EFFECT OF CLIMATE AND CULTURAL PRACTICES ON GRAPEVINE FLOWERING AND YIELD COMPONENTS

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ABSTRACT

This thesis presents results from two separate studies. First, the impact of bearer length on yield components within the canopy was investigated in season 2005/06, on a commercially-managed, mechanically-pruned vineyard of *Vitis vinifera* L. Cabernet Sauvignon in Coonawarra, South Australia. Pruning resulted in the retention of bearers with 1-7 nodes, with the weighted average bearer length being two nodes for the canopy. As bearers of one to five nodes in length were the most common, these were studied. Yield components (on a per shoot basis) were analysed according to the node position on the bearer at which the shoot arose. Both budburst and inflorescence number per node were highest at the distal node positions on each length bearer, even if the nodes were at the same positions from the base of the bearer and would normally be expected to have similar fertility. Budburst appeared to act by modifying inflorescence number per node based on the relative location of each node from the apex of the bearer. Shoots that arose from the most distal node positions had the highest flower number per inflorescence and berry number per bunch. Flower number per inflorescence was significantly higher on two-inflorescence shoots than single-inflorescence shoots. The relationship between bunch size and node position, unlike that between inflorescence number and node position, was dependent on bearer length. The relative size of the inflorescence appeared to be affected more so by the node position at which the shoot occurred on the bearer, as opposed to the actual node position on the shoot at which the inflorescence occurred. There was a positive, non-linear relationship between average fruit yield per bearer and bearer length. Although yield was highest from the bearer with the highest node number (five nodes), there was no significant difference in yield per bearer for the bearers of three to five nodes in length. If average bearer length was increased from two to three nodes, the potential yield gain per bearer is estimated at 38 per cent.

The second study presents results of correlations between bunch number and components of bunch weight (flower number and berry number) to investigate co-development of bunch number and bunch size. These data were collected from 4 vineyards in the Limestone Coast Zone of South Australia from *Vitis vinifera* L. Chardonnay, Shiraz and Cabernet Sauvignon during seasons 2002/03 to 2006/07. The significant correlations found between fertility and both bunch weight and flower number per inflorescence suggest that the same factors that affect bunch number in a particular season will also affect bunch size. When inflorescence primordia were initiated and differentiated

under cool conditions, actual bunches per node and flowers per inflorescence were low. Differences in climate between the vineyard sites were found to be minimal and therefore did not strongly affect the magnitude of the yield components at the vineyard sites. Cultural practices at each vineyard site were sufficiently variable to affect fertility levels. Genotype is thought to determine the range of flowers per inflorescence that a variety can potentially carry, whereas actual flower number per inflorescence is thought to be determined by inflorescence primordium initiation and differentiation temperatures, as well as temperatures during budburst. Despite significant correlations between flower number per inflorescence and berry number per bunch, flower number per inflorescence pre-flowering for Cabernet Sauvignon, Shiraz and Chardonnay is inversely related to actual percentage fruit set. This is possibly a survival mechanism for the grapevine as it allows the vine to maximise yield each season without detriment to its longevity. Bunches per vine accounted for the majority of the seasonal variation in yield per vine. Fluctuations in bunch number per vine (and therefore yield) are likely to be reduced by varying the number of nodes retained per vine according to the relative fruitfulness per node present pre-pruning. This practice is therefore likely to result in the seasonal variation of berries per bunch becoming a stronger driver of yield.

The commercial impacts of these studies are two-fold. Data presented will assist growers to understand the reasons for which their pruning regimes are affecting yield production and how these pruning regimes may be modified to achieve a target yield—particularly when growers are faced with seasons of low predicted fertility. In addition, data presented will allow growers to improve their crop forecasting accuracy, with a greater understanding of the link between bunch number and bunch size. In the current situation of oversupply in the wine industry, wineries are adopting a tough stance towards growers over-delivering on their grape contracts. Therefore, any assistance that can be provided to growers on improving accuracy of yield estimates will be beneficial both to the grower and winery.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution. To the best of my knowledge and belief, this work contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

S.J. McLoughlin
28/02/09

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CHAPTER ONE

GENERAL INTRODUCTION

The effect of both climate and cultural practices on grapevine yield may be substantial. Annual variability in grapevine yield is normally blamed primarily upon weather. Cultural practices on the other hand, can often impart variability in grapevine yield far beyond the bounds of a single growing season. It will be the interaction between climate and the cultural practices growers adopt to manage their vines, which will dictate their ability to meet quantity and quality goals into the future, in the face of our changing climate. A solid understanding of how climate and cultural factors impact the reproductive cycle of the grapevine is therefore necessary. To demonstrate this necessity however, annual yield variation over time must first be quantified, for its impact to be fully understood. In addition, accurate annual forecasting of grape yield is paramount.

Like all living organisms, the grapevine is under the control of its genetic make-up and the environment into which it is placed. Environmental conditions, notably temperature and light, influence both its vegetative and reproductive growth. This influence relates not only to the season in which the crop is produced, but also to past seasons, mainly the previous two (May, 2004). Grapevines begin forming their flower buds approximately 15-18 months prior to harvest. Flower buds begin to develop in axils of leaf primordia of primary latent buds during late spring and summer before entering a period of dormancy. In the following season, flowers form during a short period spanning budburst (Pratt, 1971). Bunch numbers per vine are the product of bunches per shoot and shoots per vine. Hence, they are controlled by processes that determine bud fertility as well as processes that determine the extent and nature of budburst.

Annual variations in winegrape yield continue to threaten the viability of the Australian Wine Industry, especially when unforseen. They make it difficult for vineyard managers to plan harvest in terms of truck, bin and personnel requirements. Winemakers struggle to plan vintage in terms of ascertaining required tank space, purchasing required volumes of additives and oak, and personnel. Wineries may reject excess fruit from their growers if they exceed their contracted tonnes upon delivery. Marketing departments face inability to match supply with demand which jeopardises Australia's ability to complete internationally against other winegrowers and retain brand strength in a competitive marketplace.

Australia's yield forecasting inaccuracy was determined as 33% of actual by Clingeleffer (2001). This result is meagre when considering the large impacts of yield variability on the Australian wine industry. Growers therefore need to utilise the crop forecasting system developed by Clingeleffer and other researchers, documented in Clingeleffer (2001), to improve the accuracy of their yield forecasts. In addition, growers need to understand how their cultural practices can alter yield levels when they are faced with high or low predicted fertility.

This study is divided into five chapters; chapter two reviews a wide range of available literature relating to grapevine reproduction. Chapters three and four comprise the experimental content of this thesis.

The research presented in Chapter Three seeks to investigate, in detail, the impact of bearer node number (length) retained during pruning on yield components within the canopy. Yield components (on a per shoot basis) are analysed according to the node position on the bearer at which the shoot arose. This investigation was performed in a single season on a commercially-managed (Foster's Group), mechanically-pruned vineyard of *Vitis vinifera* L. Cabernet Sauvignon in Coonawarra, in the Limestone Coast wine growing zone of South Australia.

The Limestone Coast zone of South Australia is of significant importance to Foster's Group as it contains approximately 40% of the company-owned vineyards. Accurate yield forecasting and yield regulation on these company vineyards is therefore vital to account for Foster's annual grape intake. Pruning has long been considered the cheapest tool for crop regulation during the growing season, especially if mechanised. Different pruning strategies are employed by growers as a means of setting up their vines to achieve a target cropping level. Research has shown that the proportion of buds that burst from any pruning system is affected by the number of buds retained at pruning and the length of bearers retained by the pruning style. Environmental and management practices such as pruning that affect the proportion and nature of buds that burst, can therefore exert profound influence on yield development (Krstic et al., 2005). Despite mechanised winter pruning being the most common practice in the Coonawarra wine region, the impact of these pruning systems on yield components is less well understood. The severity of the pruning cuts made as part of this pruning practice, result in the retention of bearers with varying number of nodes on each vine as documented by Clingeleffer (1989). The position on a bearer at which a node is situated was suggested by Buttrose (1969a) to affect its contribution to the total yield of the bearer, as proximal buds develop

earliest in the season when weather conditions are likely to be less favourable for bunch-primordium differentiation.

This study therefore aimed to quantify yield component variation at each node position on different bearer node numbers common to the mechanical hedge pruning system, and the relative influence of budburst on the magnitude of these yield components. The hypothesis was that variances in predicted fertility at each node position on the bearers would have the largest effect on the magnitude of other yield components. This hypothesis arose from the findings of Bessis (1965); that shoots arising from higher node positions on the bearers were more fruitful and inflorescences arising from the shoots at the higher node positions contained more flowers. The associations between bearer node number and the magnitude of inflorescence number and inflorescence size that occurred at each node position are also examined. This area of study was expected to propose which yield components were determined prior to pruning and which yield components were determined subsequent to pruning. Total yield from each of the different bearer node numbers would also be quantified. These results would be used to report practical recommendations to growers (in chapter five) for adjusting bearer node number at pruning time in order to add or remove yield, when faced with seasons of very high or very low predicted node fertility.

The research presented in Chapter Four aimed to investigate the hypothesis that bunch number and bunch weight are co-developed. This hypothesis adhered to the findings of Martin and Dunn (2000) who noted that in seasons where grape yields are relatively high, both bunch number and bunch size are relatively high. Proof of this co-development was expected to be demonstrated by positive correlations between bunch numbers and components of bunch weight (flower number and berry number). This chapter also investigated the correlation between flower number per inflorescence and berry number per bunch and in addition, how flower number per inflorescence could influence per cent fruit set. An additional study investigated the proportion of annual variation in yield which could be attributed to annual variation in bunch number per vine, berry number per bunch and weight per berry. Utilising a range of vineyards and varieties, this study aimed to verify the findings of previous studies by Dunn (2004), Martin (2004) and Clingeleffer (2001) that bunches per vine generally accounted for 60% of the seasonal variation in yield, followed by 30% for berries per bunch and 10% for weight per berry. Data for all the studies in Chapter Four were collected from 4 vineyards in the Limestone Coast Zone of South Australia from *Vitis vinifera* L. cultivars Chardonnay, Shiraz and Cabernet Sauvignon during seasons 2002/03 to 2006/07.

Chapter Five presents a summary of the experimental findings from the preceding chapters and identifies areas for potential future work. Some practical guides for grapegrowers in changing their pruning management in the face of variation in predicted node fertility and forecasting winegrape yield are also discussed.

CHAPTER TWO
REVIEW OF LITERATURE

2.1. INTRODUCTION

The annual yield of the grapevine can vary considerably from year to year, as for other perennial fruit crops. The causes of this seasonal variation in grapevine yield are complicated and driven by the interaction of a number of biotic and abiotic factors; principally weather, soil properties, pests and diseases and vineyard management practices (Krstic et al., 2005). Therefore, a solid understanding of these factors and their impact on the reproductive phase of the grapevine is necessary to enable vineyard managers to best meet their yield targets and remain viable.

2.2. THE GRAPEVINE AS A HORTICULTURAL CROP

In the wild, *Vitis Vinifera* L. is a vigorous climbing plant inhabiting forests, producing many small bunches of fruit. It uses its flexible trunk and branches to enable vertical growth towards sunlight and is supported by the trees on which it grows. The climbing habit of wild grapevines is facilitated by a series of tendrils allowing them to climb 20-30m in the forest canopy. In contrast, modern cultivated grapevines are most commonly grown on post and wire trellises of various designs to allow for mechanization of vineyard activities or less commonly, as small free-standing bushes, requiring hand manipulation. Modern viticulture employs the notion of annual hard pruning of the dormant canes to reduce bunch number and increase bunch weight and fruit quality. The grapevine has a remarkable ability to regrow after pruning and to produce new fruiting wood bearing the following season's crop (Mullins et al., 1992).

2.3. GRAPEVINE PHENOLOGY

The grapevine as a perennial plant, annually undergoes a number of sequential developmental or 'phenological' stages. The timing and length of these stages varies with grapevine variety, environment in which they are grown and climatic events impacting on the site environment. Many of these developmental stages pinpoint specific times for management intervention to enable meeting of optimum grapevine growth and fruit quality standards as required by the winery. Grapevine phenological stages are commonly described using the modified system of Eichhorn and Lorenz (E-L) developed by Coombe (1995) (Figure 2.1).

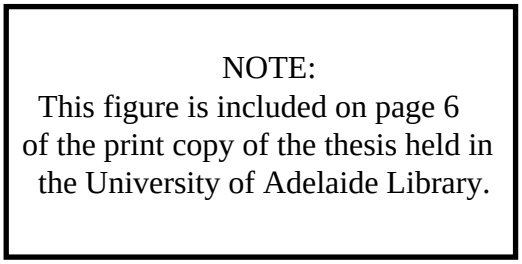


Figure 2.1. The modified E-L system from Coombe (1995).

2.3.1 Budburst (Modified E-L stages 2-4)

Budburst marks the end of dormancy and is identified by the emergence of visible leaf tissue. Budburst and early spring growth after budburst, relies on the vine's stored reserves alone, as opposed to later phases which depend largely upon photosynthetic activity of the tissues present (May ,1987; Moncur et al., 1989).

Research has shown that the timing of grapevine budburst is determined by both air temperature and soil temperature. Budburst is generally said to occur when daily mean maximum temperature exceeds 10°C (Mullins et al., 1992), however Pouget (1968) and Moncur et al. (1989) have shown that base temperatures required for budburst in dormant cuttings do vary between cultivars. The onset of budburst was also found to be advanced with higher soil temperature at 20cm depth (Alleweldt and Hofäcker, 1975). Culturally, Williams et al. (1991) found that water stress applied during the preceding season was found to affect date of budburst. Martin and Dunn (2000) also showed that a 6-week difference in winter pruning time of Cabernet Sauvignon delayed the onset of budburst.

Typically, nodes burst over a period spanning several weeks and not all of the nodes on a vine burst (Martin and Dunn, 2000). Shoots with bunches shoot earlier than shoots without bunches (Antcliff and Webster, 1955; Martin and Dunn, 2000). The proportion of nodes that burst is also strongly affected by the total number of nodes retained after pruning and the length of the bearers retained. May and Bessis (1985) showed that increasing node number per vine caused a reduction in the proportion of nodes that burst. Monitoring budburst on varying length bearers, Bessis (1965) also found that budburst had a strong tendency to increase from the base to the tip of the bearer. Antcliff and Webster (1955) speculated that the more fruitful nodes are the ones that burst in situations where a high number of nodes per vine exist; due to them acting as stronger sinks for assimilate.

2.3.2 Shoot and inflorescence development following budburst (Modified E-L stages 7-18)

Following an initial slow growth of shoots after budburst, there is massive growth of vegetative tissues during late spring (8-10 weeks after budburst), which has been termed the 'grand period of growth' (Pearce and Coombe, 2004). These new shoots initially develop from the primary buds of the compound nodes on the bearers retained after winter pruning. Should the primary bud become damaged, for example by mites, or the primary shoot is damaged, for example by frost, the accessory buds may grow (Figure 2.2). However, the accessory buds are considerably less fruitful than the primary bud (Mullins et al., 1992). It is therefore important for a grower to maximise shoot development from the primary buds.

The shoot of the current season is formed by a combination of 'fixed growth' and 'free growth'. Approximately the first twelve nodes on a shoot are produced by fixed growth; whereby internodes elongate and leaves expand from tissue pre-formed in the dormant nodes. This is followed by a period of 'free growth' involving elongation of a shoot by continuous production of new leaf primordia

by the apical meristem (Mullins et al., 1992). A rapidly growing shoot of the grapevine increases in length by three to four centimetres per day and produces a new leaf (or tendril) primordium every two to three days (Mullins et al., 1992). As with the occurrence of budburst, initial shoot growth is fuelled by the vine's stored reserves, primarily carbohydrates (May, 1987; Moncur et al., 1989). Once leaves have reached 50% of their final size, they become net exporters of photosynthates; which is usually 20 to 30 days after they first emerge from the shoot tip (Hale and Weaver, 1962). The growth of individual shoots on a particular vine is influenced by competition between these shoots; due largely to hormonal-regulated apical dominance and correlative inhibition (May, 1987).

Figure 2.2. Transverse section through a compound bud of a grapevine, showing relative positions of the leaf scar (LS), lateral shoot scar (LAT), primary bud (1) and the accessory buds (2) and (3). Adapted from Pratt, 1974.

Climatic and cultural influences have also been shown by a number of researchers to affect shoot growth. Under controlled conditions, Alexander (1965) showed that grapevine shoot growth could be increased with increasing air temperature, particularly at night. Whilst Woodham and Alexander (1966) demonstrated a positive correlation between increased shoot growth and increased root temperature. Firstly Buttrose (1969c) and then May et al. (1976) were able to link low light intensity to the production of thin shoots with long internodes and nodes of low fruitfulness. Vineyard trials by Kliewer et al. (1983) additionally showed a reduction in shoot growth in the presence of low soil moisture.

Individual shoots usually bear one to three inflorescences, each occurring opposite a leaf; with one or two inflorescences per shoot the most common for winegrape varieties. In a hot climate, these inflorescences become visible as early as 2-4 weeks after budburst in the lowest buds (Watt et al., 2008). At node positions on the shoot above those producing inflorescences, tendrils develop instead, also occurring opposite a leaf.

Inflorescence architecture consists of a number of primary branches alternately arising from the main stalk. From the primary branch stalks, secondary branching and tertiary branching occurs, finally terminating at a flower cluster, or floret. The flowers of the inflorescence differentiate and develop very rapidly following budburst, and all flower parts are formed within 10-15 days of the appearance of the inflorescence (Agaoglu, 1971). These single flowers on the inflorescences can be seen as part of compact florets at modified E-L stage 15, when shoots have separated approximately eight leaves.

2.3.3 Flowering, fertilisation and fruit set (Modified E-L stages 19-27)

Flowering time is generally consistent for multiple blocks of the same grape variety within a region. This is probably attributable to the unifying effect of the onset of spring heat in each region and year. Flowering time of an individual grape variety however, varies between regions and seasons. Flowering culminates a long and slow development of the inflorescences and flowers, beginning at a similar time one year before when latent buds are formed in late spring to early summer (Pearce and Coombe, 2004).

Flowering begins with the stage called ‘capfall’, where the flower cap, or calyptra, disconnects at the base, releasing the stamens and triggering pollen release from the anthers (pollen chambers). The pollen granules which fall on the pistil during pollination then grow down the style in a race towards the ovary; with successful fertilisation of the ovules only taking place by a single pollen tube. The whole process from pollination to fertilization takes between two to three days. Winkler et al. (1974) noted that shedding of the flower ‘cap’ was influenced by temperature, humidity and rainfall; with few flowers shedding their caps below 15°C, but as temperature approached 18-20°C, cap fall intensified.

Flowering, fertilisation and fruit set are critical periods determining grapevine yield, during which time a proportion of flowers will successfully set and become berries (Krstic et al., 2005). This

determination of berry number, accompanied by berry weight will establish harvest bunch weight. This harvest bunch weight, together with the already determined bunch number, will comprise the annual grapevine yield for any one season. Approximately 40% of the annual variation in grapevine yield can be explained by variations in bunch weight (Clingeleffer, 2001). It is generally the aim of the grower during late spring to early summer to achieve a fruit set level which will allow for a minimum yield target to be reached, without resulting in compact bunches leading to increased disease risk.

Grape inflorescences can have anything from several to more than a thousand flowers, each capable of forming a berry. Accurately calculating the proportion of flowers that develop into berries, involves counting the number of flowers present pre-flowering and the number of retained berries at harvest. For the grapevine, the proportion of flowers that become fruits (% fruit set) is determined within one or two weeks after flowering (May, 2004). There is some disagreement as to what % fruit set is considered as 'normal'. Mullins et al. (1992) has quantified percentage fruit set as ranging between 0-40%, but commonly between 20 and 30%, while Bessis (1993) considers that percentage fruit set is normal at 50%, with coulure experienced when fruit set is below 30%. The actual percentage of flowers that develop into berries is strongly influenced by the nutrition of the inflorescence before and during flowering (Coombe, 1973), grape variety, weather conditions at the time of flowering and fertilisation, crop load (carbohydrate balance), soil moisture and vineyard management practices (Krstic et al., 2005). Because fruit set occurs in late spring to early summer in the middle of the grand period of shoot growth (Pearce and Coombe, 2004), significant competition for water and nutrients is exerted by the rapidly growing shoot tip and thus can negatively affect fruit set. Growth inhibitors such as chlormequat (CCC) can improve fruit set by slowing down shoot extension (May, 1987), thereby reducing competition for water and nutrients over this period. Additionally, there has been no previous research investigating whether the number of flowers present on the inflorescence prior to flowering may also be a strong driver of % fruit set.

Anecdotally, poor fruit set can occur in all grape varieties, but is most commonly reported in varieties such as Merlot, Chardonnay and Cabernet Sauvignon grown in cooler grapegrowing regions. These three varieties in particular, show higher sensitivity to cold weather around the time of flowering and appear to be more susceptible to a special case of poor fruit set called millerandage than other grape cultivars.

Many researchers have stressed that low temperature is one of the main reasons for poor fruit set. Both Kassemeyer and Staudt (1981) and May (1992) found that low temperature affected the

development of flowers up to flowering, impacting on ovule differentiation and development. Sartorius (1926), Koblet (1966) and Staudt (1982) found that low temperature also affected ovule differentiation and development and/or number of germinating pollen grains, pollen germination and pollen tube growth. Whilst Ebadi et al. (1995a and 1995b) found that exposing plants to cold temperatures two days before flowering or at the beginning of flowering affected pollination by reducing and delaying pollen germination and pollen tube growth, consequently reducing fruit set. Varietal differences were also evident, with Chardonnay much more susceptible than Shiraz.

Poor fruit set has also been historically linked to poor boron and zinc nutrition (Bessis et al., 2000), but more recently there have been reports linking poor fruit set in Merlot in particular, to molybdenum deficiency (Williams and Bartlett, 2002; Gridley, 2003; Longbottom et al., 2004). A number of grapevine diseases have also been found to directly infect grapevine flowers, limiting their potential to form berries. These include *Botrytis cinerea* (Botrytis), *Plasmopara viticola* (Downy mildew), *Colletotrichum* sp. and possibly *Guignardia bidwellii* (Black Rot) and Greenaria *uvicola* (Bitter rot) (Hall, 2005).

2.4. GRAPEVINE REPRODUCTIVE PHASE

The reproductive phase of the grapevine occurs over a 15 to 18 month period (Figure 2.3.). During this phase, environmental and management factors influence the development of inflorescences and flowers; thus affecting yield potential and commercial viability.

Understanding the nature of the reproductive cycle of the grapevine is therefore vital for growers to enable targeted intervention at various stages of this phase, to assist in achieving desired yield levels.

Figure 2.3. The Grapevine Reproductive Phase (adapted from Wilson, 1996).

