, Bernizzoni F, Civardi S, Intrieri C. 2006. Effect of early defoliation on shoot photosynthesis and yield composition. *American Journal of Enology and Viticulture* 57 (4): 397-407.

Pratt C. 1971. Reproductive anatomy in cultivated grapes- A review. *American Journal of Enology and Viticulture* 22 (2): 92-109.

Raath P, De Plessis C. 2012. Analyse this. *South African Fruit Journal*: 13.

Rawnsley B. 2003. What is primary bud necrosis (PBN)? Annual technical issue. *The Australian & New Zealand Grapegrower & Winemaker* 464: 21-24.

Rawnsley B, Collins C. 2005. Improving vineyard productivity through assessment of bud fruitfulness and bud necrosis. Available at http://www.sardi.sa.gov.au/__data/assets/pdf_file/0004/46687/bud_necrosis.pdf [accessed 25 July 2011].

Reynolds AG, Pool RM, Mattick L. 1986. Influence of cluster exposure on fruit composition and wine quality of 'Seyval Blanc' grapes. *Vitis* 25: 85-95.

Reynolds AG, Wardle DA, Naylor AP. 1996. Impact of training system, vine spacing and basal leaf removal on 'Riesling'. Vine performance, berry composition, canopy microclimate, and vineyard labor requirements. *American Journal of Enology and Viticulture* 47(1): 63-69.

Reynolds AG, Molek T, De Savigny CD. 2005. Timing of shoot removal in *Vitis vinifera*: Impacts on yield and fruit composition variables. *American Journal of Enology and Viticulture* 56 (4): 343-356.

Rusjan D. 2010. Impact of gibberellin (GA_3) on sensorial quality and storability of table grape (*Vitis vinifera* L.). *Acta Agriculturae Slovenica*: 163-173.

Sanderson D. 2003. Fruitfulness in vertically-divided canopies. *The Australian & New Zealand Grapegrower & winemaker* 476: 18-20.

Sánchez LA, Dokoozlian NK. 2005. Bud Microclimate and Fruitfulness in *Vitis vinifera* L. *American Journal of Enology and Viticulture* 56 (4): 319-329.

Sánchez LA, Dokoozlian NK, Goffinet MC. 2015. Variation in the nodes of *Vitis vinifera* L.: Double Compound buds. Available at http://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CBwQFjAA&url=http%3A%2F%2Fiv.ucdavis.edu%2Ffiles%2F108817.pdf&ei=7imuVKzwHYr0UpnCgbgB&usg=AFQjCNFsKg-tM2eUTSA-anLNcypSzHEdEA&sig2=GV5bzHoTat9tU0LxH7N8Vg [accessed 5 January 2015].

Scholefield PB, May P, Neales TF. 1977. Harvest-pruning and trellising of 'Sultana' vines. II. Effects on early spring development. *Scientia Horticulturae* 7: 123-132.

Scholefield PB, Neals TF, May P. 1978. Carbon balance of the ‘Sultana’ vine *(Vitis vinifera* L.) and the effects of autumn defoliation by harvest-pruning. *Australian Journal of Plant Physiology* 5: 561-570.

Sepulveveda G, Kliewer WM. 1986. Effect of high temperature on grapevines (*Vitis vinifera)*. II. Distribution of soluble sugars. *American Journal of Enology and Viticulture* 37 (1): 20-25.

Smart RE. 1974. Photosynthesis by grapevine canopies. *Journal of Applied Ecology*. 11: 997-1006.

Smart RE. 1982. Vine manipulation to improve wine grape quality. In: Proc. Grape Wine Centennial Symp., (ed). Webb, D., pp 362-75. June Univ. California Press, Davis.

Smart RE, Shaulis NJ, Lemon ER. 1982. The effect of ‘Concord’ vineyard microclimate on yield. II. The interrelationships between microclimate and yield expression. *American Journal of Enology and Viticulture* 33: 106-116.

Smart RE, Robinson JB, Due GR, Brien CJ. 1985. Canopy microclimate modification for the cultivar ‘Shiraz’. II. Effects on must and wine composition. *Vitis* 24: 119-128.

Smart RE, Smith SM, Winchester RV. 1988. Light quality and quantity effects on fruit ripening for 'Cabernet Sauvignon'. *American Journal of Enology and Viticulture* 39 (3): 250-258.

Smart RE, Dick JK, Gravett IM, Fisher BM. 1990. Canopy management to improve grape yield and wine quality-principles and practices. *South African Journal for Enology and Viticulture* 11(1): 3-17.

Smith J, Holzapfel B. 2002. Vine nutrition. The post-harvest period carbohydrate reserves and vine productivity. *The Australian & New Zealand Grapegrower & Winemaker* 478: 31-34.