The grapevine reproductive cycle starts in Year 1 with induction and initiation of the inflorescence primordia in spring, carrying through to January. By the end of summer, these inflorescence primordia differentiate and enter dormancy. In spring of the second year, budburst occurs and simultaneously, individual flowers are formed on the inflorescences initiated the previous year. Flowering and fruit set follows in late spring to early summer at the end of Year 2. Flowers that have successfully developed into berries continue to grow through summer before ripening in the autumn of Year 3. In summary, harvest of the fruit from inflorescences initiated in Year 1 does not occur until Year 3.

2.4.1 Node Fertility and Inflorescence development

Like most other spring-flowering perennials, grapevines commence forming their flower buds during the preceding season. Flower formation in grapevines follows three critical steps (Dunn, 2005):

a) Induction of the anlagen
b) Initiation and early differentiation (branching) during spring
c) Further branching terminating in the formation of individual flowers at budburst

For grapevines grown in temperate climates, steps a) and b) are usually completed during the previous season. Individual flowers, on the other hand, are not formed until during budburst in the current season (Barnard, 1932; Snyder, 1933; Winkler and Shemsettin, 1937; Srinivasan and Mullins, 1981; Scholefield and Ward, 1975; Watt et al., 2008).

Flower formation in grapevines involves complex step-wise processes. The first signal (floral induction) suggesting the start of the flowering cycle is probably hormonally triggered and commences the development of embryonic flower tissues. The first visible signal (floral initiation) is when the apical meristem initiates the development of uncommitted primordia called 'anlagen' in the apices of the primary bud on shoots of the current season. The anlagen initiation occurs in early spring inside basal nodes around the time of flowering and progresses up the shoot. The exact timing of initiation is dependant on grape variety, the growing region (accumulated heat units) and the node position along the growing shoot (Krstic et al., 2005; Watt et al., 2008). Buttrose (1974a) in carrying out growth cabinet studies, was able to demonstrate that floral induction occurs 20 days prior to the initiation of anlagen for Muscat of Alexandria and Lavee et al. (1967) through field studies was able to demonstrate that floral induction occurs 18 days prior to the initiation of anlagen for Sultana. May (1964), Buttrose (1970a) and Dunn (2005) indicated that during this time of floral induction, environmental conditions may play an important role in affecting the ability of the meristem to respond to floral stimuli to initiate development of the anlagen, as there is a close positive relationship between the size of the meristem and the resultant level of inflorescence initiation.

Anlagen are essentially undifferentiated cells, with the potential to develop into inflorescence primordia, transitional forms between inflorescence and tendril primordia, and tendril primordia (Barnard, 1932; Barnard and Thomas, 1933). The kind of primordium that develops is thought to be affected by the balance of a number of key hormones in the vine (cytokinin and gibberellin). In forming the first two kinds of primordia, the anlage first forms a bract primordia, then divides into a

primary ‘inner’ arm and secondary ‘outer’ arm. The ‘outer’ arm (often referred to as a ‘wing’) if formed may be floral, or a tendril or may develop into a shoot (rare). The occurrence of, and the relative size of wings, is a seasonal characteristic of fruitfulness.

Differentiation of branch initials on the inner arm and often the outer arm may occur before the node enters dormancy (Barnard and Thomas, 1933) and occurs at the same time as the current season’s crop is being set and ripened prior to harvest. After dormancy and during budburst of the following season, further branching takes place, terminating in the formation of individual flowers. Light microscope (Barnard, 1932; Barnard and Thomas, 1933) and scanning electron microscope studies (Srinivasan and Mullins, 1981) of developing latent buds, reveal that anlagen which undergo extensive branching prior to dormancy form inflorescences, while those that possess only two or three branches form tendrils. Recent scanning electron microscope studies of Watt et al. (2008) have shown that not only is the extent of inflorescence primordia differentiation affected by climate, but inflorescence primordia that developed in a hot climate were substantially larger than inflorescence primordia that developed in a cool climate. Dunn and Martin (2007) have suggested that the extent of branching the inflorescence primordium has undergone prior to dormancy contributes significantly towards the size of the inflorescence emerging in the following season. In addition, inflorescence primordia that develop in hot climates are perhaps less sensitive to temperature fluctuations over budburst due to their size being ‘more committed’ as a result of the branching they have undergone prior to dormancy (Watt et al., 2008).

In summary, it appears that the concept of co-development of bunch number and bunch size being examined during this research has a theoretical basis. Dunn and Martin (2000) showed that average flower number per inflorescence was significantly higher on two-bunch shoots than on single-bunch shoots, suggesting that conditions during the previous spring that favour the initiation and/or differentiation of uncommitted primordia also pre-condition inflorescences to have more flowers. The floral initiation and differentiation processes determine potential yield by regulating the development of anlagen into inflorescence primordia (potential bunch numbers). It also appears that the extent of branching these inflorescence primordia undergo prior to dormancy, predetermines the potential size of the bunch. Because of the large variation in yield parameters from year to year, accurate yield estimation has long been a difficult task for growers. Clingeleffer (2001) found that bunch number alone could typically explain 60-70% of the annual variation in yield. However, an assessment of potential fertility (bunch number) of developing nodes is subsequently becoming a widely-adopted

industry tool to aid growers in setting 'informed' pruning guidelines in attempt to stabilise yields to a particular set yield target.

2.4.2 Flower development

During budburst of the season following inflorescence initiation, the inflorescence primordia undergo additional extensive branching, differentiating individual flowers and floral parts (Barnard, 1932; Snyder, 1933; Winkler and Shemsettin, 1937; Agaoglu, 1971; Scholefield and Ward, 1975; Srinivasan and Mullins, 1981). Environmental and management practices such as pruning that affect the proportion and nature of nodes that burst, can therefore exert profound influence on yield development (Krstic et al., 2005) (refer to section 2.6).

Flowers and floral parts (sepals, petals, stamens and pistil) complete their formation within 10-15 days of the appearance of the inflorescence from the bursting latent bud (Agaoglu, 1971). From this time, the flower is fully developed and awaits flowering. The arrangement of these flowers on an inflorescence becomes visually clear once the inflorescence begins to rapidly elongate prior to flowering (Bennett, 2002). The number of flowers on the outer arm can be up to one third of that of the inner arm and about half of the flowers on an inflorescence can be found on the lowest four primary branches (May, 1987). Troll (1964) describes inflorescences as consisting of a 'main axis' (arm) which terminates in the 'primary inflorescence' on which flowers are situated singularly or in groups of three. The primary inflorescence carries side branches which are copies of itself. These side branches may also carry additional branches themselves and also carry flowers situated singly or in groups of three.

The number of flowers formed on an inflorescence primordium determines the potential number of berries that may be set on that bunch, and thus potential bunch size. It is possible to detect the seasonal variability in potential bunch size before flowering, by counting flowers or first order branches on inflorescences (May, 1987; Bennett, 2002; Dunn and Martin, 2003). As bunch size contributes 30-40% of the variation in annual yield, early determination of bunch size, along with the knowledge of actual inflorescence number, allows the grower to implement yield regulation techniques where necessary to aid in achieving a particular yield target.

2.5. ENVIRONMENTAL FACTORS INFLUENCING INFLORESCENCE AND FLOWER DEVELOPMENT

Critical factors for inflorescence initiation in the node are also those which are closely associated with vine vigour; they include, temperature, light, nutrient availability, water stress and hormone balance (Wilson, 1996). The latter will not however, be discussed in this review.

2.5.1 Temperature

The fact that fruitfulness in grapevines is promoted by high temperature has been demonstrated in many statistical studies (Huglin, 1958; Alleweldt, 1963; Baldwin, 1964; Smit, 1970), all reporting enhanced fruitfulness in terms of number of bunches per shoot or flowers per inflorescence (Palma and Jackson, 1981) after higher temperatures were imposed during node development. Growth cabinet studies by Buttrose (1969a) confirmed the findings of the statistical studies by demonstrating that both the number and fresh weight of inflorescence primordia increased (in Muscat Gordo Blanco) with increasing temperature up to 35°C. Cultivar sensitivities to temperature were studied in growth cabinets by Buttrose (1970b) who concluded that differences were evident in the way cultivars' fruitfulness responds to the environment. Most cultivars had a temperature optimum for fruitfulness of 30-35°C, whereas differences in fruitfulness were more noticeable at low temperature (and low light) and thought to be related to whether the cultivars were domesticated in warm or cool-climates.

Low temperatures cause low fruitfulness in grapevines by delaying and reducing the level of induction (Buttrose, 1974a). The occurrence of low temperatures three weeks prior to the initiation of anlagen was found by Buttrose (1969b) to have the greatest effect on induction. Grapevine vegetative growth on the other hand, is affected somewhat differently by temperature. Buttrose (1968) showed that dry matter accumulation in the shoot is greatest at 20°C and falls off at higher temperatures. Buttrose (1974a) concluded that temperature may have some qualitative as well as quantitative effect on node development and fruitfulness, so the actual temperature experienced, rather than the temperature summation, could be important. Growth cabinet studies carried out by Buttrose (1969a), involved varying the number of hours of high and low temperatures supplied on a daily basis to grapevines and monitoring fruitfulness accordingly. Grapevines given less than four hours per day of high temperature (30°C) had nodes equally as unfruitful as grapevines receiving constant low temperatures (18°C). On the other hand, for grapevines receiving four hours of high temperature, node fruitfulness was almost equivalent to grapevines receiving 16 hours of high

temperature. Interestingly, Buttrose (1969a) found that the weight of the inflorescence primordia developed under the short pulse of high temperatures was lower than those developed under a normal high temperature regime (16 hours of 30°C: 8 hours of 18°C). It was therefore concluded by Buttrose (1974a) that temperature independently controls the differentiation of inflorescence primordia on the one hand and their rate of development on the other.

Temperature has also been found to influence the number of flowers produced per inflorescence. Studies of the effects of temperature on differentiation (branching) during budburst confirmed that nodes bursting at low temperatures (12°C) produced inflorescences with more flowers than those bursting at 25°C in Cabernet Sauvignon and Merlot (Pouget, 1981) and Cardinal and Alicante Grenache (Ezzili, 1993). Similarly, Kliewer (1975) reported that keeping vines at root temperatures of 11°C as opposed to 35°C (with a constant air temperature) resulted in a significant reduction in the number of berries per bunch (flower number not reported). In a field study, Dunn and Martin (2000) staggered pruning to alter the temperatures bursting shoots endured. They found that inflorescences did have fewer flowers on later-bursting shoots (presumably when ambient temperatures were higher). In May's (2004) opinion however, temperature conditions at budburst in Australia are unlikely to be sufficiently high to cause a reduction in flower number per inflorescence as seen in experiments by Pouget (1981) and Ezzili (1993).

The effect of temperature on flower number was surmised by Pouget (1981) to be due to its effect on the growth of the developing shoot in relation to inflorescence differentiation. He noted that cooler temperatures slowed vegetative growth, decreasing the 'speed' of budburst, allowing inflorescence differentiation to occur over a longer period of time, resulting in more flowers being formed. Bennett (2002) expanded on this theory, suggesting that low temperatures are likely to, a) decrease the rate of carbohydrate reserve immobilisation in the roots and trunks of vines to the bursting buds at the time of flower formation, and b) decrease the rate of vegetative growth, leaving a greater proportion of carbohydrates available for flower formation, thereby prolonging flower formation and increasing the number of flowers formed per inflorescence. May (1987) proposed an alternative theory of temperature effects on flower number per inflorescence, suggesting that cytokinins as promoted by higher temperature, may enhance the enlargement of the early produced flowers, which in turn could inhibit the formation of other flowers.

Aerial temperatures below certain limits affect fruit set detrimentally, through their effect on pollination and fertilisation (May, 2005). Flowering occurs irregularly under wet conditions and prior

to air temperatures reaching 15-17°C as stigma viability is reduced. If this unfavourable weather lasts for two to three days in succession, flowers fail to open completely and both pollination and fertilisation are compromised, resulting in partially-fertilised or unfertilised ovaries. Temperature also affects the speed of pollen tube growth inside the pistil. Studies using various *Vitis vinifera* cultivars showed pollination occurred between 16-27°C (Mayer, 1964) but temperatures lower than 15°C caused pollen tube elongation to be insufficient and too slow to enable fertilisation.

High temperatures have also been found to negatively affect fruit set. Kliewer (1977) held Pinot Noir and Carignane vines at 25°C, 35°C or 40°C during the day from days 2 to 8 pre-flowering until days 9 to 14 after the start of flowering and noted that per cent fruit set was significantly lower at the two higher temperatures.

2.5.2 Light

Plants respond to changes in light quality, light quantity and day length (Dunn, 2005). Although grapevines have evolved from forest-dwelling habitats, they possess no typical photosynthetic characteristics of shade-tolerant plants such as low light saturation of photosynthesis (Kriedemann, 1968). The grapevine's requirements for light to enable reproduction have therefore been demonstrated in many studies, commonly involving shading. May and Antcliff (1963) and Srinivasan and Mullins (1981) importantly identified a four-week period during late spring as the critical time period during which shading causes a decrease in fruitfulness for the following season.

In controlled-environment studies, Buttrose (1969a) was able to show that both number and size of inflorescence primordia increased in proportion to light intensity. Morgan et al. (1985) also observed a significant reduction in fruitfulness in terms of shoots per node, flowers per inflorescence and bunches per shoot in the following season after exposing grapevines to low PPFD (photosynthetic photon flux density). Effects of light intensity on fruitfulness of grapevines are independent of temperature (Buttrose, 1970a), but in field studies it is hard to separate the effects of temperature and light. Field studies have however supported the findings of Buttrose (1969a), whereby buds situated inside the canopy of field-grown vines were found to be less fruitful than buds at the exterior receiving more sunlight (May et al., 1976). Other studies by May (1965), Hopping (1977) and Perez and Kliewer (1990) have also shown that shading reduces the formation of inflorescence primordia in grapevines. Low light intensity was also linked with a reduction in bunches per shoot or shoots per node (May and Antcliff, 1963; May et al., 1976; Smart et al., 1982a). Fruitfulness in grapevines subjected to low light intensity also appears to be cultivar specific, perhaps indicative of the climate

of the cultivar's origin. Buttrose (1970b) found that Riesling was much more fruitful that Shiraz at lower light intensities.

The response of grapevines to photoperiod (daylength) was tested by Alleweldt (1964). Vegetative growth was found to increase with longer days, but fruitfulness appeared to be non-responsive. Buttrose (1969b, 1974a) did however, show that the number of inflorescence primordia per node for some grapevine cultivars appeared to increase with the quantity of light available with long days in comparison to short days. If high intensity light was applied for more than 12 hours per day, the induction of inflorescence primordia was improved (Buttrose, 1969b). In contrast, the accumulation of dry matter in the whole plant was related to the total light energy received and not to the number of hours of illumination (Buttrose, 1969b). Buttrose (1974a) concluded that the mechanism leading to the induction of inflorescence primordia, despite its requirement for high energy light, is not identical to the mechanism leading to dry weight accumulation (i.e. photosynthesis).

2.5.3 Water stress

Water stress can reduce inflorescence formation in latent buds (Dunn, 2005). The number and weight of inflorescence primordia were found to progressively decrease with increased water stress in studies of potted vines conducted by Buttrose (1973). Loveys and Kriedemann (1973) demonstrated that water stress in grapevines caused a reduction in photosynthesis due to stomatal closure. From this finding, Buttrose (1974a) surmised that water stressed plants are likely to have a shortage of available carbohydrates. Because the induction of bunch primordia in grapevine nodes is partly related to the supply of available carbohydrates, water stress is likely to reduce inflorescence formation in latent buds. On the other hand, Stoïev and Nikov (1956) found that irrigation during the floral-initiation period promoted development of the second and third bunches on shoots, and hence increased yield per vine. Skinner and Matthews (1989) also reported increases in fruitfulness after irrigations, but vine water status was not quantified.

In certain instances, mild water stress has been found to improve inflorescence primordia development in grapevines (Smart et al., 1974) and in fruit trees (Magness, 1953). Similar results were also documented by Carbonneau and Casteran (1979) and Smart and Coombe (1983) from irrigation trials, noting a decline in fruitfulness with irrigation intensity. Water status was not however quantified in these studies. Dunn (2005) suggested that mild water stress may limit vegetative growth during initiation, leading to a better-lit canopy and improved initiation and differentiation of anlagen. A different perspective was offered by Buttrose (1974a), who considered that water stress may restrict

root growth to a greater extent than photosynthesis, causing carbohydrates to actually accumulate in the shoots, thus increasing fruitfulness.

Water stress can also impact on fruit set and grape maturity. Severe water stress induced by Hardie and Considine (1976) during the first three weeks after flowering caused a reduction in fruit set. Thereafter, yield losses from water stress imposed post set were associated with reduced berry size and, following stress after veraison, the failure of fruit to mature**.** Matthews and Anderson (1989) also noted that water stress, especially imposed early in the growing season, caused a reduction in berries per bunch (a result of reduced fruit set). Water deficits imposed in olives have also resulted in decreased flower number per inflorescence and fruit per tree (Hartmann and Panetsos, 1961). Safran and Dochberg (1966) noted that irrigation caused an increase in flowers per inflorescence and bunches per vine. On the other hand, Carbonneau and Casteran (1979) found that mean flower numbers in the growing node in an irrigated block were about half as great as in an unirrigated block.

2.6. CULTURAL FACTORS INFLUENCING INFLORESCENCE AND FLOWER DEVELOPMENT

2.6.1 Canopy management

The preceding section has highlighted the relative importance of light and temperature on inflorescence and flower formation in grapevines. It is therefore fitting that much research has been tailored around manipulating the light environment in particular, of the grapevine, and investigating its influences on yield.

The major emphasis of canopy management is usually to reduce excessive canopy shading through trellis-training systems, control of shoot number and spacing, leaf removal in the fruiting zone and control of shoot vigour (Dry, 2000). Kliewer (1982) found that by changing trellis systems from a single tier to a training system dividing the canopy, node fruitfulness in the following season was improved. This effect was identified by Kliewer and Smart (1989) to be primarily due to an improvement of the light environment at the renewal zone (the zone in which the nodes holding the following season's crop are developing). Dry (2000) suggested that more specifically, this response of greater yield per node appears to be mainly a consequence of the light environment of the basal nodes (which in more shaded canopies tend to be of lower fruitfulness). Although training systems with two or more tiers can improve the light environment of the developing nodes, there have also been reports of these training systems negatively affecting yield. Shaulis and Smart (1974), May et

al. (1976) and Smart et al. (1990) all completed studies showing that shoots arising from near the bottom of the canopy were much lower in productivity. These results are presumably indicative of situations where the top tier of these tiered systems has shaded out the lower tier(s) sufficiently to depress bud fruitfulness.

Leaf removal around the fruiting zone of the canopy is generally carried out to increase light and airflow into the bunch zone, to enhance ripening and reduce potential disease pressure through decreasing humidity inside the canopy. Additionally, leaf removal has in some cases, been found to improve the viability of the developing inflorescence primordia. Removal of leaves at the fruiting zone of a very dense Sauvignon Blanc canopy during fruit set, resulted in increasing shoots per node, bunches per shoot and flower number per bunch (Kliewer and Smart, 1989). However, yield improvements through leaf removal have not always eventuated. A lack of vine response was seen by Howell et al. (1994) removing leaves mid-way between set and veraison in Pinot Noir and by Zoecklein et al. (1992) removing leaves two to three weeks after flowering in Riesling and Chardonnay. May and Antcliff (1963) recognised that the time during which shading can affect fruitfulness was critical. They determined that fruitfulness was only reduced if shade was applied during a four week period in late spring around flowering. It is therefore plausible that the leaf removal experiments undertaken by Howell et al. (1994) and Zoecklein et al. (1992) were carried out beyond this critical period to affect fruitfulness of the developing inflorescence primordia. It may also be possible that these experiments were not carried out on canopies with severe shading problems; therefore the relative improvement in light reaching the developing buds were not as great post-leaf removal as was found in the Sauvignon Blanc. Additionally, response to light post-leaf removal may be varietally specific. It is known that in general, Sauvignon Blanc has lower fruitfulness of the basal buds (Wolf, 2008) compared to many other *Vitis vinifera* cultivars. Therefore the response of this variety to changing light conditions may often be greater than that of other varieties such as Pinot Noir, Chardonnay and Riesling lacking this characteristic.

Shoot thinning in some situations has also been shown to improve yield (Shaulis and May, 1971; Shaulis, 1982). Dry (2000) interpreted that the severity of thinning determines the balance between an improved light environment within the canopy and any detrimental effects of increased vigour. Reynolds et al. (1994) removed approximately 50% of shoots in Riesling and found a small but significant effect on bunch number per shoot in the following season. However Dry and Coombe (1994) thinned 65% of shoots causing an increase in primary bud necrosis.

Another cultural practice carried out to stimulate fruit node formation for the following season as well as improving fruit set in the current season, is tipping (or topping) (Thomas and Barnard, 1937). May (1965) noted that increasing the transport of photoassimilates into developing buds contributed to an improvement in fruitfulness. This practice of tipping carried out just pre-flowering in late spring to early summer during the grand period of shoot growth, can reduce the competition for water and nutrients exerted by the rapidly growing shoot tips, thereby allowing a greater nutritional flux into differentiating inflorescence primordia and the current season's flowering bunches.

2.6.2 Vine response to pruning system

Pruning has long been considered the cheapest tool for crop regulation of grapevines during the growing season. Different pruning strategies are employed by growers as a means of setting up their vines to achieve an agreed cropping level. The impact of a pruning system on yield components is probably less well understood.

Mechanisation of winter pruning has been achieved in Australian winegrape production via the adoption of mechanical hedging, (May and Clingeleffer, 1977; Freeman and Cullis, 1981) as is commonly undertaken in Coonawarra, South Australia. When this pruning method was first introduced in the late 1970s, Clingeleffer (1989) believed that node number could not be well regulated. However, the number of nodes retained by this pruning method of late, is commonly tightly regulated by altering the position of cuts and the severity of pruning. Advancement in pruning equipment has also allowed mechanical hedging to become a more precise activity. Unlike traditional hand-pruning systems though, nodes per bearer is usually between one and six (Clingeleffer, 1989) in a mechanical hedging system.

A number of researchers have noted differences in yield components arising from different length bearers. Clingeleffer (1989) found a positive linear relationship between yield and bearer length. Longer bearers were found to have smaller bunches, but importantly, juice composition varied little between bunches on the different length bearers. López-Miranda (2002) and López-Miranda et al. (2001, 2004) found that budburst and fruit set increased from lower to higher node positions. Bessis (1965) noted that budburst increased from the base to the tip of the bearers, shoots arising from the higher node positions of the bearers were more fruitful and bunches arising from the shoots at the higher node positions contained more flowers. Dunn and Martin (2000) found that lower inflorescences on two-inflorescence shoots averaged significantly higher flower numbers than upper

inflorescences and both averaged significantly higher flower numbers than inflorescences on single-inflorescence shoots.

2.7. CONCLUSION

The reproductive cycle of the grapevine occurs over a 15-18 month period, during which time inflorescence number followed by inflorescence size is determined. Management intervention at critical stages aims to regulate yield. It's not always successful.

Development of inflorescence number is most affected by temperature, light, nutrient availability, water stress and hormone balance. Canopy management practices such as controlling shoot number and spacing, leaf removal at the fruiting zone, controlling shoot vigour, tipping and shoot positioning undertaken during the growing season are generally carried out to enhance the light environment of the current season's crop and the developing inflorescences for the following season's crop.

Flowering, fertilisation and fruit set are critical periods determining inflorescence size and therefore grapevine yield. Weather conditions around the time of flowering and fertilisation, crop load, nutritional status, soil moisture, grape variety and vineyard management practices are all crucial in determining the success or failure of potential harvest bunch size.

Annually, grapevines are pruned to a node number calculated as sufficient to achieve the desired yield and quality. Pruning has long been considered the cheapest tool for crop regulation during the growing season, especially if mechanised. Research has shown that the proportion of nodes that burst from any pruning system is affected by the number of nodes retained after pruning and the length of bearers retained by the pruning style. However, the impact of a mechanised pruning system on yield components is not well understood and will be investigated as part of this research.

CHAPTER THREE

ANALYSIS OF YIELD COMPONENT VARIATION FROM DIFFERENT BEARER NODE NUMBERS IN A MECHANICALLY PRUNED SYSTEM

3.0 INTRODUCTION

In order to achieve the desired balance between vegetative growth and crop load—a production characteristic of premium-quality grapes (Coombe and Iland, 2004)—growers must first understand how their pruning regimes affect yield production, as pruning is the cheapest tool for crop regulation.

Grapevine yield comprises bunch number and the size of the bunch. Budburst affects which nodes on a bearer will produce the shoots on which bunches are located. During the time of flowering in spring and continuing into summer, initiation and differentiation of bunch primordia and preliminary determination of their size occurs in the latent buds (Dunn and Martin, 2000) which will determine the crop load of the following season. Environmental conditions which favour the production of high bunch number have been shown by Buttrose (1969a) to promote large bunch size in Muscat Gordo Blanco (syn. Muscat of Alexandria).

Mechanisation of winter pruning is common in the Coonawarra wine region of South Australia. The severity of the pruning cuts made as part of this pruning practice, result in the retention of bearers with varying numbers of nodes on each vine. Clingeleffer (1989) studied this pruning method and reported bearer lengths in this system to range between one and six nodes in length. The position on a bearer at which a node is situated affects its contribution to the total yield of the bearer, as proximal buds are known to develop earliest in the season when weather conditions are likely to be less favourable for bunch-primordium differentiation (Buttrose, 1969a).

<u>This study aimed to provide some answers to the following major questions:</u>

i) What is the variation in bearer node number within a vine as caused by the mechanical pruning and which bearer node number contributes the most to yield? Is the magnitude of bunch number and bunch size that occurs at each node position affected by this total bearer node number? It is predicted that quantification of yield differences by bearer node number might be used when adjustments need to be made via pruning in order to achieve a target yield when faced with seasons of very high or very low node fruitfulness.

ii) How do yield components vary at each node position on different bearer node numbers common to the mechanical hedge pruning system? It is presumed that variances in predicted fruitfulness on the bearers from the proximal to distal node positions would have the largest effect on the magnitude of other yield components and the location of the nodes that contribute most to the yield of the bearer.

iii) How important is the influence of budburst on final yield? Monitoring budburst on varying length bearers, Bessis (1965) found that budburst had a strong tendency to increase from the proximal to the distal nodes on the bearer. This work aimed to verify Bessis' findings and to link budburst at preferred nodes on the bearer with the magnitude of the yield components that occurred at these node positions.

iv) How does the number of fruitful, non-fruitful and blind nodes change when bearer node number is increased? It was presumed that this area of work would show that bearers with more nodes had the greatest yield due to the greatest number of fruitful nodes and the highest fruitfulness at these fruitful node positions.

v) How do single as opposed to multiple inflorescences on a shoot vary in size? This work was proposed to provide further evidence for a positive correlation between bunch number and bunch size development.

vi) Does the node position at which a bunch occurs on a shoot affect its size? The aim of this work was to further confirm the findings of Dunn and Martin (2000) and Trought and Bloomfield (unpublished) in Trought et al. (2007) who suggested that node position did affect inflorescence size.

The depth of this proposed research into yield components that occur on different bearer node numbers in a canopy is believed to be unmatched by previous studies. Although these experiments were executed on mechanically-pruned vines, it was expected that many of the findings would not only be important for other winegrowing regions from which mechanical pruning takes place, but would also enhance our fundamental knowledge of grapevine physiology and be applicable for hand-pruning.

3.1 MATERIALS AND METHODS

3.1.1 Experimental Site

This study was conducted over season 2005/2006 in a commercial vineyard located within the Coonawarra region of the Limestone Coast zone in South Australia. The *Vitis vinifera* L. Cabernet Sauvignon vines, clone G9V3, were planted on own roots in 1984, in an east-west orientation with a spacing of 2.20m and 2.75m within and between rows respectively. Prior to commencement of the study, vines were mechanically saw-pruned to a 'tight box hedge' (225 mm wide and 200mm high with a target node number of 100 per vine. The 'box hedge' mechanical pruning system resulted in a range of bearer node numbers being retained on each vine as the fruiting wood for the following season. Prior to pruning, the bearers were observed to grow outward from the cordon at varying angles, so that when viewed cross-sectionally, bearers formed an arc around the cordon.

3.1.2 Experimental Design

Pre-Budburst

Two adjacent rows within the commercial block were chosen for this study. Vines were paired across the two rows to allow for destructive sampling from one vine prior to flowering and the second vine at harvest. Trunk circumference and bud number measurements were conducted in order to pair vines. Vines were chosen where their trunk circumference differed by less than 10mm and the node number per vine differed by less than 10. Where vines with matching trunk circumference and node number could not be found within three vine spaces along the rows, node number was reduced as required. Fifty-four vine pairs were chosen along the rows and the first and last panel were excluded.

The range of bearer node numbers retained on each vine was examined post-pruning (Figure 3.2). The bearer lengths between one and five nodes were the most common and one bearer of each node number was chosen and tagged with coloured flagging tape on each vine. The bearers were chosen so as to have a similar diameter and spatial location between the paired vines.

One week prior to Flowering

In order to confirm that the tagged bearers were similar to the total population, the Merbein Bunch Count (Antcliff et al., 1972) was conducted. The growth from each node position on each bearer present was quantified within a randomly positioned 0.3m segment (refer section 3.1.3) on one vine of every pair in the study. Budburst (positive or negative), shoot fruitfulness, number of

inflorescences per fruitful shoot and the node position on each shoot at which an inflorescence occurred was recorded. A bearer was assumed to be inside the segment when the base of the bearer fell within the segment.

Just prior to Flowering (EL18)

Tagged bearers from one vine of every pair (54 in total) were destructively sampled in the field and returned to the laboratory for analysis. Measurements of bearer diameter, positive or negative bud burst, shoot fruitfulness (a fruit bearing shoot with a least one inflorescence, referred to as 'fruitful'; a non-fruiting shoot, referred to as 'non-fruitful'; a node without a shoot or with a shoot which ceased growth after one or two small leaves have unfolded, referred to as 'blind'), shoot length, number of leaves per shoot, number of inflorescences per fruitful shoot, node position on each shoot at which an inflorescence occurred, inflorescence fresh weight and number of flowers per inflorescence were recorded. Inflorescences were individually placed into marked paper bags and dried at room temperature on a bed of silica gel until no further loss of weight was recorded. Inflorescence dry weights were then subsequently recorded.

Just prior to Commercial Harvest (within a week)

Tagged bearers from the remaining vine of every pair were destructively sampled in the field and returned to the laboratory for analysis. Measurements of bearer diameter, positive or negative bud burst, shoot fruitfulness, shoot length, number of leaves per shoot, number of bunches per fruitful shoot, node position on each shoot from at which a bunch occurred, bunch weight, number of berries per bunch and berry weight were completed.

3.1.3 Vine Measurements

Trunk circumference

A tape measure was placed around the outer edge of the vine trunk at 330 mm above the ground and the length of the circumference recorded.

Identifying random segment placement for Merbein Bunch Counting population study

Random segment location was generated using Grape Forecaster Version 5 where a segment is a 'slice' across a vine row, with a known length (S. Martin, DPI Tatura, 2001).

Bearer cross-sectional area and peduncle cross-sectional area

Kincrome 150mm digital vernier callipers (Scoresby, Australia) were opened to just touch the outer edge of the bearer or peduncle. Two diameter measurements were recorded at 90° angles to each other. The cross-sectional areas were assumed to be circular and calculated from the average of the diameter measurements. The bearer diameter measurements were taken just below the first clear node and the peduncle measurements taken at the mid-point of the peduncle.

Shoot length

A tape measure was used to record shoot length. Lengths were reported to the nearest 10mm.

Leaves per shoot

The number of clear node positions on the shoot, starting from the base and working up to the shoot tip were counted. It was assumed that the last leaf counted was the last leaf fully separated from the shoot tip. The average internode length was calculated by dividing the shoot length by the number of leaves per shoot.

Flower number per inflorescence

Just prior to the onset of flowering, individual flowers on each inflorescence collected were destructively counted by pulling off groups of flowers (florets) with tweezers. The number of flowers from each floret was summed to calculate total flower number per inflorescence.

Weight per flower

Weight per flower was calculated by dividing the total inflorescence weight by the number of flowers; the result therefore including a proportion of rachis weight.

Berry number per bunch

For each bunch collected pre-harvest, all coloured berries (hens and chickens) were plucked off the bunch and counted, with LGOs not included. 'Hen' berries are normal-sized (9-17mm, Cholet *et al*. 2002) berries with seeds. 'Chicken' berries are small (4-7mm, Cholet *et al*. 2002) berries that are ripe at harvest and are either seedless or contain seed traces (May 2004). 'LGOs' (live green ovaries) are not true berries – they are green and seedless, do not develop colour or flavour, do not accumulate sugar and do not contribute to yield (Longbottom and Dry, 2008).

Berry weight per berry

All coloured berries (hens and chickens) were plucked off each bunch and the total number recorded. The total weight of these berries was then measured. The total number of coloured berries was then divided by the total weight of the berries.

Berry weight (bunch weight per berry)

In order to compare weight per flower with weight per berry, a calculated weight per berry was used by dividing weight per bunch by the number of coloured berries (hens and chickens, not LGOs) on the bunch. This berry weight, like weight per flower, included a proportion of rachis weight.

Bunch weight

At harvest, bunches on shoots from each tagged bearer from the remaining vine pairs in the study were removed and weighed. These bunches were not the same as those inflorescences used to determine flower number per inflorescence pre-flowering.

Percentage fruit set

Inflorescences and bunches did not always occur at the same node positions on each bearer length from the vines in each pair. Therefore, averaged flower number per inflorescence and averaged berry number per bunch values for each node position on each bearer length were used to calculate percentage fruit set at each node position. Percentage fruit set was calculated by dividing berry number per bunch (hens and chickens only) by flower number per inflorescence and then applying a multiplication factor of 100.

3.1.4 Statistical Analysis

Analysis of variance for data sets was performed using 'Minitab' version 13 for Windows. Statistical significance between treatments is indicated using LSD bars at the 5% level. Least Significant Difference calculations were performed using the t distribution – inverse cdf (Table 7, Watson).

3.2 RESULTS

3.2.1 Impact of bearer node number on vegetative and yield components

3.2.1.1 Bearer node numbers retained after pruning

Two- and three-node bearers were the most common bearer node numbers retained after pruning and seven-node bearers were the longest recorded (Figure 3.1). Bearers between one- and five-nodes in length were common to almost all vine pairs in the study and were consequently the bearer lengths analysed in detail. Average cross-sectional area of the base of these bearers varied with node number. Five-node bearers were significantly thinner than all the other bearer lengths. Four node bearers were significantly thinner than the one-node bearers (Figure 3.2). Bearer cross-sectional area did not contribute to the proportion of nodes that burst on each bearer length (Table 3.1).

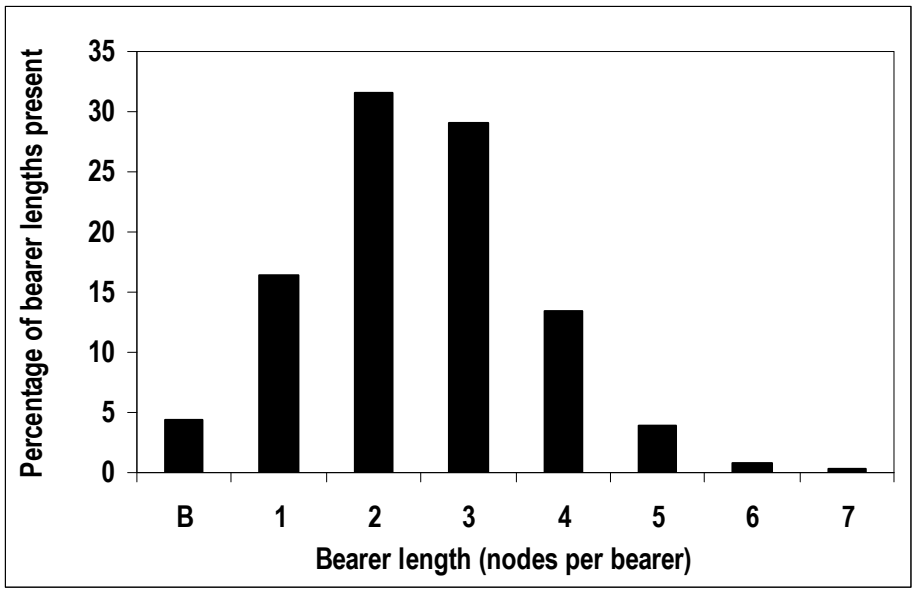


Figure 3.1 Frequency distribution of nodes per bearer after hedge pruning *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data represent the variation in bearer node numbers present within a 0.3m segment placed randomly over one vine of every pair in the study. The total number of bearers captured in this Figure is 364. Initial data was transformed from total number of bearers in each category to a percentage form. 'B' represents bearers for which only the base bud position was retained during pruning.

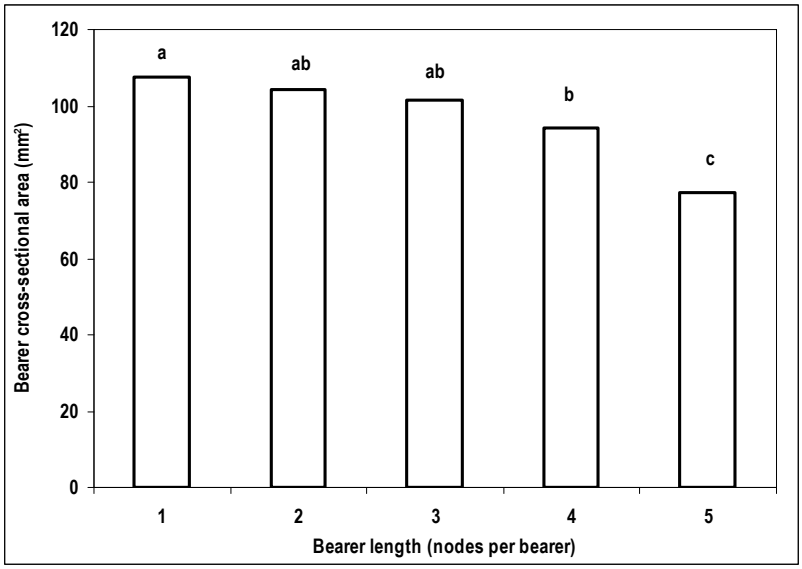


Figure 3.2 Average cross-sectional area of bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means with the same letter indicating no significant difference using LSD at 5%. Sample size ranged between 50 to 54 for each of the bearer lengths, as the full range of bearer lengths was not present across every replicate in the study.

Table 3.1. The effect of bearer cross-sectional area on the proportion of buds bursting on bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean) with budburst of the basal node position in addition to the count node positions included for each bearer node number. Means with the same letter within each bearer node number category are not significantly different using LSD at 5%. Sample size varied between the treatments and is included to equate to the relative size of the LSDs. Categories with sample size of 3 or below are not shown.

Bearer length (nodes per bearer)	Proportion of nodes bursting (including base bud position and count nodes)	N	Bearer cross-sectional area (mm^2)
One node bearer	one node burst	31	$109.04^{a} \pm 7.34$
	all nodes burst	20	$112.43^{a} \pm 9.54$
Two node bearer	two nodes burst	44	$105.87^{a} \pm 5.06$
	all nodes burst	4	$125.08^{a} \pm 14.96$
Three node bearer	two nodes burst	38	$100.25^{a} \pm 5.21$
	three nodes burst	10	$110.91^{a} \pm 13.32$
Four node bearer	two nodes burst	34	$94.19^{a} \pm 5.11$
	three nodes burst	12	$91.46^{a} \pm 8.37$
Five node bearer	two nodes burst	17	$79.43^{a} \pm 7.40$
	three nodes burst	19	$75.17^{a} \pm 4.68$
	four nodes burst	10	$83.01^{a} \pm 6.97$
			$LSD_{\%5}$ NS

3.2.1.2 Trends in measured yield components from the proximal to the distal node positions on the bearers.

When node positions a-f of Figure 3.3 are considered, there was a significant increase in percentage budburst at the proximal compared with the distal node positions on each bearer node number (Figure 3.4). The two most distal node positions on all bearer lengths except the one-node bearer showed at least a 75% chance of bursting (Figure 3.4). These same node positions also showed the greatest proportion (at least 70%) of fruitful as opposed to non-fruitful shoots (Figure 3.5).

The proportion of base bud positions that burst was less than 10% on all bearer lengths except for the base bud position on the one-node bearers, where there was approximately 45% budburst (Figure 3.4). Of the 45% of base bud positions which burst on these one-node bearers, fruitful shoots arose from only 30% of the burst nodes (Figure 3.5). Similar trends to the pattern of burst nodes were seen for the inflorescence number per burst node (Figure 3.6), flower number per inflorescence (Figure 3.7) and berry number per bunch (Figure 3.8). Flower number per inflorescence was strongly related to inflorescence weight pre-flowering, with peduncle cross-sectional area also highly correlated with inflorescence weight and flower number per inflorescence (Table 3.2). Berry number per bunch was strongly correlated with bunch weight at harvest, while peduncle cross-sectional area and berry weight poorly (although still significantly) correlated with bunch weight at harvest and peduncle cross-sectional area also correlated reasonably poorly (but significantly) with berry number per bunch at harvest (Table 3.2).

Excluding the one-node bearer length, the distal node position on each bearer length, made terminal via the pruning process, generally showed a much higher percentage budburst, percentage fruitfulness and inflorescence number per shoot than non-terminal nodes at the same node position (counted from the base of the bearer) on longer bearers (Figures 3.4, 3.5 and 3.6). This result for bunch number was unmatched by that of inflorescence or bunch size, as represented by flower number per inflorescence and berry number per bunch (Figures 3.7 and 3.8).

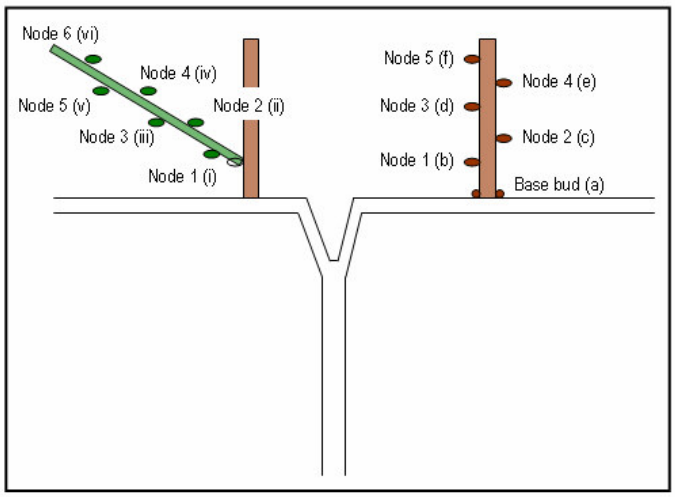


Figure 3.3 Diagram of grapevine indicating bearer (brown) and node positions on bearer (a-f) and shoot (green) and node positions on shoot (i-vi).

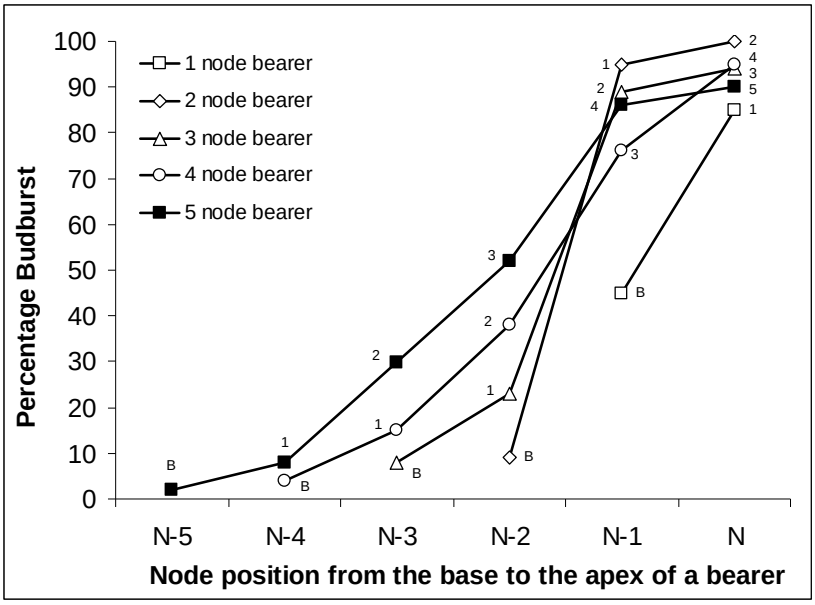


Figure 3.4 Percentage budburst at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Percentage budburst = 100 x number of burst buds/total number buds per node position (burst buds plus blind buds[1]). Data points are means. N = highest node position on each bearer length. Data point furthest to the left for each bearer node number represents the base bud position whilst the remaining points represent count nodes (as annotated). Significant differences between the data points have not been reported due to the data being count data as opposed to numerical data. Sample size ranged from 50 to 54 for each of the node positions on each bearer length, as the full range of bearer lengths was not present across every replicate in the study.