Smith D. 2003. Grapevine bud dissection- don't cut of your fruit this winter. *The Australian & New Zealand Grapegrower & Winemaker* 471: 17-20.

Smith JP, Holzapfel BP. 2009. Cumulative responds of 'Semillon' grapevines to late season perturbation of carbohydrate reserve status. *American Journal of Enology and Viticulture* 60 (4): 461-470.

Sommer KL, Islam MT, Clingeleffer PR. 2000. Light and temperature effects on shoot fruitfulness in *Vitis vinifera* L. cv. 'Sultana': Influence of trellis type and grafting. *Australian Journal of Grape and Wine Research* 6: 99-198.

Srinivasan C, Mullins MG. 1978. Control of flowering in the grapevine (*Vitis vinifera* L.): Formation of inflorescences *in vitro* by isolated tendrils. *Plant Physiology* 61: 127-130.

Srinivasan C, Mullins MG. 1980. Effects of temperature and growth regulators on formation of anlagen, tendrils and inflorescences in *Vitis vinifera* L. *Annals of Botany* 45: 439-446.

Srinivasan C, Mullins MG. 1981. Physiology of flowering in the grapevine- A review. *American Journal of Enology and Viticulture* 32 (1): 47-63.

Strydom J. 2006. Canopy manipulation practices for optimum colour for 'Redglobe' (*V. Vinifera* L.). MSc thesis, University of Stellenbosch, South Africa.

Swanepoel JJ, Archer E. 1988. The ontogeny and development of *Vitis vinifera* L. 'Chenln Blanc' inflorescence in relation to phenological stages. *Vitis* 27: 133-141.

Tardaguila J, Diago MP, Yoda FM, Poni S, Vilanova M. 2008. Effect of timing of leaf removal on yield, berry maturity, wine composition and sensory properties of cv. 'Grenache' grown under non irrigated conditions. *Journal International des Sciences de la Vigne et du Vin (*42): 221-229.

Terence RB, Richard M, Dunst M, Paula J. 2002. Seasonal dry matter, starch and nutrient distribution on 'Concord' grapevines roots. *HortScience* 37 (2): 313-316.

Thomas JE, Barnard C. 1937. Fruit bud studies. III. The 'Sultana'. Some relations between shoot growth, chemical composition, fruit bud formation and yield. *Journal of the Council for Scientific and Industrial Research* 10: 143-157.

Vasconcelos MN, Greven M, Winefield SC, Trought MCT, Raw V. 2009. The flowering process of *Vitis vinifera*: A review. *American Journal of Enology and Viticulture* 60 (4): 411- 434.

Vasudevan L, Wolf TK, Welbaumand GG, Wisniewski ME. 1998. Reductions in bud carbohydrates are associated with grapevine bud necrosis. *Vitis* 37 (4): 189-190.

Vasquez S, Fidelibus M. 2011. Using grapevine bud dissection to access yields. Available at http://iv.ucdavis.edu/files/24501.pdf [accessed 1 May 2012].

Volschenk CG, Hunter JJ. 2001. Effect of seasonal canopy management on the performance of 'Chenin blanc'/'99 Richter' grapevines. *South African Journal for Enology and Viticulture* 22 (1): 36-40.

Williams LE, Neja RA, Meyer JL, Yates LA, Walker EL. 1991. Postharvest irrigation influences budbreak of 'Perlette' grapevines. *HortScience* 26: 1081.

Williams EL. 2012. Bud development and fruitfulness of grapevines. Available at www.bud development and fruitfulness of grapevines.com [access 3 March 2012].

Winkler AJ, Williams WO. 1945. Starch and sugars of *Vitis vinifera. Plant Physiology* 20: 412-432.

Wolf TK, Warren MK. 1995. Shoot growth rate and density affect bud necrosis of 'Riesling' grapevines. *Journal of the American Society for Horticultural Science* 120 (6): 989-996.

Windell NE. 2012. Leaf blackening and the control thereof in selected 'Protea' species and cultivars. MSc Thesis, University of Stellenbosch, South Africa.

Wium D. 2013. Free Grape Growing Tips and Help To Grow Your Own Grapes. Available at http://www.my-grape-vine.com/blog/?s=pruning+thompson+seedless [accessed 12 November 2013].

Zoecklein BW, Wolf TK, Duncan NW, Judge JM, Cook MK. 1992. Effect of fruit zone leaf removal on yield, fruit composition, and fruit rot incidence of 'Chardonnay' and 'White Riesling' (*Vitis vinifera* L.) grapes. *American Journal of Enology and Viticulture* 43 (2): 139-148.