[1] Blind bud is a bud without a shoot or with a shoot which ceased growth after 1 or 2 small leaves have unfolded (Antcliff et al., 1972)

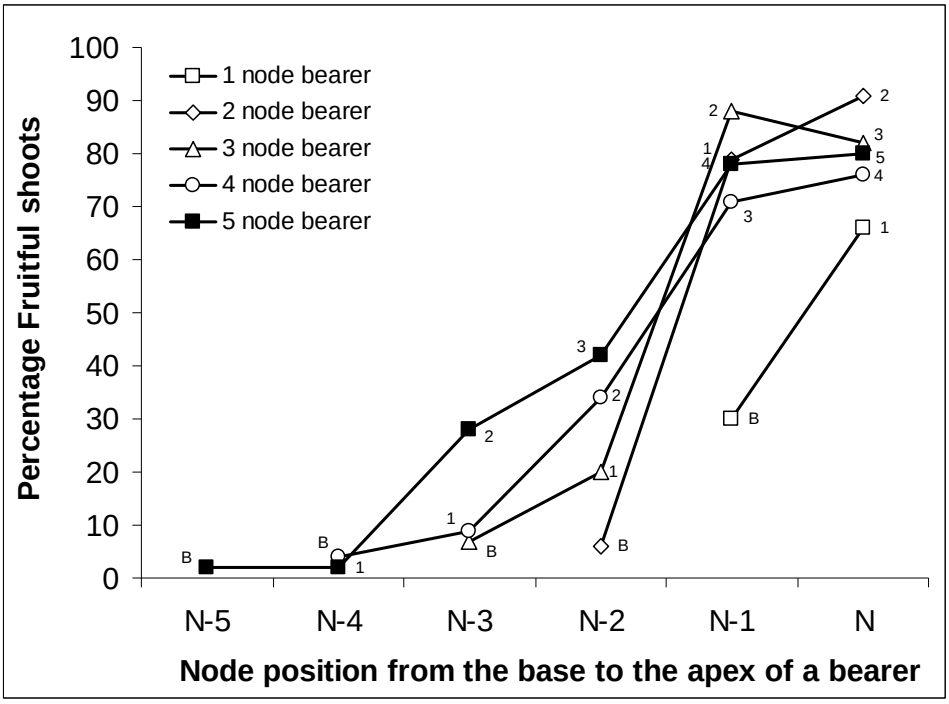


Figure 3.5 Percentage shoot fruitfulness at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Percentage fruitful shoots = 100 x number of shoots with bunches/total number nodes at each node position on a bearer (non-fruitful shoots plus blind nodes[1]). Data points are means. N = highest node position on each bearer length. Data point furthest to the left for each bearer node number represents the base bud position whilst the remaining points represent count nodes (as annotated). Significant differences between the data points have not been reported due to the data being count data as opposed to numerical data. Sample size ranged between 50 to 54 for each of the node positions on each bearer length, as the full range of bearer lengths was not present across every replicate in the study.

[1] Blind node is a node without a shoot or with a shoot which ceased growth after 1 or 2 small leaves have unfolded (Antcliff et al., 1972)

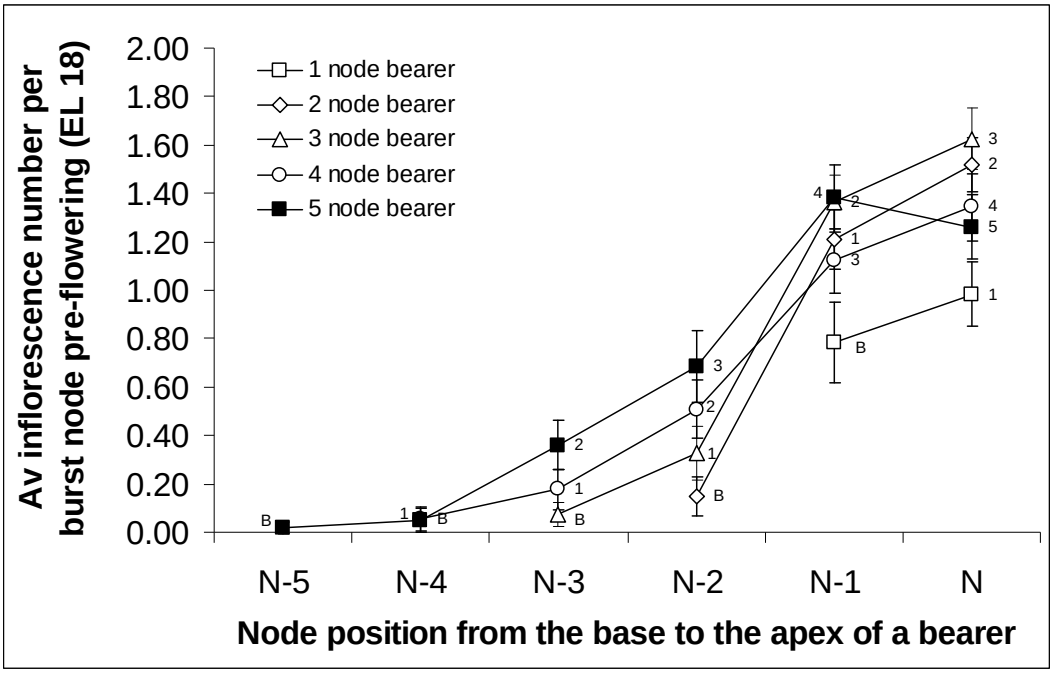


Figure 3.6 Average inflorescence number per burst node at each node position pre-flowering for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean). N = highest node position on each bearer length. Data point furthest to the left for each bearer node number represents the base bud position whilst the remaining points represent count nodes. Sample size ranged between 48 to 60 for each of the node positions on each bearer length.

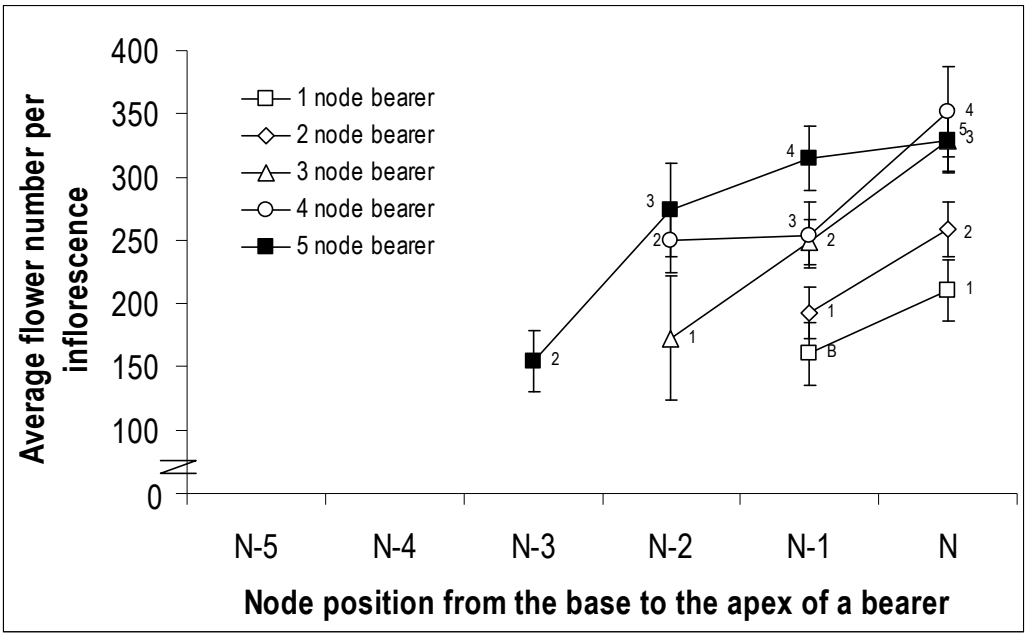


Figure 3.7 Average flower number per inflorescence at each node position pre-flowering for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean). N = highest node position on each bearer node number. Data points shown only represent count nodes (as annotated) except for the one-node bearer where the data point on the left represents the base bud position. Sample size ranged between 10 to 55 for each of the node positions on each bearer length. Data points omitted where sample size was less than 4.

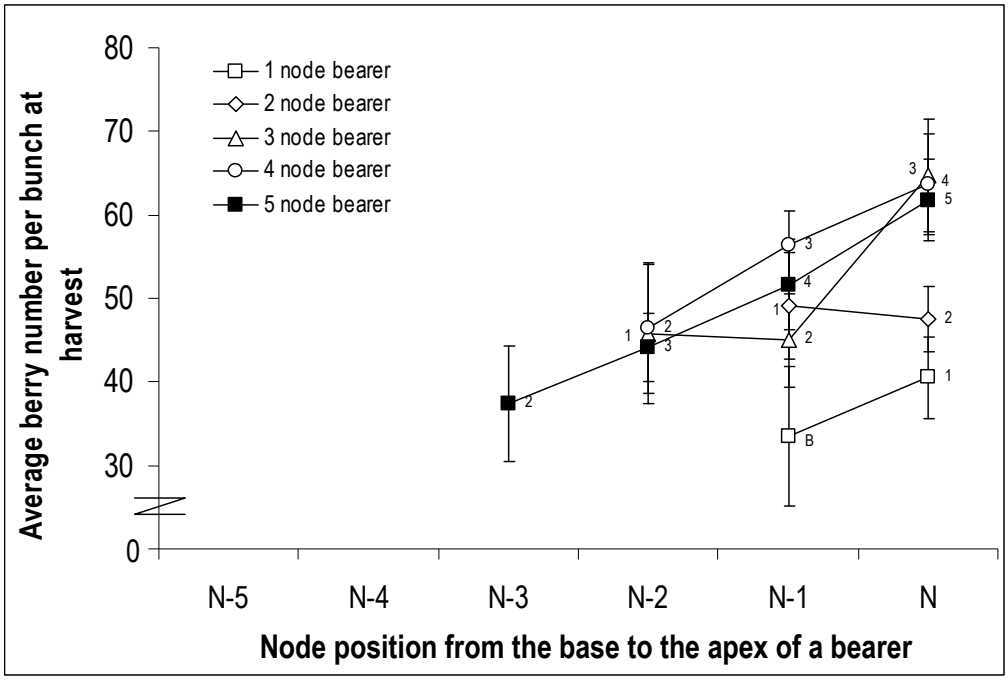


Figure 3.8 Average berry number per bunch at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean). N = highest node position on each bearer node number. Data points shown only represent count nodes except for the one-node bearer where the data point on the left represents the base bud position (as annotated). Sample size ranged between 7 to 53 for each of the node positions on each bearer length. Data points omitted where sample size was less than 5.

Table 3.2. Matrix of correlation coefficients determined for linear correlations from the treatment means of the measured variables for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Significant correlations between the variables are indicated as *p<0.05, **p<0.01 and ***p<0.001.

PRE-FLOWERING			HARVEST			
	Inflorescence weight	Peduncle cross-sectional area		Bunch weight	Peduncle cross-sectional area	Berry number per bunch
Peduncle cross-sectional area	0.770 ***		Peduncle cross-sectional area	0.360 ***		
Flower number per inflorescence	0.810 ***	0.580 ***	Berry number per bunch	0.870 ***	0.430 ***	
			Berry weight	0.160 ***	0.001	0.017 *

3.2.1.3 Effect of node position on fruit set.

When node positions a-f of Figure 3.3 are considered, apart from the four-node bearers, the most basal node positions (for which there were data) on each bearer node number, showed the highest percentage fruit set (= the highest proportion of flowers that developed into berries) (Figure 3.9).

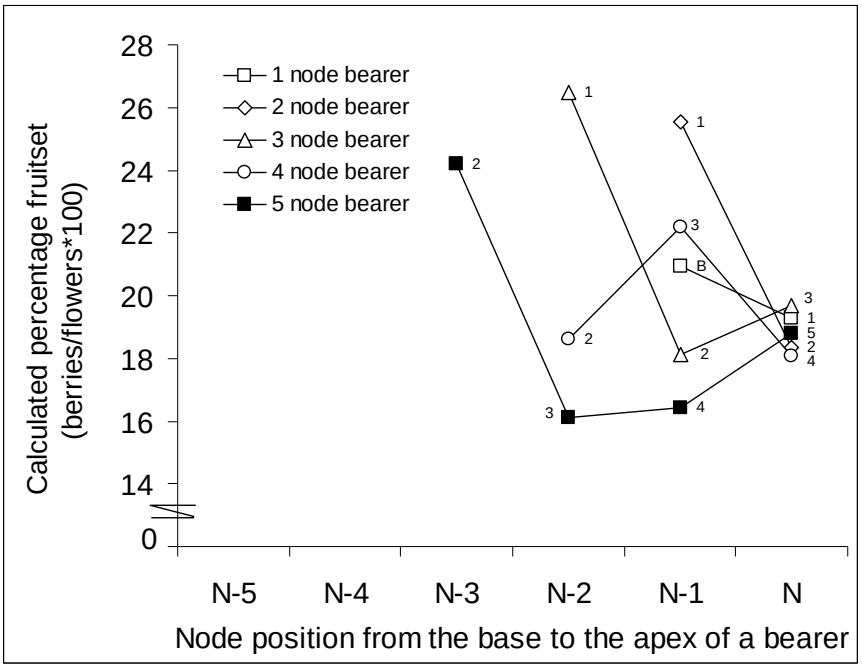


Figure 3.9 Calculated percentage fruit set at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means. N = highest node position on each bearer node number. Data points shown only represent count nodes except for the one-node bearer where the data point on the left represents the base bud position (as annotated). Significant differences between the data points have not been reported due to the data points being a calculation of flower number and berry number data. Sample size of each of the flower number and berry number data sets for each node position used to calculate percentage fruit set, ranged from 7 to 55. Data points omitted where sample size was less than 7.

3.2.1.4 Effect of node position on weight per flower and weight per berry.

When node positions a-f of Figure 3.3 are considered, weight per flower was highest at the distal compared with the proximal node positions on each bearer node number (Figure 3.10). The distal node position on each bearer node number (made terminal via the pruning process) generally showed a higher weight per flower (although not always significantly higher) than non-terminal nodes at the same node position (counted from the base of the bearer) on longer bearers (Figure 3.10). Weight per berry showed little variation between node positions on each bearer node number (Figure 3.11). Node positions made terminal via pruning did not have heavier berries compared with non-terminal nodes at the same node position on longer bearers (Figure 3.11).

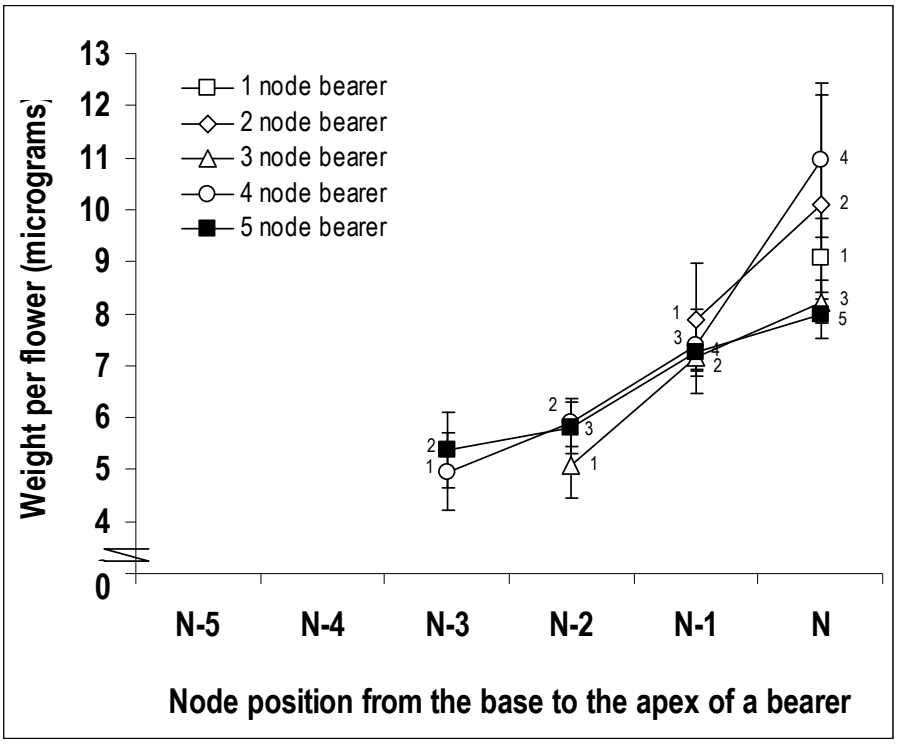


Figure 3.10 Average weight per flower at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean). N = highest node position on each bearer node number. Data points shown only represent count nodes (as annotated). Sample size ranged between 7 to 74 for each of the node positions on each bearer node number. Data points omitted where sample size was less than 7.

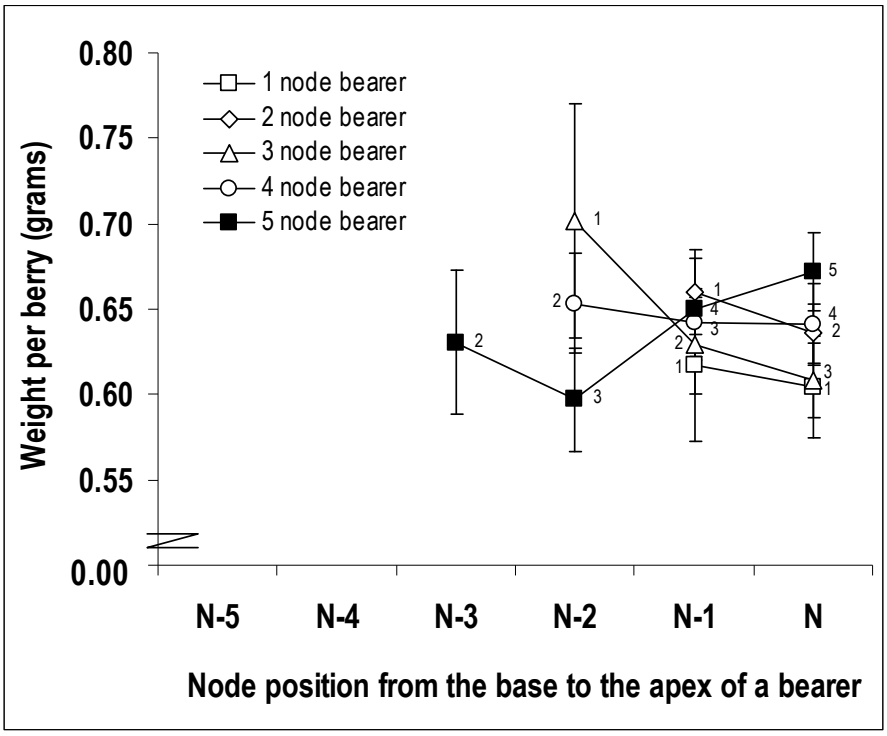


Figure 3.11 Average weight per berry at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean) for bunch weight per berry. N = highest node position on each bearer node number. Data points shown only represent count nodes except for the one-node bearer where the data point on the left represents the base bud position (as annotated). Sample size ranged between 13 to 63 for each of the node positions on each bearer node number. Data points omitted where sample size was less than 7.

3.2.1.5 Relationships between yield and node position and yield and bearer node number and the change in the proportion of fruitful, non-fruitful and blind nodes on different bearer node numbers.

When node positions a-f of Figure 3.3 are considered, average pre-flowering inflorescence weight per node (Figure 3.12) increased from the lower to the higher node positions on all bearer node numbers. There was a positive relationship between average yield per bearer and bearer length (nodes per bearer); however, this relationship was non-linear, with no statistically significant increase in yield per bearer once bearer node number increased past three nodes (Figure 3.13).

Pre-flowering, there was a highly significant correlation between bearer length and the average fruitfulness type (fruitful, non-fruitful, blind) of the bearer ($p<0.001$) (A1.1, Appendix 1) whereby the bearers with the smaller node number were on average, more fruitful than bearers with the higher

node number. This result was possibly affected by bearer cross-sectional area. The correlation between bearer cross-sectional area and fruitfulness type showed a highly significant result ($p<0.001$) (A1.2, Appendix 1) whereby bearers with fruitful shoots tended to have a larger cross-sectional area compared to bearers which had non-fruitful shoots or blind nodes. As bearer length increased, the proportion of blind nodes increased and the proportion of both fruitful and non-fruitful nodes on a bearer decreased (Figure 3.14). Bearers of one or two nodes in length had the greatest proportion of non-fruitful shoots and the three-node bearers had the lowest proportion of non-fruitful shoots (Figure 3.14).

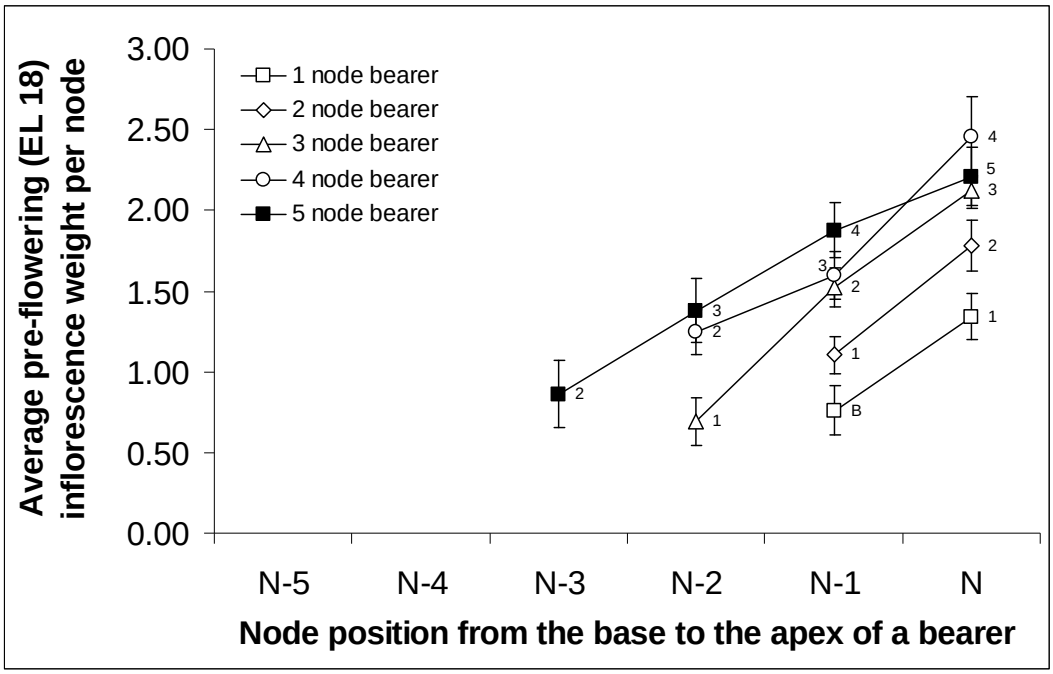


Figure 3.12 Average weight pre-flowering at each node position for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data points are means ± standard error (mean). Weight per node represents the addition of each inflorescence weight that occurred at each node position on a bearer. N = highest node position on each bearer node number. Data points shown only represent count nodes except for the one-node bearer where the data point on the left represents the base bud position (as annotated). Sample size ranged between 16 to 78 for each of the node positions on each bearer node number. Data points omitted where sample size was less than 8.

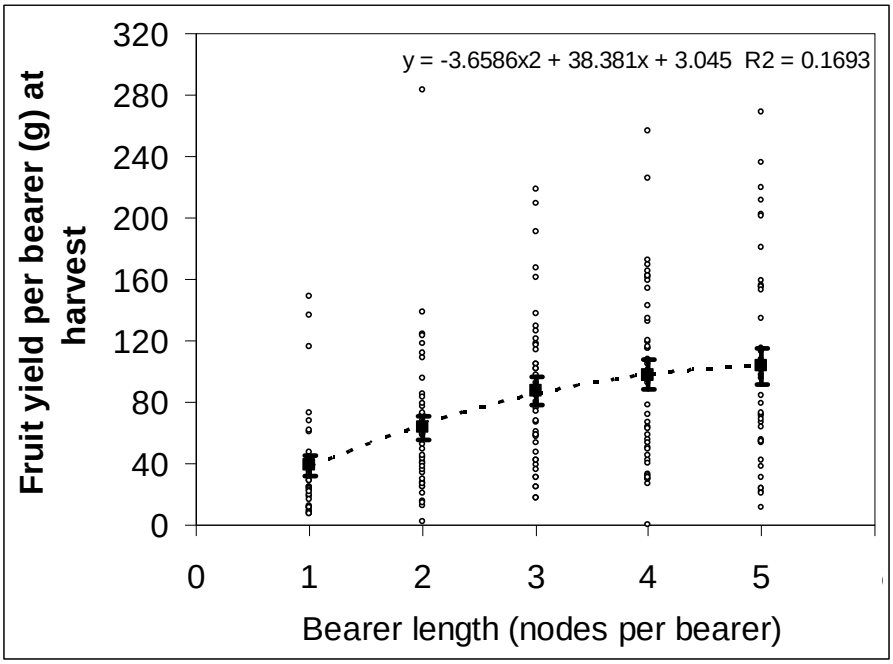


Figure 3.13 Average yield per bearer pre-harvest for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Regression was conducted using all values (open circles) with means additionally presented for clarity. Bold squares are means ± standard error (mean). Sample size varied from 36 to 48 per bearer node number. Data for base bud positions was included for each bearer.

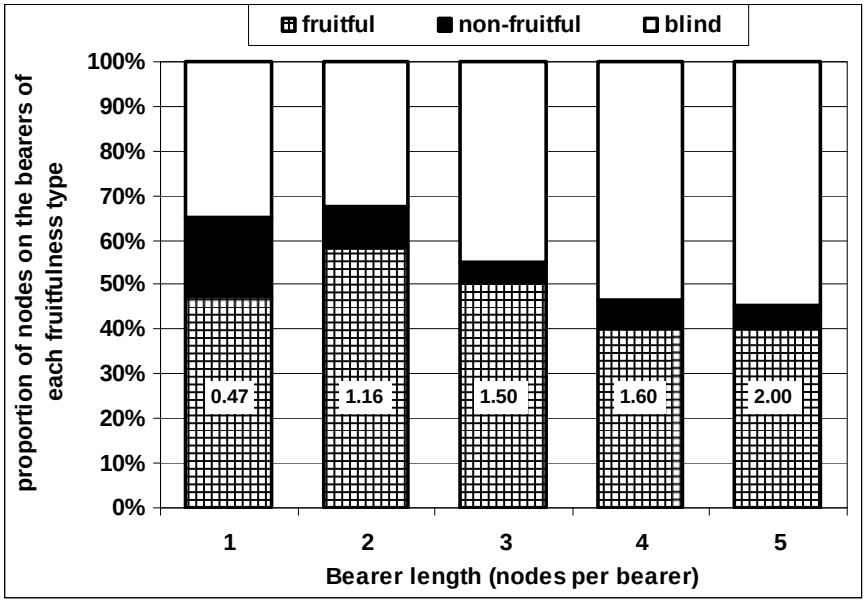


Figure 3.14 Effect of bearer node number on the proportion of fruitful, non-fruitful and blind[1] nodes per bearer pre-flowering for the bearer lengths between 1 and 5 nodes for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data represent the proportionate make-up of nodes of each fruitfulness type on each bearer node number and include results for base buds. Sample size for the number of nodes analysed across all bearer lengths was 1043, ranging from 114 nodes on the one-node bearers to 297 nodes on the five-node bearers. General Linear Model of fruitfulness type x bearer length returned a highly significant result of $p<0.001$. Actual number of fruitful nodes for each bearer node number indicated in boxes and calculated from bearer length multiplied by proportion of fruitful nodes on each bearer.

3.2.2 Size differences of single as opposed to multiple inflorescences on a shoot

When node positions i-vi of Figure 3.3 are considered, basal inflorescences were significantly heavier, had thicker peduncles and more flowers per inflorescence than apical inflorescences on two-inflorescence shoots (Table 3.3). The inflorescences on three-inflorescence shoots followed a similar pattern; however, the small sample size made statistically significant patterns hard to distinguish.

The inflorescence weight, peduncle cross-sectional area and flower number per inflorescence of the single inflorescences on a shoot were more similar to the apical inflorescences as opposed to the basal inflorescences on the two-inflorescence shoots. The average inflorescence weight and flower number per inflorescence of the single inflorescences were, however, significantly higher than that of the apical inflorescences of the two-inflorescence shoots (Table 3.3). The apical inflorescences on

[1] Blind node is a node without a shoot or with a shoot which ceased growth after 1 or 2 small leaves have unfolded (Antcliff et al., 1972)

the three-inflorescence shoots were significantly lighter, had fewer flowers per inflorescence and thinner peduncles than the other inflorescence categories in this study (Table 3.3).

Table 3.3. The influence of inflorescence node position on yield components for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean). Means with the same letter within columns are not significantly different using LSD at 5%. Sample size varied between the treatments and is included to equate to the relative size of the LSDs. No LSDs are stated for weight per flower because the data are calculations from treatment means. Weight per flower = inflorescence weight / flower number per inflorescence.

		PRE-FLOWERING						
Inflorescence position	**N**	**Inflorescence weight (g)**		**Peduncle cross-sectional area (mm²)**		**Flower number per inflorescence**		**Weight per flower (micrograms)**
			LSD		**LSD**		**LSD**	
1-infl basal	206	1.37^{c} ± 0.07	0.08	3.72^{b} ± 0.16	0.19	199.29^{b} ± 7.75	9.02	6.87
2-infl basal	281	2.28^{a} ± 0.07	0.09	5.33^{a} ± 0.15	0.18	321.81^{a} ± 8.32	9.68	7.08
2-infl apical	280	1.20^{d} ± 0.06	0.07	3.66^{b} ± 0.13	0.15	161.13^{c} ± 7.52	8.75	7.45
3-infl basal	6	2.66^{abcd} ± 1.04	1.44	7.13^{ab} ± 2.62	3.61	362.67^{abc} ± 147.20	202.2	7.33
3-infl middle	6	1.39^{bcd} ± 0.51	0.71	4.60^{abc} ± 1.88	2.59	170.59^{bc} ± 71.89	98.77	8.15
3-infl apical	6	0.34^{e} ± 0.10	0.14	1.83^{c} ± 0.43	0.60	37.33^{d} ± 17.40	23.91	9.11

When there were two bunches on a shoot pre-harvest, average bunch weight, peduncle cross-sectional area and berry number per bunch decreased significantly from the basal to the apical position (Table 3.4). Berry weight followed the opposite pattern (Table 3.4). Bunch weight and berry number per bunch were significantly higher for the basal bunch when two bunches were present on a shoot, compared with bunches on the single-bunch shoots (Table 3.4). Berry weight on the single-bunch shoots was not significantly different to the basal bunch of the multiple-bunch shoots (Table 3.4). The bunch weight, peduncle cross-sectional area and berry number per bunch of the single bunches on a shoot were mid-placed in magnitude compared with the results of the basal and apical bunches on the two-bunch shoots (Table 3.4).

Whilst the weight per flower data precluded calculations of significance, increases were noted as the inflorescence was located at a more distal position on the shoot (Table 3.3). This result was opposite to that of flower number per inflorescence and inflorescence weight. Weight per flower was the least

for single inflorescences and most comparable to that of the basal inflorescences of the two-inflorescence shoots.

At a value of 24%, fruit set was similar for the single-bunch shoots and apical bunches on the two-bunch shoots. Fruit set was lower (20%) on the basal bunches of the two-bunch shoots (Table 3.4).

Table 3.4. The influence of bunch node position on yield components for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean). Means with the same letter within columns are not significantly different using LSD at 5%. Sample size varied between 160-221 for each of the treatments for the different analyses. There was only a single case of three bunches per shoot remaining at harvest and this data was omitted. No LSDs are stated for percentage fruit set because the data are calculations from treatment means. Percentage fruit set = flower number per inflorescence / berry number per bunch x 100.

	HARVEST								
Bunch position	**Bunch weight (g)**		**Peduncle cross-sectional area (mm^2)**		**Berry number per bunch**		**Berry weight per berry(g)**		**Percentage fruit set**
		LSD		**LSD**		**LSD**		**LSD**	
1-bnch basal	31.31^{b} ± 1.42	1.65	5.43^{a} ± 0.59	0.68	47.05^{b} ± 1.89	2.17	0.56^{b} ± 0.01	0.01	24
2-bnch basal	40.74^{a} ± 1.63	1.90	6.04^{a} ± 0.20	0.23	62.81^{a} ± 2.13	2.47	0.55^{b} ± 0.01	0.01	20
2-bnch apical	25.17^{c} ± 1.40	1.63	4.47^{b} ± 0.18	0.21	38.56^{c} ± 2.07	2.40	0.58^{a} ± 0.01	0.01	24

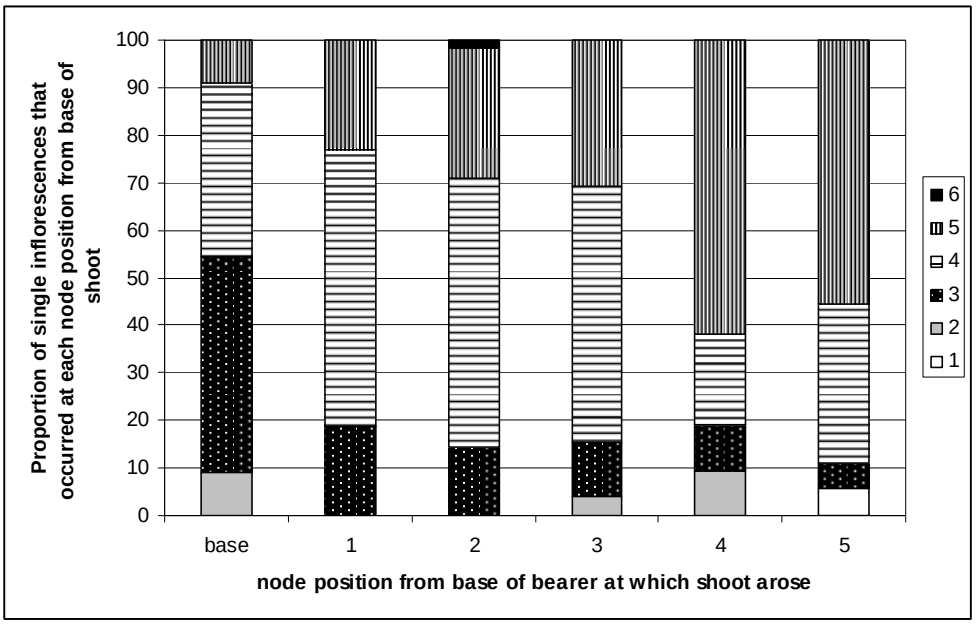
3.2.3 Relationship between the size of the inflorescence and the node position on the shoot at which it is located.

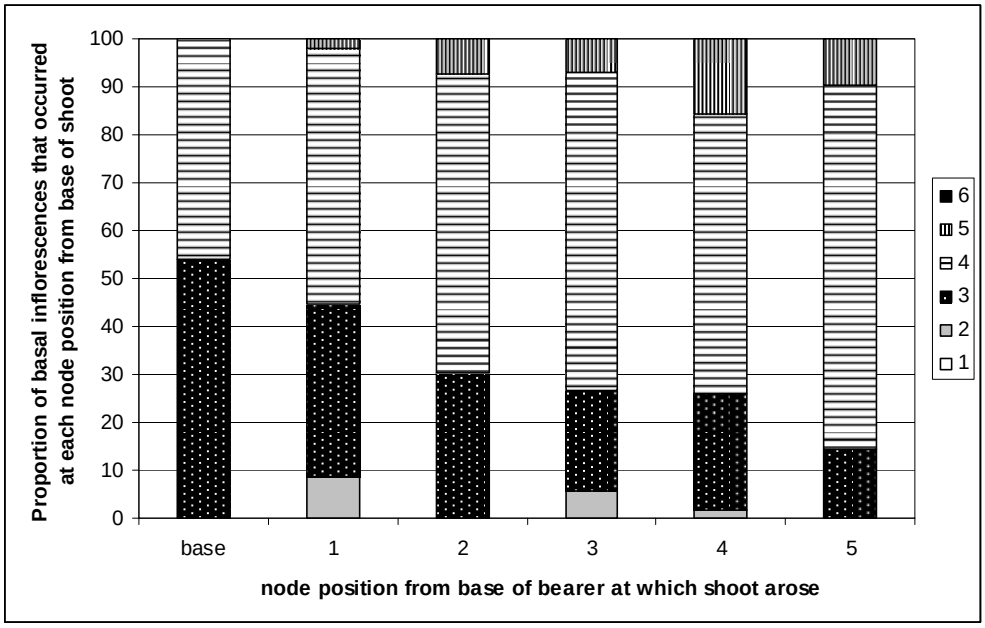
As shoots occurred on more distal node positions on the bearer (Figure 3.3 node positions a-f) inflorescences on these shoots occurred at more distal node positions as well (Figure 3.3 node positions i-vi, Figure 3.15). This result held for both single inflorescence shoots and the apical and basal inflorescence of the two-inflorescence shoots (Figure 3.15).

When shoots from all node positions on the bearer were pooled, inflorescences at node position 5 as opposed to node positions 3 or 4, counted from the base on the single-inflorescence shoots, were significantly heavier. The same result occurred for the basal inflorescence on the two-inflorescence shoots (Figure 3.15, Table 3.5). The apical inflorescences on the two-inflorescence shoots, however, showed a reverse trend in inflorescence weight with node position. Inflorescences at node position 6 were significantly lighter than inflorescences at node positions 4 and 5 on the shoot

(Figure 3.15, Table 3.5). The flower number per inflorescence and peduncle cross-sectional area showed a comparable trend to the inflorescence weights across the node positions (Table 3.5). The average peduncle cross-sectional areas for the single inflorescences were comparable to those of the apical inflorescences of the two-inflorescence shoots, irrespective of node position at which the inflorescences arose (Table 3.5). The inflorescence weight, peduncle cross-sectional area and flower number per inflorescence of the basal inflorescences on the two-inflorescence shoots were significantly higher across all node positions compared with the other inflorescence positions.

When shoots collected pre-flowering were analysed separately according to their node position on the bearer, there was no significant difference for inflorescence weight, flower number per inflorescence and peduncle cross-sectional area for inflorescences that occurred at different node positions on the single-inflorescence shoots (Table 3.6). Likewise, the same results were evident for both the basal and apical inflorescences (assessed separately) on the two-inflorescences shoots (Table 3.7) and deviations from this result are attributed to chance.





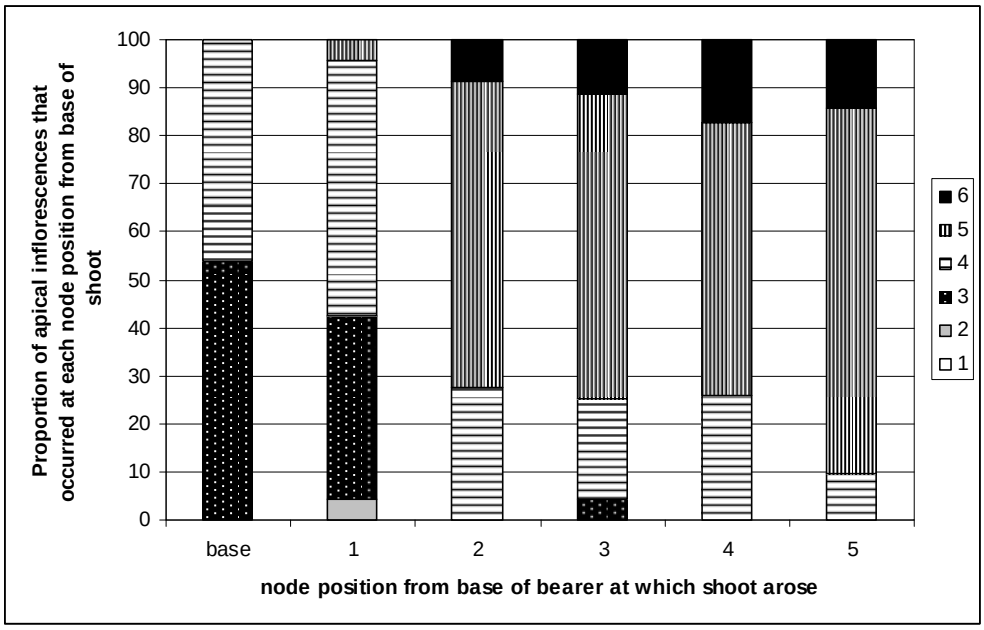


Figure 3.15 a,b,c. One hundred per cent stacked columns showing the range of node positions at which inflorescences arose on each shoot, based on the location of the shoot from the base of the bearer for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Figure a – single inflorescence shoots; Figure b – basal inflorescence of two-inflorescence shoots; Figure c - apical inflorescence of two-inflorescence shoots. Sample size for the single inflorescence shoots was 179. Sample size for the two-inflorescence shoots was 279 each for the basal and apical inflorescences.

Table 3.5. The influence of node position on the shoot at which an inflorescence is located, on its pre-flowering yield components for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean). Means with the same letter within columns are not significantly different using LSD at 5%. Statistical differences not displayed for summed data section of the table.

		PRE-FLOWERING					
Inflorescence position on the shoot	**N**	**Inflorescence weight (g)**		**Peduncle cross-sectional area (mm²)**		**Flower number per inflorescence**	
			LSD		**LSD**		**LSD**
1 infl/sht-node 3	28	1.15 ^{de} ± 0.16	0.19	3. 05 ^{d} ± 0.34	0.41	181.07 ^{cd} ± 18.51	22.29
1 infl/sht-node 4	87	1.27 ^{d} ± 0.09	0.11	3.76 ^{cd} ± 0.26	0.31	195.32 ^{c} ± 11.58	13.69
1 infl/sht-node 5	57	1.64 ^{c} ± 0.13	0.15	4.04 ^{c} ± 0.30	0.35	214.84 ^{c} ± 15.49	18.44
2 infl/sht basal-node 3	76	2.31 ^{b} ± 0.14	0.16	5.58 ^{b} ± 0.30	0.35	340.08 ^{ab} ± 15.98	18.88
2 infl/sht basal-node 4	195	2.31 ^{b} ± 0.09	0.10	5.18 ^{b} ± 0.19	0.22	321.80 ^{b} ± 9.50	11.06
2 infl/sht basal-node 5	22	3.09 ^{a} ± 0.34	0.42	7.01 ^{a} ± 0.60	0.72	389.74 ^{a} ± 33.35	40.50
2 infl/sht apical-node 4	75	1.27 ^{d} ± 0.11	0.14	3.71 ^{cd} ± 0.26	0.31	178.18 ^{c} ± 14.45	17.07
2 infl/sht apical-node 5	170	1.10 ^{de} ± 0.06	0.07	3.46 ^{cd} ± 0.15	0.17	145.53 ^{d} ± 8.51	9.90
2 infl/sht apical-node 6	29	0.83 ^{e} ± 0.14	0.17	3.39 ^{cd} ± 0.33	0.40	89.77 ^{e} ± 17.06	20.50

Table 3.6. Comparison of pre-flowering yield components, for single inflorescences at different node positions counted from the base of the shoot, on shoots arising from different node positions from the base of the bearer for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean). Means with the same letter within columns and node position from the base of the bearer, are not significantly different using LSD at 5%. Only data for count nodes is presented. Data from node position 4 from the base of the bearer is omitted due to a lack of inflorescences occurring at more than one node position.

			SINGLE INFLORESCENCE SHOOTS PRE-FLOWERING					
Node position from base of bearer	**Node position from base of shoot**	**N**	**Inflorescence weight (g)**		**Peduncle cross-sectional area (mm^2)**		**Flower number per inflorescence**	
				LSD		**LSD**		**LSD**
1	**3**	9	0.85[a] ± 0.20	0.24	2.30 [a] ± 0.33	0.40	135.22 [a] ± 23.96	31.52
	4	28	1.12[a]± 0.12	0.14	3.51 [a] ± 0.35	0.41	177.96 [a] ± 17.44	21.00
	5	11	1.18[a] ± 0.30	0.35	3.57 [a] ± 0.69	0.82	172.45 [a] ± 41.66	53.37
2	**3**	8	1.39[a] ± 0.26	0.35	3.94 [a] ± 0.60	0.81	236.75 [a] ± 28.66	38.39
	4	31	1.27[a] ± 0.14	0.16	3.55 [a] ± 0.39	0.46	201.19 [a] ± 18.59	22.31
	5	15	1.68[a] ± 0.21	0.26	4.23 [a] ± 0.32	0.65	212.33 [a] ± 21.97	27.35
3	**4**	14	1.17[a] ± 0.21	0.26	3.70 [a] ± 0.64	0.26	187.57 [a] ± 28.88	34.91
	5	8	1.29[a] ± 0.24	0.35	3.04 [a] ± 0.43	0.35	163.25 [a] ± 33.75	48.08
5	**4**	6	2.01[a] ± 0.42	0.60	5.99 [a] ± 0.53	0.75	281.50 [a] ± 35.96	51.24
	5	10	2.31[a] ± 0.27	0.35	5.15 [a] ± 0.54	0.71	309.50 [a] ± 35.77	45.85

Table 3.7. Comparison of pre-flowering yield components, for both basal and apical inflorescences that occur at different node positions on the shoot, and occur on shoots at different node positions on the bearer for hedge pruned *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005).

Data are means ± standard error (mean). Means with the same letter within columns, node position from the base of the bearer and inflorescence position (basal or apical) are not significantly different using LSD at 5%. Only data for count nodes is presented. Data from node position 5 from the base of the bearer is omitted due to a lack of inflorescences occurring at more than one node position. Shoot node positions with a sample size of 10 or less were omitted.

				TWO-INFLORESCENCE SHOOTS PRE-FLOWERING					
Node position from base of bearer	Node position from base of shoot	Relative position of inflorescence	N	Inflorescence weight (g)		Peduncle cross-sectional area (mm^2)		Flower number per inflorescence	
					LSD		LSD		LSD
1	3	basal	17	1.79 [a] ± 0.29	0.36	4.61[a] ± 0.66	0.81	282.47[a] ± 34.35	42.41
	4	basal	25	1.53 [a] ± 0.11	0.14	4.05[a] ± 0.34	0.41	218.24[a] ± 14.08	17.04
	4	apical	18	0.88 [a] ± 0.21	0.25	3.10[a] ± 0.45	0.55	125.11[a] ± 25.05	30.83
	5	apical	25	0.58[a] ± 0.10	0.12	2.65[a] ± 0.33	0.40	74.56[a] ± 15.45	18.69
2	3	basal	21	2.38[a] ± 0.22	0.27	5.77[a] ± 0.59	0.72	331.05[a] ± 21.46	26.17
	4	basal	43	2.01[a] ± 0.15	0.17	4.55[b] ± 0.36	0.42	292.63[a] ± 16.38	19.50
	4	apical	19	1.20[a] ± 0.16	0.19	3.62[a] ± 0.39	0.48	156.00[a] ± 18.95	23.23
	5	apical	44	0.90[a] ± 0.11	0.13	3.11[b] ± 0.33	0.39	130.59[a] ± 15.49	18.45
3	3	basal	15	2.32[a] ± 0.35	0.43	5.50[a] ± 0.68	0.84	367.40[a] ± 44.98	56.01
	4	basal	47	2.48[a] ± 0.15	0.17	5.31[a] ± 0.31	0.37	348.85[a] ± 16.47	19.19
	4	apical	15	1.35[a] ± 0.29	0.36	3.67[a] ± 0.58	0.72	186.20[a] ± 38.85	48.38
	5	apical	45	1.31[a] ± 0.12	0.13	3.86[a] ± 0.26	0.30	180.53[a] ± 15.95	18.99
4	3	basal	14	3.01[a] ± 0.36	0.45	6.57[a] ± 0.81	1.01	413.29[a] ± 40.44	50.65
	4	basal	34	2.90[a] ± 0.22	0.27	6.20[a] ± 0.50	0.60	392.15[a] ± 22.16	26.60
	4	apical	15	1.93[a] ± 0.32	0.39	4.59[a] ± 0.87	1.09	284.47[a] ± 30.21	37.62
	5	apical	33	1.39[a] ± 0.16	0.19	3.90[a] ± 0.31	0.37	165.73[b] ± 19.97	23.97

DISCUSSION

3.3.1 Impact of bearer node number on vegetative and yield components

3.3.1.1 Bearer node numbers retained after pruning

The process of mechanical hedge pruning using saws relies on the operator moving these saws inwards or outwards and upwards or downwards from the cordon wire along the vine row to produce a 'box' shape which contains the target node number per vine (Figure 3.16). The annual fruiting wood (which will become the bearers in the following season) grows out at different angles and at different heights from the cordon in this type of pruning system. Therefore, the specific dimensions of this box shape facilitated the variation in bearer lengths (and the most common lengths) reported in Figure 3.1. These results were of similar magnitude to those reported in another study of mechanical pruning in Coonawarra by Clingeleffer (1989).

It was noted that the five-node bearers originated from the base or the centre of the hedge whereas the shorter bearers originated from points much closer to the outer edge of the hedge. This is why different length bearers result during this mechanical pruning process. The average internode length of the different length bearers was calculated but found not to significantly differ between bearers of different node number (results not included). This result does not explain why the five-node bearers in particular were significantly thinner than the other bearer lengths (Figure 3.2). Although this difference in bearer cross-sectional area may be a phenomenon related specifically to this pruning style, it is suggested that thickening of the cell walls in the ray tissue (Mullins et al., 1992) during the lignification process in the previous season may not have occurred to the same extent in these canes (of higher node number positioned more internally in the canopy) compared with the shorter canes positioned closer to the outer edge of the hedge. Within each bearer node number, the proportion of nodes that burst was not, however, driven by this bearer cross-sectional area (Table 3.1), so it is surmised that budburst was not adversely affected on the five-node bearers even though they were significantly thinner than the shorter bearer lengths (Figure 3.2).

Figure 3.16 Mechanical hedge saw pruning: *Vitis vinifera* cv. Cabernet Sauvignon vines at Coonawarra (2005) pre-pruning (left) and post-pruning (right).

3.3.1.2 Trends in measured yield components from the proximal to the distal node positions on the bearers.

Percentage budburst was found to be highest at the most distal node positions on each bearer length studied (Figure 3.4). This stimulation of nodes to burst in higher proportions from the more distal positions is a necessity for a tree-climbing plant such as a grapevine (Martin and Dunn, 2000). This observed hierarchy in budburst, in particular, can be attributed to the grapevine's budburst regulation mechanisms of hormonally-driven apical dominance, the relative sink of the nodes on each length bearer based on their fruitfulness and the influence of the pruning cut. Movement of auxins from the distal towards the proximal end of the bearer suppresses budburst at the nodes closest to the base of the bearer and results in earlier budburst of the most distal nodes (Clingeleffer, 1989). These most distal nodes were also noted by Antcliff and Webster (1955), Bessis (1965) and Martin and Dunn (2000) to burst earlier than proximal node positions due to their higher fruitfulness and thus preferential requirement for assimilates. Pool et al. (1978) observed earlier budburst at node positions proximal to pruning cuts. This observation was subsequently explained by Shulman et al. (1983) as being caused by a preferential increase in respiration at these node positions.

Inflorescence number per burst node pre-flowering was also all found to be highest at the most distal node positions for every bearer node number studied (Figure 3.6). Although the hierarchy of budburst described above promotes budburst at nodes with the highest fruitfulness, this node-to-node variation in fruitfulness (bunch number) on a bearer is already pre-determined prior to the phenological stage of budburst, due to several influences. The first is a genetically-fixed

phenomenon which describes the quadratic trend in fruitfulness from the proximal part of the cane to the middle portion (peaking approximately at node 10) and then the subsequent decrease towards the distal portion (May, 1987). The second is the variation in actual fruitfulness level from the proximal node position to the distally-retained node position on a cane—which varies from season to season. For this study, the distal node position on all bearers showed the highest inflorescence number (or actual fruitfulness) (Figure 3.6) due to both the genetic influence on fruitfulness and the unique microclimate of temperature and light at each node position and that surrounding the individual shoots (Sanchez and Dokoozlian, 2005). As temperature and light are lowest in the interior of the canopy due to shading, the number of inflorescence primordia is lowest at the proximal end of each cane (May and Cellier,1973). On the other hand, inflorescence primordia per node tends to be higher at more distal node positions on the cane (at the node positions observed for this study) because these primordia develop later in time, when temperature and light conditions are more favourable (Buttrose, 1969a; May and Cellier,1973). The third involves the balance between shoot growth in the current season and the development of the uncommitted primordia in the latent buds. Boss et al. (2003) and Sreekantan and Thomas (2005) suggested that when uncommitted primordia are formed in latent buds they usually develop into tendrils when they are formed on rapidly elongating shoots, due to a suppression of the floral stimulus. This result of lower bunch number at more proximal node positions on all bearer lengths studied was shown in Figure 3.6. As shoot elongation is rapid in mid-late spring in Coonawarra when inflorescence primordium initiation begins, it is plausible that shoot growth in terms of dry weight accumulation may affect this initiation. In addition, shoot growth in terms of dry weight accumulation is more rapid in mid-late spring when temperatures are around 20ºC (Buttrose, 1968), whereas bud development both in terms of bunch primordia and size is optimal at around 30ºC (Buttrose, 1969a) through late spring to summer. Hence, bunch primordia that develop at the proximal node positions on a bearer, develop in sub-optimal conditions - conditions that preferentially favour shoot growth.

The observation that shoots that arose from distal node positions on the bearers also displayed higher flower number per inflorescence (Figure 3.7) can be attributed to the conditions during the previous spring which preferentially favoured inflorescence initiation at these distal node positions, and resulted in more branching prior to dormancy that determined the relative size of the inflorescence in terms of the number of flowers on the inflorescence (Barnard, 1932; Srinivasan and Mullins, 1981; Dunn and Martin, 2000). It is likely that the greater number of berries per bunch arising from shoots at the distal node positions on the bearers (Figure 3.8), also found by Lopez-

Miranda and Yuste (2004), were as a direct result of these higher flower numbers per inflorescence at the distal node positions and to a lesser extent, the success of flowering.

3.3.1.3 Comparison of yield components at a terminal node position on a bearer compared with the same non-terminal node position on a longer bearer.

After pruning, the node positions (on each length bearer) that were previously exposed to the most optimal light and temperature environment during initiation will be positioned proximally to the pruning cut at the outer edge of the hedge. It was from these distal nodes on each bearer length that the highest percentage budburst and inflorescence number was recorded (Figures 3.4, 3.6). It was also apparent that that the distal node position on each bearer length (made terminal via the pruning process) had more inflorescences than a non-terminal node of the same node position counted from the base on longer bearers (Figure 3.6). For example, the terminal node position two counted from the base of the two-node bearer had more inflorescences per node than node position two of the three-node bearer, which in turn had more inflorescences per node than node position two of the four-node bearer, which in turn had more inflorescences per node than node position two of the five-node bearer (Figure 3.6). This relationship between inflorescence number and node position therefore appeared to be dependent on bearer length, that is, inflorescence number at each node position on a bearer appeared to be influenced by its proximity to the distal-node position on the bearer.

Inflorescence number was also likely affected by the relative budburst percentage at each node position on the bearer, with higher budburst on the shorter bearers (Figure 3.4). It is possible that budburst acted by modifying potential inflorescence number per node, based on the relative location of each node from the apex of the bearer. Therefore, the factors that affect budburst (discussed in section 3.3.1.2) such as hormonally-driven apical dominance, the strength of the sink of the terminal node positions and the effect of the pruning cut are perhaps stronger drivers of yield potential in the mechanically-pruned hedge than have previously been considered. Latent buds on grapevine shoots undergo differentiation in acropetal succession rather than differentiation over a number of buds at any one time (Buttrose, 1969b). Therefore, it is expected that had the bearers retained post-pruning been of equal node number as for hand-pruning systems (where the bearers generally originate at the same distance from the cordon, with exposure to the same light environment for each node situated at the same position from the base of the bearer), then inflorescence number per node may have actually been independent of bearer length, as was the case for flower number per inflorescence.

The relationship between bunch size and node position appeared to be independent of bearer length. For example, the terminal-node position two on the two-node bearer showed a similar average flower number per inflorescence and berry number per bunch to the node position two of the three-node bearer and the node position two of the four-node bearer (Figures 3.7, 3.8). Although flower number is highest at the most distal node positions on all length bearers (Figure 3.7), when average flower number per inflorescence is compared for the same node position counted from the base of a bearer across all bearer lengths, flower number appears to be determined solely by this node position on the bearer at which it occurs, as opposed to being affected (like inflorescence number) by the total node number of the bearer retained at pruning. This result for flower number and berry number was somewhat unsurprising for a number of reasons. Previous research conducted by Antcliff and Webster (1955) and Buttrose (1969a) showed that environmental factors that promote differentiation of the bunch primordia also promote growth in size of the primordia. Hence inflorescence size was expected to be greater at more distal node positions on all bearer node numbers (Figure 3.7) as was reported for inflorescence number (Figure 3.6). The similarity of flower number per inflorescence at the same node position counted from the base on bearers of different lengths can be accounted for by the timing of flower formation itself. Flowers begin to form during budburst in the current season (Barnard, 1932; Snyder, 1933; Winkler and Shemsettin, 1937; Scholefield and Ward, 1975; Srinivasan and Mullins, 1981). Because flower number had not been fully determined at the onset of budburst, it is suggested that the factors affecting inflorescence number during budburst could not affect flower number per inflorescence at that stage.

3.3.1.4 Effect of node position on fruit set.

Percentage fruit set was calculated at each node position on a bearer for which there was both flower number and berry number data available. Results showed that the highest proportion of flowers that developed into berries occurred at the most proximal node position on all bearer node numbers apart from the four-node bearers (Figure 3.9). This observation confirms that of López-Miranda (2002) who found that fruit set tended to decrease from the proximal to the distal parts of the canes in Verdejo. The higher than expected average flower number at node position two from the base on the four-node bearer (Figure 3.7) is suggested as the cause of the lower than expected percentage fruit set of 19% at this node position in Figure 3.9.

This observed relationship between fruit set and node position from the base of the bearer implies that small inflorescences in terms of the number of flowers on the inflorescence (more common at the proximal node positions on a bearer) tend to set a higher proportion of these flowers into berries

and vice versa with inflorescences that carry a large flower number, commonly found at distal node positions on the bearer. Both flower number per inflorescence (Figure 3.7) and berry number per bunch (Figure 3.8) were, however, lowest at the proximal node positions on all bearer node numbers—therefore, even with the higher percentage fruit set at these proximal node positions, bunch weight at these positions was still smaller compared with more distal node positions (results not shown).

The weight of the inflorescence and the number of flowers on an inflorescence also appeared to be correlated positively with the thickness of the peduncle (Table 3.2)—the trends for which also increased from the proximal to the distal node positions on each bearer node number (results not shown). Although the relationship between peduncle cross-sectional area and bunch weight was weaker at harvest than pre-flowering (Table 3.2), a positive correlation suggests that there was a general trend for heavier bunches to have thicker peduncles. Wilson (1996) suggested that larger peduncles acted to increase the availability of nutrients to flowers, thereby improving fruit set and resulting in heavier bunches at harvest. Whilst this reasoning is plausible, the fruit set results in Figure 5.8 show that the actual proportion of flowers that developed into berries (percentage fruit set) was not greater at the distal node positions where inflorescences had thicker peduncles. It is suggested that the peduncle does not primarily determine the proportion of flowers that develop into berries. Because 75% of the vascular system development of the rachis occurs after flowering (Ribéreau-Gayon et al. 1998), rachis development is therefore primarily affected by the size of the bunch post-flowering, according to the actual number of berries (or sinks) present. Hence, at harvest, bunches at proximal node positions on the bearers still showed smaller peduncles than bunches at more distal node positions on the bearers (results not shown).

3.3.1.5 Effect of node position on weight per flower and weight per berry.

Node position on a bearer at which an inflorescence occurred appeared to affect weight per flower, but not weight per berry. Weight per flower was higher at the distal compared with the proximal node positions on each bearer length (Figure 3.10), but weight per berry varied little between node positions on each bearer length (Figure 3.11). It therefore could be assumed that the heavier inflorescences recorded on the distal node positions on a bearer were a product of more flowers per inflorescence (Figure 3.7) and a heavier average weight per flower (Figure 3.10).

Taking into account the findings of Antcliff and Webster (1955), Bessis (1965) and Martin and Dunn (2000) that budburst occurs earlier at distal node positions on a bearer (not measured here), the results of my study suggest that the earlier-bursting distal node positions act as stronger sinks for assimilate on any bearer length, thereby advancing floral development compared with later-bursting proximal node positions.

The time at which the inflorescences were collected in the field may have also determined the growth stage of the individual flowers on the inflorescences. Leading up to the flowering process, flowers increase in size as their calyptra and pistils near maximum development (May, 1987) and inflorescences rapidly expand and change in weight. Flowering on distal shoots precedes flowering on proximal shoots (May, 1987) and flowers of each inflorescence are staggered in their development leading up to flowering, based on their access to metabolites (May, 2004). Flowers of various sizes are therefore found on all inflorescences when collected just pre-flowering. It is therefore conceivable that the higher average flower weight recorded just prior to flowering from inflorescences on the distal node positions of almost all bearer node numbers (Figure 3.10) was accounted for by the advanced growth of these flowers, due to their shoots acting as preferential sinks for nutrition. Thus the observed effect of node position on weight per flower was unlikely to be real and rather a consequence of apical dominance at the distal node positions on the bearer lengths studied. In addition, a more accurate measurement of flower weight may have been gained by recording actual flower weight, as opposed to calculating flower weight from inflorescence weight (defined as rachis weight plus flowers weight) divided by flower number per inflorescence. It is expected that the proportion of inflorescence weight attributed to the rachis, rapidly changed as the inflorescences expanded leading up to flowering and therefore this would have reduced the overall accuracy of the calculated flower weight results.

Because field sampling time appeared to affect weight per flower at the different node positions on each bearer length, the same may also be said for weight per berry. Because berry collection occurred within a week of harvest, maximum berry weight had been reached by all berries, regardless of their position on the bearer; therefore variances in berry weight according to node position on the bearer were insignificant (Figure 3.11). Weight per berry is known to only account for up to 10% of the seasonal variation in yield per vine (Martin, 2004). It was therefore expected that node position on a bearer would not impact on weight per berry to the extent recorded for weight per flower. Consequently, distal node positions at which weight per flower was heaviest did not result in the heavier weights per berry (Figure 3.11).

3.3.1.6 Relationships between yield and node position and yield and bearer node number and the change in the proportion of fruitful, non-fruitful and blind nodes on different bearer node numbers.

Average weight per node pre-flowering was higher at the distal compared with the proximal node positions on all bearer node numbers (Figure 3.12). This result was expected because it reflected the same trends shown by the individual yield components of inflorescence number (Figure 3.6) and flower number per inflorescence (Figure 3.7) on the bearers. As was the case for inflorescence number (Figure 3.6), the distal node positions on each bearer node number (made terminal by pruning) generally showed higher yields than non-terminal nodes at the same node position counted from the base on longer bearers (Figure 3.12). For example, node position three from the base on the three-node bearer recorded a higher average weight per node than node position three of the four-node bearer, which in turn recorded a higher average weight per node than node position three of the five-node bearer. As bunch number alone is known to typically explain 60-70% of the annual variation in yield (Clingeleffer, 2001), it follows that inflorescence number was a stronger driver of weight per node than inflorescence weight (described by flower number per inflorescence and berry number per bunch)—for which this relationship between yield and node position influenced by bearer node number was not evident (Figures 3.7 and 3.8).

The positive, non-linear relationship between average yield per bearer and bearer node number showed that five-node bearers had the highest yield of all the bearer node numbers studied, but there was no significant difference in yield per bearer for bearers of three, four or five nodes in length (Figure 3.13) This yield per bearer and bearer length relationship importantly quantifies the potential magnitude of yield improvement that could result for the trial block, should pruning be adjusted in low-fruitfulness seasons in order to achieve target yields. For example, if the average bearer length was increased from two to three nodes, yield per bearer would potentially increase by 38 per cent. On the other hand, if the average bearer node number was increased from two to five nodes in length, yield per bearer would increase by 63 per cent.

As only fruitful shoots contribute to the yield of the bearer, the highest proportion of fruitful shoots was found on the two-node bearers (Figure 3.14). However, yield per bearer showed a significant increase from the two- to three-node bearers (Figure 3.14). This yield increase was a direct result of higher actual fruitfulness (Figure 3.6) and higher berry number per bunch (Figure 3.8) on the fruitful shoots on the three-node bearers than the two-node bearers. In addition, despite the fact that the five-node bearers had a higher proportion of 'blind' nodes than the shorter bearers (Figure 3.14), again it was the higher fruitfulness and larger bunch size of the fruitful shoots on this bearer length

that resulted in the highest average yield per bearer being recorded by the five-node bearers (Figure 3.13).

3.3.2 Size difference of single as opposed to multiple inflorescences on a shoot

Inflorescence weight, flower number, bunch weight and berry number per bunch were significantly greater at the basal position on multiple-bunch shoots than on single-bunch shoots (Tables 3.3 and 3.4). These findings agree with those of Dunn and Martin (2000), who observed that conditions during the previous spring that favour the initiation and/or differentiation of uncommitted primordia will also pre-condition inflorescences to have more flowers. In addition, when multiple inflorescence primordia are present per bud, inflorescence primordia size (of the dominant primordium when more than one is present) is larger than if there is only a single inflorescence primordium present (J. Smith, pers. comm.). This observation indicates that carbohydrate/nutrient sink of the developing inflorescence primordia varies according to the number present per bud.

Berry weight at harvest showed no significant difference on single bunches or basal bunches on two-bunch shoots (Table 3.4). This result reflected the similarity in weight per flower between these bunch positions at the pre-flowering stage (Table 3.3), which confirms the findings of May (2004) who noted that variations in flower size pre-flowering persisted through to harvest. Berry weight at harvest between these two bunch positions did not reflect the difference in berry number per bunch at these bunch positions (Table 3.4). Berry number per bunch was found to be very weakly correlated with berry weight (Table 3.2). Therefore, berry weight does not appear to be a result of the number of sinks within a bunch, but rather the 'preconditioned' size of the berry as indicated by flower size. Berry weight on the basal bunches of two-bunch shoots was significantly less than that on the apical bunches of two-bunch shoots (Table 3.4) and this result can also be explained by the average weight per flower differences for these two bunch positions (Table 3.3).

Proximal bunches on multiple-bunch shoots had heavier inflorescences and bunches, more flowers and berries and thicker peduncles than distal bunches (Tables 3.3 and 3.4). These results matched findings by May and Cellier (1973), Dunn and Martin (2000), and Trought and Bloomfield (unpublished data) in Trought et al. (2007). Dunn and Martin (2000) interpreted the weight differences reported by May and Cellier (1973) as a direct result of differences in flower number per inflorescence and not fruit set. This study showed that there was a very strong and significant relationship between flower number and inflorescence weight (Table 3.2) and in addition, average percentage fruit set was in fact lower for the proximal inflorescences than the distal inflorescences

(Table 3.4). Fruit set therefore did not contribute to the heavier proximal bunches. Furthermore, these differences in weight per bunch that stem from the proximity of the bunch to the base of the shoot have been reported very early in the inflorescence initiation process before flowers become visible. Wilson (1996) found that when there were multiple inflorescence primordia within a bud, one primordium was always bigger than the other.

3.3.3 Relationship between the size of the inflorescence and the node position on the shoot at which it is located.

The hypothesis for this area of work, little studied by other researchers, was that the node position at which an inflorescence occurs on a shoot would affect the size of the inflorescence. Bunches are known to occur opposite leaves at nodes in the region between nodes 3 and 8 from the base of the shoot—node positions that were already present in the bud (Buttrose, 1969a). Figure 3.15 demonstrated this, as the majority of inflorescences occurred at node positions 3 to 6 counting from the base of the shoot. Despite variation in node position on a shoot at which inflorescences arose, as shoots arose from more distal node positions on the bearer, inflorescences on these shoots also tended to occur at more distal node positions (Figure 3.15). The exact node position on a shoot at which an inflorescence occurs is perhaps related back to the unique micro-climate surrounding each node position at the time of initiation and differentiation. As bunch primordia initiation and differentiation occurs in acropetal succession (Buttrose, 1969b), it is suggested that, as temperature and light conditions improve, bunches are initiated gradually at more distal node positions on a shoot primordium.

Tables 3.6 and 3.7 showed that when shoots were assessed separately by node position on the bearer from which they arose, inflorescence weight and its constituents—flower number and peduncle cross-sectional area—showed no significant difference when the inflorescences arose at different node positions from the base of the shoot. In contrast, when shoots that arose from node positions one to five on the bearers were pooled, shoot node position at which an inflorescence arose appeared to affect yield components. Table 3.5 showed that all measured yield components were highest for a single inflorescence on a shoot when it occurred at the more distal shoot node position and the same occurred for the basal inflorescence of the two-inflorescence shoots. In addition, all measured yield components were lowest for the apical inflorescence of the two-inflorescence shoots that occurred at the more distal shoot node position.

It is suggested that the analysis reported in Table 3.5, where shoots that arose from different node positions on the bearer were pooled, did not allow reasonable conclusions to be drawn as to whether node position at which an inflorescence arose on a shoot had an effect on the weight of the inflorescence. The node position on a bearer at which a shoot occurred appeared to affect inflorescence weight to a greater degree than node position on a shoot at which an inflorescence occurred. Data reported in section 3.3.1 has clearly shown that inflorescence weight is higher at the distal than the proximal node positions on all bearer lengths studied. Therefore, it is logical that inflorescence weight was lowest for single inflorescence shoots, for example, when inflorescences arose at node position 3 from the base of the shoot compared with node positions 4 and 5 (Table 3.5). This is because the shoots that arose from the more proximal node positions on the bearers (eg base bud position to node position 3), more commonly had inflorescences at node positions 3 and 4 on shoots than at node positions 4 and 5, in comparison to distal node positions 4 and 5 on the bearers (Figure 3.15). It is also suggested that the heavier inflorescences that occurred on the shoots at more distal node positions on the bearers resulted from these shoots supplying more water and nutrients to the developing inflorescences as these shoots were longer and larger in cross-sectional area (data not shown).

Two studies that measured inflorescence size at different node positions on a shoot, both reported a decrease in flower number at more distal shoot node positions on two-inflorescence shoots (Dunn and Martin, 2000; Trought and Bloomfield (unpublished) in Trought et al., 2007). Although these findings matched trends reported in Table 5.7, it is believed that their results may have been confounded as they were not reported by node position on the bearer length studied.

3.4 CONCLUSIONS

- Both budburst and inflorescence number per node were highest at the distal node positions on each bearer node number.
- Consistent with other published information by Dunn and Martin (2007), the results presented in this chapter provide strong evidence to support the hypothesis that flower number is not completely determined by the time of budburst. The relationship between bunch size and node position, unlike that between bunch number and node position, was not dependent on bearer length.

- Budburst appeared to act by modifying inflorescence number per node based on the relative location of each node from the apex of the bearer. Budburst is, therefore, perhaps a stronger driver of yield potential in the mechanically-pruned hedge than previously considered.
- Shoots that arose from the most distal node positions had the highest flower number per inflorescence and berries per bunch.
- Higher berry numbers per bunch on distal nodes were a direct result of higher flower numbers per inflorescence and to a lesser extent, the success of flowering.
- Larger peduncle size appeared not to determine the proportion of flowers that developed into berries.
- Bunches at distal node positions at harvest recorded larger peduncles than those at proximal node positions, possibly indicating that the vascular system of the peduncle developed in response to the number of sinks carried by the bunch.
- Flower number per inflorescence was significantly higher on two-inflorescence shoots than single-inflorescence shoots.
- Shoots that arose from proximal node positions on bearers had inflorescences that occurred at more proximal node positions on the shoot and these inflorescences were generally smaller. The relative size of the inflorescence thus appears to be affected more so by the node position at which the shoot occurred on the bearer, as opposed to the actual node position on the shoot at which the inflorescence occurred.
- The positive, non-linear relationship between average fruit yield per bearer and bearer node number showed that yield was highest from the bearer with the highest node number (five nodes).
- There was no actual significant difference in yield per bearer for the bearers of three to five nodes in length.
- If average bearer length was increased from two to three nodes, the potential yield gain per bearer is estimated at 38 per cent.
- Modifying pruning to retain slightly longer bearers may be adopted by growers who want to increase yield with minimum impact on canopy structure, or by growers faced with seasons of low potential bud fruitfulness.

CHAPTER FOUR

RELATIONSHIPS BETWEEN FERTILITY, INFLORESCENCE SIZE AND SUBSEQUENT NUMBER OF BERRIES PER BUNCH

4.0 INTRODUCTION

Bunch number alone can typically explain 60-70% of the annual variation in yield (Clingeleffer, 2001). Therefore, 30-40% of the annual variation in yield can be attributed to bunch weight. Large variation in grapevine yield parameters from year to year increases the difficulty of crop forecasting. With wineries adopting a tough stance towards growers over-delivering on their grape contracts, any assistance that can be provided to growers on improving accuracy of crop forecasts through a greater understanding of the development of bunch number and bunch size, will be beneficial both to the grower and winery. In addition, vintages have become more compact in recent seasons. With this phenomenon, the optimum time for harvesting each block of grapes is likely to have narrowed and therefore, accurate crop forecasting is important to aid wineries in planning their intake schedules based on tank availability and for the grower, organising hand pickers, machine harvesters, bins and trucks with which to deliver their fruit to the winery.

This research aims to investigate the hypothesis that bunch number and bunch weight are co-developed. Proof of this co-development is expected to be demonstrated by positive correlations between bunch numbers and components of bunch weight (flower number and berry number).

<u>This study aimed to provide some answers to the following major questions:</u>

i) Are the variables fertility and flower number per inflorescence related? Are the variables fertility and berry number per bunch related? Are the variables fertility and bunch weight related? Do these relationships change in different seasons or for different varieties?

ii) Is there a strong relationship between flower number per inflorescence, berry number per bunch and fruit set? Does this relationship vary by variety or vineyard? Does flower number per inflorescence correlate with berry number per bunch?

iii) What proportion of the annual variation in yield can be attributed to annual variation in bunch number, berry number per bunch and weight per berry? Are these proportions affected by vineyard or variety?

4.1 MATERIALS AND METHODS

4.1.1 Experimental Site

This study utilised yield data collected annually between 2003 and 2007 from the winegrowing regions of Coonawarra, Robe, Padthaway and Bordertown within the Limestone Coast zone of South Australia (Figure 4.1). All vineyard blocks were commercially-managed and of the varieties, *Vitis vinifera* L. Cabernet Sauvignon, Shiraz and Chardonnay. In addition, blocks were of varying age, clone, trellis type and vine density and grown for commercial to super-premium end use. Vineyards within each of the four winegrowing regions were managed by different vineyard managers.

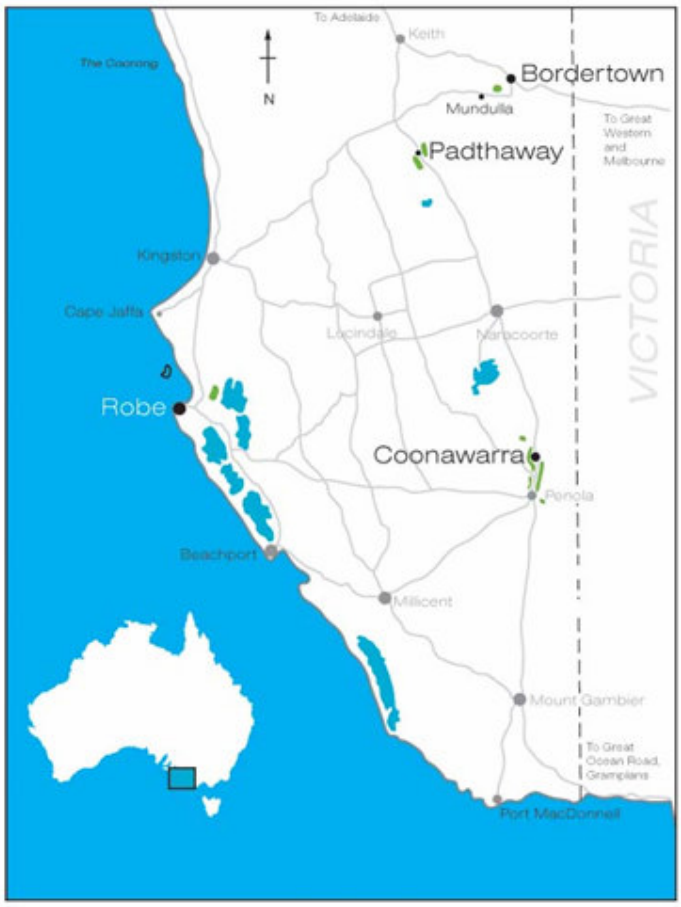


Figure 4.1. Map of Limestone Coast Zone showing placement of vineyards in the study.

4.1.2 Experimental Design

Vineyard blocks were only included in this study when yield component data was available for at least three out of the five years of the data collection period. No treatments were applied to the vineyard blocks in the study. Instead, yield components were analysed from these blocks by variety and vineyard to investigate correlations.

4.1.3 Vine Measurements

Fertility

Actual fertility is described in this chapter by 'bunch number per node' and was calculated by dividing bunch number per vine by count node number per vine. This calculation was performed to account for the variation in vine density, trellis type and pruning styles across the blocks in the study.

Bunch number per vine

Sixty segments of 0.6m in length were randomly marked across each vineyard block. At harvest time, bunches were removed and counted separately from each of the segments. For each block, the average number of bunches per segment was then multiplied by the vine spacing for the block and divided by the segment length of 0.6m to determine the average bunch number per vine.

Flower number per inflorescence

For each vineyard block just prior to the onset of flowering, sixty inflorescences were destructively collected, from randomised positions across each block. Individual flowers on each inflorescence collected were destructively counted by pulling off groups of flowers (florets) with tweezers. The number of flowers from each floret was summed to calculate total flower number for each inflorescence. Flower numbers per inflorescence of the sixty inflorescences were then averaged and reported for each block.

Berry number per bunch

For each bunch collected at harvest, all coloured berries (hens and chickens) were plucked off the bunch and counted, with LGOs not included.

Bunch weight

At harvest, the total weight of bunches from each of the 0.6m segments randomly marked across each vineyard block was recorded and divided by the number of bunches in each segment to

calculate average segment bunch weight. An average of the sixty segment bunch weights then determined the average bunch weight for the block. Bunches removed to determine bunch weight at harvest were not the same as those inflorescences used to determine flower number per inflorescence pre-flowering.

Percentage fruit set

Berry number per bunch (including hens and chickens, not LGOs) was divided by flower number per inflorescence and then multiplied by 100.

Yield

Yield was reported as weight per vine. At harvest time, bunches were removed from each of the sixty 0.6m segments and weighed. The total weight per vine for each block was calculated by averaging the weight per vine from each of the segments in the block and then multiplying this value by the vine spacing and then dividing by the segment length.

4.1.4 Climatic data

Climatic data for the Coonawarra, Padthaway and Bordertown vineyards was sourced from the Bureau of Meteorology weather stations located in or near to the Coonawarra, Padthaway and Keith townships. Climatic data for the Robe vineyard was sourced as a combination of the on-site Agrilink weather station and the Bureau of Meteorology weather station in the Robe township.

4.1.5 Statistical Analysis

Analysis of variance for data sets was performed using 'Minitab' version 13 for Windows. Statistical significance between treatments measured to the 95% level was performed using the t distribution – inverse cdf (Table 7, Watson).

Correlation analysis was performed using 'Minitab' version 13 for Windows. Relative strengths of the correlations in terms of p-values, were reported to the 0.1, 1 and 5% levels.

Multi-linear regression analysis was performed using 'Minitab' version 13 for Windows to determine the fractions of seasonal variation in weight per vine accounted for by the seasonal variation in bunches per vine, berries per bunch and weight per berry. In a step-wise process, weight per vine was regressed against bunches per vine, then bunches per vine plus berries per bunch and finally by bunches per vine plus berries per bunch plus weight per berry. The regression between weight per

vine and bunches per vine issued the r-squared value (or coefficient of determination) for bunches per vine. The regression between weight per vine and bunches per vine plus berries per bunch issued a second r-squared value which was subtracted from the r-squared value (coefficient of determination) for bunches per vine to determine the r-squared value (coefficient of determination) for berries per bunch. The regression between weight per vine and bunches per vine plus berries per bunch plus weight per berry issued the third r-squared value which was subtracted from the sum of the r-squared values for bunches per vine and berries per bunch, to determine the r-squared value (coefficient of variation) for weight per berry.

4.2 RESULTS

4.2.1 Fertility

4.2.1.1 Effect of variety on fertility (bunches per node) and yield components.

Shiraz and Cabernet Sauvignon fertility (bunch number per node) were each positively and significantly correlated with bunch weight, flower number per inflorescence and berry number per bunch (Table 4.1). Chardonnay fertility was positively and significantly correlated with bunch weight and berry number per bunch (Table 4.1). There was no significant difference ($p>0.05$) in average fertility or berry number per bunch between the varieties (Table 4.2).

Table 4.1. Correlation between the variables fertility and bunch weight, flower number per inflorescence and berry number per bunch.

Data are correlation coefficients (r). Different numbers of blocks from each vineyard were reported (Coonawarra-71 blocks; Robe-42 blocks; Padthaway-53 blocks; Bordertown-25 blocks) and different numbers of blocks from each variety were reported (Chardonnay (CHR)–52 blocks; Shiraz (SHI)-60 blocks; Cabernet Sauvignon (CAS)-82 blocks). Fl. no. = flower number per inflorescence, bry no. = berry number per bunch. *,**,***,NS indicate significance at less than or equal to the 5%, 1% and 0.1% levels respectively or not significant.

	All varieties bunch wt	CHR bunch wt	SHI bunch wt	CAS bunch wt	All varieties fl no.	CHR fl no.	SHI fl no.	CAS fl no.	All varieties bry no.	CHR bry no.	SHI bry no.	CAS bry no.
All varieties fertility	0.432 ***				0.350 ***				0.414 ***			
CHR fertility		0.466 ***				0.262 NS				0.461 ***		
SHI fertility			0.509 ***				0.377 **				0.404 ***	
CAS fertility				0.662 ***				0.441 ***				0.558 ***

Table 4.2. Effect of variety on fertility and yield components.

Data are means ± standard error (mean) pooled over all vineyard sites (Coonawarra, Robe, Padthaway and Bordertown) and growing seasons (2002/03 – 2006/07). Means with the same superscript letter within columns are not significantly different using LSD at 5%. CHR = Chardonnay, SHI = Shiraz, CAS = Cabernet Sauvignon.

Var	N	Fertility (bunches per node)		Bunch wt (g)		Flower number per inflorescence		Berry number per bunch		% Fruit Set	
			LSD		LSD		LSD		LSD		LSD
CHR	44	0.90[a] ± 0.03	0.08	73.53[a] ± 3.14	7.45	213.27[b] ± 8.85	21.07	82.08[a] ± 3.09	7.37	40.15[a] ± 1.55	3.66
SHI	53	1.04[a] ± 0.05	0.11	69.72[a] ± 2.87	6.85	187.00[b] ± 8.84	21.04	71.38[a] ± 2.92	6.96	40.52[a] ± 1.63	3.89
CAS	69	1.0 [a] ± 0.05	0.11	48.21[b] ± 2.04	4.81	284.29[a] ± 11.01	26.02	70.40[a] ± 2.18	5.15	26.73[b] ± 0.95	2.25

4.2.1.2 Effect of growing season and temperature on fertility (bunches per node) and yield components.

Mean fertility differed between growing seasons (Table 4.3). The lowest mean fertility, flower number per inflorescence, berry number per bunch and bunch weight were recorded in season 2002/03 (Table 4.3). Heat summations from October to November and November to December in the season prior to the vintage year were lowest for season 2002/03 compared with all other seasons (Table 4.4). Both fertility and flower number per inflorescence were significantly lower in 2002/03 ($p<0.05$) compared with all other seasons. Bunch weight was significantly lower ($p<0.05$) in season 2002/03 compared with all other seasons except 2006/07 (Table 4.3). Flower number per inflorescence was significantly higher ($p<0.05$) in season 2003/04 compared with all other seasons except 2006/07 (Table 4.3). Bunch weight and berry number per bunch were significantly higher ($p<0.05$) in season 2003/04 compared with all other seasons except 2005/06 (Table 4.3).

Table 4.3. Effect of growing season on fertility and yield components.

Data are means ± standard error (mean) pooled over all vineyard sites (Coonawarra, Robe, Padthaway and Bordertown). Means with the same superscript letter within columns, are not significantly different using LSD at 5%.

Growing season	N	Fertility (bunches per node)		Bunch wt (g)		Flower number per inflorescence		Berry number per bunch	
			LSD		LSD		LSD		LSD
2002/03	23	0.67[b] ± 0.04	0.10	43.09[c] ± 2.69	6.54	150.07[c] ± 10.20	24.76	56.14[b] ± 2.68	6.50
2003/04	43	1.17[a] ± 0.05	0.13	80.12[a] ± 3.29	7.83	314.67[a] ± 15.21	36.23	85.39[a] ± 3.08	7.33
2004/05	49	1.04[a] ± 0.03	0.08	57.36[b] ± 2.21	5.27	208.41[b] ± 10.08	24.01	65.53[b] ± 1.96	4.67
2005/06	46	1.07[a] ± 0.04	0.11	69.42[ab] ± 4.12	9.81	219.41[b] ± 10.37	24.69	84.45[a] ± 3.45	8.23
2006/07	30	0.90[a] ± 0.06	0.15	54.23[bc] ± 2.95	7.09	256.46[ab] ± 15.01	36.06	67.30[b] ± 3.67	8.82

Table 4.4. Heat summation during inflorescence primordium initiation and differentiation periods at Coonawarra, Robe and Padthaway for seasons 2002/03 to 2006/07.

Heat summation = (average monthly temperature – 10) x number days in month.

VINEYARD	HEAT SUMMATION (BASE 10) OCT-NOV IN SEASON PRIOR TO SEASON OF VINTAGE YEAR DURING INFLORESCENCE PRIMORDIUM INITIATION					HEAT SUMMATION (BASE 10) NOV-DEC IN SEASON PRIOR TO SEASON OF VINTAGE YEAR DURING INFLORESCENCE PRIMORDIUM DIFFERENTIATION				
	Vintage year					Vintage year				
	2003	2004	2005	2006	2007	2003	2004	2005	2006	2007
	Inflorescence Primordium Initiation Period					Inflorescence Primordium Differentiation Period				
	Oct – Nov 01	Oct – Nov 02	Oct – Nov 03	Oct – Nov 04	Oct – Nov 05	Nov – Dec 01	Nov – Dec 02	Nov – Dec 03	Nov – Dec 04	Nov – Dec 05
Coonawarra	191	287	228	297	297	255	443	466	424	436
Robe	195	298	318	393	405	250	478	486	490	501
Padthaway	202	304	272	345	348	267	469	489	487	470

4.2.1.3 Effect of variety and growing season on fertility (bunches per node) and yield components.

When growing seasons were split by variety, there was no significant difference ($p>0.05$) in mean Cabernet Sauvignon or Chardonnay fertility between any of the growing seasons studied (Table 4.5). Fertility of Shiraz was significantly lower ($p<0.05$) in season 2002/03 than all other seasons except 2006/07 (Table 4.5).

4.2.1.4 Effect of vineyard site and variety on fertility (bunches per node) and yield components.

Robe Cabernet Sauvignon fertility was significantly higher ($p<0.05$) than Padthaway Cabernet Sauvignon but this difference was not matched by flower number per inflorescence (Table 4.6). There was no significant difference ($p<0.05$) in Cabernet Sauvignon flower number per inflorescence or bunch weight across the vineyards (Table 4.6). Padthaway Cabernet Sauvignon had significantly fewer ($p<0.05$) berries per bunch and significantly lower ($p<0.05$) fruit set than Bordertown Cabernet Sauvignon (Table 4.6).

There was no significant difference ($p<0.05$) in Chardonnay fertility, flower number per inflorescence, berry number per bunch or fruit set across the vineyards (Table 4.6). However, bunch weight of Robe Chardonnay was significantly higher ($p<0.05$) than Coonawarra Chardonnay (Table 4.6).

There was no significant difference ($p>0.05$) in mean Shiraz fertility or fruit set between the vineyard sites (Table 4.6). However, bunch weight and berry number per bunch of Bordertown Shiraz was significantly higher ($p<0.05$) than both Coonawarra and Padthaway Shiraz (Table 4.6). Flower number per inflorescence and berry number per bunch of Bordertown Shiraz were significantly higher ($p<0.05$) than Robe Shiraz (Table 4.6).

For all vineyards, temperatures during both inflorescence primordium initiation and differentiation were lowest for vintage 2003 compared with all other seasons (Table 4.4). Temperatures during inflorescence primordium initiation and differentiation were relatively similar at each vineyard across all seasons except 2003 (Table 4.4). The degree of association between the variables of inflorescence initiation temperature and fertility and inflorescence differentiation temperature and fertility were both stronger for Robe and Padthaway Cabernet Sauvignon compared with Coonawarra Cabernet Sauvignon (Table 4.7).

Table 4.5. Effect of variety and season on fertility and yield components.

Data are means ± standard error (mean) pooled over all vineyard sites (Coonawarra, Robe, Padthaway and Bordertown). Means with the same superscript letter within columns and variety are not significantly different using LSD at 5%.

Variety	Growing Season	N	Fertility (bunches per node)		Flower number per inflorescence		Berry number per bunch		% Fruit set	
				LSD		LSD		LSD		LSD
Cabernet Sauvignon	2002/03	13	$0.68^{a} \pm 0.10$	0.30	$177.00^{c} \pm 12.97$	32.69	$53.72^{c} \pm 3.86$	9.73	$31.54^{a} \pm 2.27$	5.72
	2003/04	19	$1.19^{a} \pm 0.11$	0.29	$373.82^{a} \pm 21.56$	52.87	$80.82^{a} \pm 4.08$	10.02	$22.34^{b} \pm 1.16$	2.85
	2004/05	21	$1.06^{a} \pm 0.08$	0.20	$251.10^{b} \pm 15.22$	37.14	$62.95^{bc} \pm 2.82$	6.87	$26.83^{ab} \pm 1.88$	4.69
	2005/06	18	$1.14^{a} \pm 0.12$	0.29	$266.00^{b} \pm 19.55$	48.1	$80.87^{ab} \pm 5.10$	12.54	$31.96^{a} \pm 2.07$	5.09
	2006/07	11	$0.93^{a} \pm 0.11$	0.29	$349.73^{ab} \pm 15.85$	40.63	$69.22^{abc} \pm 5.60$	14.36	$19.86^{b} \pm 1.53$	3.93
Shiraz	2002/03	5	$0.60^{b} \pm 0.07$	0.20	$106.40^{c} \pm 10.91$	32.9	$59.69^{b} \pm 3.83$	11.53	$58.01^{a} \pm 5.79$	17.45
	2003/04	13	$1.37^{a} \pm 0.09$	0.23	$268.92^{a} \pm 22.24$	56.06	$88.28^{a} \pm 6.42$	16.21	$34.32^{a} \pm 2.54$	6.39
	2004/05	16	$1.08^{a} \pm 0.08$	0.21	$154.81^{bc} \pm 10.25$	25.41	$61.89^{b} \pm 3.65$	9.05	$41.54^{a} \pm 2.81$	6.96
	2005/06	16	$1.01^{a} \pm 0.07$	0.18	$174.38^{b} \pm 10.21$	25.31	$75.08^{ab} \pm 6.06$	15.01	$43.73^{a} \pm 2.89$	7.16
	2006/07	10	$0.95^{ab} \pm 0.13$	0.34	$192.48^{ab} \pm 9.09$	23.57	$64.52^{ab} \pm 7.43$	19.25	$33.38^{a} \pm 3.31$	8.59
Chardonnay	2002/03	5	$0.69^{a} \pm 0.10$	0.31	$123.80^{b} \pm 8.89$	26.81	$58.91^{b} \pm 6.43$	19.39	$47.42^{ab} \pm 3.40$	12.25
	2003/04	11	$0.90^{a} \pm 0.06$	0.16	$266.55^{a} \pm 23.85$	61.13	$89.87^{ab} \pm 6.22$	15.93	$35.11^{b} \pm 4.05$	7.33
	2004/05	11	$0.94^{a} \pm 0.04$	0.11	$213.09^{a} \pm 14.75$	37.80	$75.73^{b} \pm 3.05$	7.82	$37.26^{ab} \pm 3.81$	6.91
	2005/06	12	$1.03^{a} \pm 0.04$	0.10	$209.58^{a} \pm 7.72$	19.62	$102.33^{a} \pm 4.33$	11.00	$49.23^{a} \pm 2.99$	5.38
	2006/07	9	$0.80^{a} \pm 0.11$	0.28	$213.56^{a} \pm 10.30$	27.09	$68.04^{b} \pm 9.39$	17.46	$31.98^{b} \pm 3.95$	7.35

Table 4.6. Effect of vineyard site and variety on fertility and yield components.

Data are means ± standard error (mean) pooled over all growing seasons (2002/03 – 2006/07). Means with the same superscript letter within columns and variety are not significantly different using LSD at 5%.

Variety	Vineyard	N	Fertility (bunches per node)		Bunch weight (g)		Flower number per inflorescence		Berry number per bunch		% Fruit Set	
				LSD		LSD		LSD		LSD		LSD
Chardonnay	Robe	8	$1.05^{a} \pm 0.05$	0.12	$94.58^{a} \pm 4.92$	13.18	$205.82^{a} \pm 21.32$	57.13	$91.63^{a} \pm 6.47$	17.33	$45.84^{a} \pm 1.98$	5.31
	Coonawarra	14	$0.91^{a} \pm 0.06$	0.14	$59.88^{b} \pm 3.85$	9.65	$201.57^{a} \pm 13.57$	34.00	$76.10^{a} \pm 5.32$	13.32	$39.16^{a} \pm 2.95$	7.38
	Padthaway	21	$0.83^{a} \pm 0.06$	0.13	$74.83^{ab} \pm 4.45$	10.86	$230.88^{a} \pm 15.17$	37.02	$80.82^{a} \pm 5.35$	13.06	$36.34^{a} \pm 2.41$	5.87
	Bordertown	5	$0.92^{a} \pm 0.10$	0.31	$78.12^{ab} \pm 7.11$	21.45	$203.00^{a} \pm 22.29$	67.2	$92.16^{a} \pm 6.91$	20.83	$46.71^{a} \pm 3.77$	11.37
Shiraz	Robe	18	$1.20^{a} \pm 0.06$	0.16	$80.10^{ab} \pm 4.66$	11.47	$162.57^{b} \pm 9.81$	24.13	$68.77^{b} \pm 4.57$	11.25	$43.02^{a} \pm 2.31$	5.69
	Coonawarra	20	$1.00^{a} \pm 0.07$	0.16	$67.87^{b} \pm 2.61$	6.37	$179.70^{ab} \pm 13.88$	33.93	$68.03^{b} \pm 2.37$	5.79	$42.30^{a} \pm 3.55$	8.70
	Padthaway	15	$0.90^{a} \pm 0.11$	0.26	$59.72^{b} \pm 6.91$	17.22	$181.46^{ab} \pm 15.13$	37.68	$63.26^{b} \pm 6.88$	17.13	$36.08^{a} \pm 3.36$	8.38
	Bordertown	7	$1.22^{a} \pm 0.13$	0.36	$101.67^{a} \pm 8.27$	22.72	$282.53^{a} \pm 34.34$	94.37	$105.02^{a} \pm 7.74$	21.27	$38.78^{a} \pm 2.81$	7.72
Cabernet Sauvignon	Robe	15	$1.28^{a} \pm 0.10$	0.25	$57.92^{a} \pm 3.50$	8.71	$252.93^{a} \pm 22.08$	54.98	$73.14^{ab} \pm 5.22$	13.01	$29.89^{a} \pm 1.21$	3.02
	Coonawarra	37	$1.03^{ab} \pm 0.06$	0.15	$44.37^{a} \pm 2.74$	6.56	$263.26^{a} \pm 16.06$	38.54	$67.81^{ab} \pm 2.76$	6.63	$28.02^{a} \pm 1.46$	3.50
	Padthaway	17	$0.86^{b} \pm 0.07$	0.16	$47.98^{a} \pm 4.27$	10.54	$328.08^{a} \pm 16.29$	40.21	$61.12^{b} \pm 4.68$	11.56	$18.90^{b} \pm 1.29$	3.20
	Bordertown	13	$0.97^{ab} \pm 0.08$	0.21	$54.49^{a} \pm 5.84$	14.71	$323.04^{a} \pm 36.18$	91.18	$86.75^{a} \pm 5.33$	13.43	$29.64^{a} \pm 2.59$	6.52

Table 4.7. Correlation between the variables inflorescence initiation and differentiation temperatures on fertility and flower number per inflorescence for Cabernet Sauvignon.

Data are correlation coefficients (r). Different numbers of Cabernet Sauvignon blocks from each vineyard were reported (Robe-15 blocks; Coonawarra-37 blocks; Padthaway-17 blocks). *,**,***,NS indicate significance at less than or equal to the 5% , 1% and 0.1% levels respectively or not significant. Initiation and differentiation temperatures refer to those reported in Table 4.7.

	Robe fertility	Robe flower no. per infl	Coon fertility	Coon flower no. per infl	Pad fertility	Pad flower no. per infl
Robe initiation temp	0.758 ***					
Robe differentiation temp		0.632 **				
Coon initiation temp			0.274 NS			
Coon differentiation temp				0.352 *		
Pad initiation temp					0.795 **	
Pad differentiation temp						0.649 **

4.2.2 Fruit Set

4.2.2.1 Effect of vineyard site and variety on flower number per inflorescence, berry number per bunch and fruit set.

Flower number and berry number were strongly and significantly associated for all Robe varieties and for Padthaway Shiraz and Bordertown Chardonnay (Table 4.8). There was no significant correlation between flower number per inflorescence and berry number per bunch for Coonawarra Chardonnay and Shiraz, Padthaway Cabernet Sauvignon and Bordertown Shiraz and Cabernet Sauvignon (Table 4.8).

When blocks of the same variety across the four vineyards were pooled, Cabernet Sauvignon blocks showed significantly more ($p<0.05$) flowers per inflorescence, significantly higher ($p<0.05$) bunch weight and significantly lower ($p<0.05$) fruit set compared with both Shiraz and Chardonnay (Table 4.2). There was no difference between bunch weight, flower number per inflorescence, berry number per bunch and fruit set for Shiraz compared to Chardonnay (Table 4.2).

4.2.2.2 Effect of season on flower number per inflorescence, berry number per bunch and fruit set.

In season 2002/03, mean flower number per inflorescence for Cabernet Sauvignon was significantly lower ($p<0.05$) compared with all the other seasons and fruit set was significantly higher ($p<0.05$) than in seasons 2003/04 and 2006/07 (Table 4.5). When Cabernet Sauvignon berries per bunch was highest in season 2003/04 and lowest in season 2002/03, the same results were reflected for flowers per inflorescence for these seasons (Table 4.5). Whilst there was also a trend between low flower number per inflorescence and higher fruit set for Shiraz and Chardonnay, this trend showed less significance than for Cabernet Sauvignon (Table 4.5). The smaller sample numbers of the Shiraz and Chardonnay may have affected these results. When flowers per inflorescence were lowest in season 2002/03 for all varieties, berries per bunch were also lowest compared to the other seasons (Table 4.5). Mean daily temperatures over the fruit set period were also lowest in 2002 for most of the four vineyard sites in the study (Table 4.9).

Table 4.8. Correlation between the variables flower number per inflorescence and berry number per bunch.

Data are correlation coefficients (r). Different numbers of blocks from each vineyard were reported (Coonawarra-71 blocks; Robe-42 blocks; Padthaway-53 blocks; Bordertown-25 blocks) and different numbers of blocks from each variety were reported (Chardonnay (CHR)–52 blocks; Shiraz (SHI)-60 blocks; Cabernet Sauvignon (CAS)-82 blocks). *,**,***,NS indicate significance at less than or equal to the 5% , 1% and 0.1% levels respectively or not significant.

	Coon CHR berry no. per bunch	Coon SHI berry no. per bunch	Coon CAS berry no. per bunch	Robe CHR berry no. per bunch	Robe SHI berry no. per bunch	Robe CAS berry no. per bunch	Pad CHR berry no. per bunch	Pad SHI berry no. per bunch	Pad CAS berry no. per bunch	Btown CHR berry no. per bunch	Btown SHI berry no. per bunch	Btown CAS berry no. per bunch
Coon CHR flower no. per infl	0.141 NS											
Coon SHI flower no. per infl		0.100 NS										
Coon CAS flower no. per infl			0.436 ***									
Robe CHR flower no. per infl				0.825 **								
Robe SHI flower no. per infl					0.700 ***							
Robe CAS flower no. per infl						0.742 ***						
Robe CHR flower no. per infl							0.436 *					
Pad SHI flower no. per infl								0.663 ***				
Pad CAS flower no. per infl									0.316 NS			
Btown CHR flower no. per infl										0.825 *		
Btown SHI flower no. per infl											0.721 NS	
Btown CAS flower no. per infl												0.566 NS

Table 4.9. Mean daily temperature over the fruit set period at Coonawarra, Robe, Padthaway and Bordertown for years 2002 to 2007.

Fruit set period was defined to occur within the bounds of 15th November to 15th December for each vineyard and season. Year displayed is that in which the fruit set occurred for the crop harvested in the following year.

VINEYARD	YEAR				
	2002	2003	2004	2005	2006
Coonawarra	15.76	18.24	17.90	16.57	17.83
Robe	17.46	18.33	18.82	17.57	15.51
Padthaway	16.27	19.08	19.04	17.22	18.97
Bordertown	16.47	19.28	18.99	17.09	19.36
AVERAGE	16.49	18.73	18.70	17.11	17.92

4.2.3 Variation in Yield

Over the five years of study (2003-2007) summed for blocks at Robe, Coonawarra and Padthaway vineyards, the fraction of seasonal variation in yield that was accounted for by bunches per vine was 47% for Cabernet Sauvignon, 63% for Shiraz and 81% for Chardonnay (Table 4.10). Bunches per vine accounted for the majority of the seasonal variation in yield per vine for all vineyard x variety combinations except for Padthaway Cabernet Sauvignon and Shiraz (Table 4.10). The fraction of seasonal variation berries per bunch accounted for, was 26% for Cabernet down to 10% for Chardonnay. The fraction of seasonal variation weight per berry accounted for was 12% for Cabernet Sauvignon and 7% for both Shiraz and Chardonnay (Table 4.10) Robe was the only vineyard for which the fractions of seasonal variation in yield that were accounted for by bunches per vine, berries per bunch and weight per berry were similar across varieties (Table 4.10). Robe and Coonawarra Shiraz yields were both dominated by bunches per vine, whereas Padthaway yield was dominated approximately equally by bunches per vine and berries per bunch (Table 4.10). Yield variation in Cabernet Sauvignon appeared to be more driven by berries per bunch at both Padthaway and Coonawarra, compared with at Robe (Table 4.10). The number of berries per bunch was also a more important determinant of Chardonnay yield at Coonawarra, compared to at Padthaway (Table 4.10).

For different variety x vineyard combinations, growing season did not consistently affect the magnitude of variation in Robe and Coonawarra yield, accounted for by the variation in bunches per vine or berries per bunch (Table 4.11). This was possibly affected by a lack of significance between berry number per bunch from the particular growing seasons reported in Table 4.11 for either vineyard (Table 4.12). For Padthaway, however, growing season affected the magnitude of

variation in yield components similarly across all varieties (Chardonnay, Shiraz and Cabernet Sauvignon) with the 2003/04 and 2005/06 seasons showing higher variation in berries per bunch compared with seasons 2004/05 and 2006/07, particularly for Chardonnay and Shiraz (Table 4.11). The two seasons for which variation in yield could be attributed to high variation in berries per bunch, reported significantly higher berry number per bunch than the two seasons for which there was low variation in the yield component berries per bunch (Table 4.12).

Table 4.10 Fractions of seasonal variation in weight per vine accounted for by the seasonal variation in bunches per vine, berries per bunch and weight per berry from 2003 – 2007 for *Vitis vinifera* cv. Chardonnay, Shiraz and Cabernet Sauvignon at Robe, Coonawarra and Padthaway.

Data are averages for each variety and vineyard. Variety x vineyard combinations for which sample size was less than 2 blocks were omitted.

		Variation accounted for (r^2)		
	N	**BUNCHES PER VINE**	**BERRIES PER BUNCH**	**WEIGHT PER BERRY**
ROBE SHI	11	88	3	4
ROBE CAS	13	79	0	6
COON CHR	14	35	32	10
COON SHI	19	81	8	1
COON CAS	37	55	27	10
PAD CHR	21	75	14	9
PAD SHI	15	42	45	5
PAD CAS	17	24	56	12
ALL CHR	35	81	10	7
ALL SHI	45	62	18	7
ALL CAS	67	47	26	12

Table 4.11 Fractions of seasonal variation in weight per vine accounted for by the seasonal variation in bunches per vine, berries per bunch and weight per berry by growing season for *Vitis vinifera* cv. Chardonnay, Shiraz and Cabernet Sauvignon at Robe, Coonawarra and Padthaway.

Data are averages for each variety and vineyard. Variety x vineyard combinations for which sample size was less than 2 blocks were omitted.

			Variation accounted for (r^2)		
VINEYARD	SEASON	N	BUNCHES PER VINE	BERRIES PER BUNCH	WEIGHT PER BERRY
PAD CHR	2003/04	4	62.1	36.1	1.8
PAD CHR	2004/05	5	84.0	7.9	7.8
PAD CHR	2005/06	5	42.7	34.6	21.3
PAD CHR	2006/07	5	94.0	0.5	5.1
ROBE SHI	2003/04	4	94.1	4.7	1.2
ROBE SHI	2005/06	4	22.1	76.6	1.3
COON SHI	2003/04	4	62.0	36.6	1.4
COON SHI	2004/05	5	90.2	0.3	3.1
COON SHI	2005/06	4	83.0	2.2	1.5
COON SHI	2006/07	4	99.7	0.2	0.1
PAD SHI	2004/05	4	99.0	0.0	1.0
PAD SHI	2005/06	4	14.6	83.4	2.0
PAD SHI	2006/07	4	88.2	11.7	0.1
ROBE CAS	2003/04	4	37.9	53.3	1.5
ROBE CAS	2005/06	4	89.0	8.4	2.6
COON CAS	2003/04	9	78.0	11.0	1.9
COON CAS	2004/05	10	42.2	14.5	28.6
COON CAS	2005/06	10	1.4	80.9	14.6
PAD CAS	2004/05	5	56.5	37.5	4.7
PAD CAS	2006/07	5	62.6	33.2	4.1

Table 4.12 Flower number per inflorescence, berry number per bunch and percentage fruit set by season from 2003/04 to 2006/07.

Data are means ± standard error (mean) pooled over all varieties (Cabernet Sauvignon, Shiraz and Chardonnay). Means with the same superscript letter within columns and vineyards are not significantly different using LSD at 5%.

Vineyard	Season	N	Mean flower number per inflorescence	LSD	Mean berry number per bunch	LSD	Mean % fruit set	LSD
Robe	2002/03	5	126.00^{c} ± 15.20	45.83	52.23^{b} ± 3.33	10.03	44.45^{a} ± 7.48	22.56
	2003/04	12	266.06^{a} ± 20.88	53.04	90.43^{a} ± 3.52	8.94	36.05^{a} ± 2.64	6.71
	2004/05	13	148.42^{bc} ± 11.33	28.54	55.70^{b} ± 3.02	7.60	37.84^{a} ± 2.84	7.16
	2005/06	12	221.75^{ab} ± 16.57	42.09	88.60^{a} ± 3.62	9.20	41.50^{a} ± 2.30	5.83
Coonawarra	2002/03	9	145.33^{b} ± 20.12	52.93	48.31^{b} ± 3.40	8.93	38.13^{ab} ± 5.59	14.71
	2003/04	16	319.92^{a} ± 24.41	60.53	68.78^{a} ± 3.60	8.93	22.94^{b} ± 1.65	4.08
	2004/05	18	219.06^{b} ± 12.48	30.72	70.26^{a} ± 2.24	5.51	34.16^{a} ± 2.61	6.43
	2005/06	18	186.06^{b} ± 10.20	25.19	76.07^{a} ± 4.28	10.57	42.80^{a} ± 3.16	7.79
	2006/07	10	246.80^{ab} ± 27.42	71.07	77.98^{a} ± 4.92	12.75	35.59^{ab} ± 2.56	6.64
Padthaway	2002/03	5	162.80^{b} ± 20.44	61.64	58.24^{b} ± 3.97	11.96	38.41^{a} ± 5.65	17.05
	2003/04	9	319.10^{a} ± 27.99	73.62	95.80^{a} ± 6.69	17.60	31.04^{a} ± 2.40	6.31
	2004/05	14	245.07^{ab} ± 24.59	61.58	64.30^{b} ± 4.38	10.98	30.80^{a} ± 4.00	10.01
	2005/06	11	222.82^{ab} ± 17.75	45.49	80.27^{ab} ± 9.21	23.59	37.13^{a} ± 4.21	10.80
	2006/07	14	255.70^{ab} ± 23.37	58.52	53.47^{b} ± 4.64	11.63	22.47^{a} ± 2.48	6.21
Bordertown	2002/03	4	175.00^{a} ± 18.49	61.54	76.05^{c} ± 1.28	4.25	44.93^{a} ± 4.82	16.03
	2003/04	6	391.22^{a} ± 56.78	161.82	103.97^{ab} ± 6.81	19.41	29.62^{a} ± 5.09	14.50
	2004/05	4	209.25^{a} ± 12.91	42.95	80.45^{bc} ± 1.68	5.58	38.86^{a} ± 2.34	7.80
	2005/06	5	332.40^{a} ± 42.61	128.48	116.67^{a} ± 8.30	25.02	37.56^{a} ± 5.12	15.44
	2006/07	6	274.33^{a} ± 29.45	83.94	81.76^{abc} ± 4.24	12.09	31.60^{a} ± 3.84	10.95

4.3 DISCUSSION

4.3.1 Fertility

4.3.1.1 Correlations between fertility (bunches per node) and yield components.

Martin and Dunn (2000) have noted that in seasons where grape yields are relatively high, both bunch number and bunch size are relatively high. The hypothesis for section 4.3.1 is, therefore, that in seasons of relatively high fertility expressed as bunch number per node, potential bunch weight is also relatively high. This hypothesis infers that there is co-development of bunch number and bunch weight, whereby the same factors that affect the relative number of bunches that develop, also affect the relative size of the bunches that develop, in terms of flower number per inflorescence in particular. This study has shown positive, significant ($p<0.05$) correlations for each of the varieties measured (Chardonnay, Shiraz and Cabernet Sauvignon) between the variables fertility and bunch weight, fertility and flower number per inflorescence and fertility and berry number per bunch (Table 4.1) when blocks of each variety were each pooled from four vineyards across the Limestone Coast (Robe, Coonawarra, Padthaway and Bordertown).

4.3.1.2 Effect of growing season on fertility (bunches per node) and yield components

Fertility was significantly lower ($p<0.05$) in growing season 2002/03, compared with other seasons, when blocks of each variety were pooled (Table 4.3). The same result (although not significant) also occurred when blocks of each variety were analysed separately by growing season (Table 4.5). These varying fertility levels were regulated by relative differences in temperature in the season prior to that of the vintage year—during inflorescence primordium initiation and differentiation (Table 4.4). Watt et al. (2008) stated that anlagen initiation was first observed in latent buds at node position 4, six weeks after budburst and two weeks before that at the lower node positions, and branches were first observed nine weeks after budburst. These findings on inflorescence initiation and differentiation in a cool climate were approximated in the Limestone Coast, ie. from October to November for inflorescence initiation and November to December for inflorescence differentiation (Table 4.4) based on long-term average budburst from 7-21st September for all varieties and vineyards in this study. Inflorescence primordium initiation and differentiation would have occurred under the coolest conditions for the crop harvested in 2003, compared with the other seasons (Table 4.4). Both fertility and flower number per inflorescence for the 2002/03 growing season were significantly lower ($p<0.05$) than all other growing seasons when blocks of each variety were pooled (Table 4.3). The same result (although

not significant) also occurred when blocks of each variety were analysed separately by growing season (Table 4.5). In addition, bunch weight and berry number per bunch were lower in 2002/03 than the other growing seasons (Table 4.3). These findings are consistent with the positive, significant ($p<0.05$) correlations between fertility and bunch weight established previously (Table 4.1). Because inflorescence primordia initiation and differentiation occurred under relatively similar climatic conditions for all vintages except 2003 (Table 4.4), a general lack of significance in fertility and yield components between all other seasons except 2003 was expected (Tables 4.3 and 4.5).

4.3.1.3 Effect of variety and vineyard site on fertility (bunches per node)

Temperature differences between the vineyards during inflorescence primordium initiation appeared relatively small (Table 4.4). However, the fact that Cabernet Sauvignon was the only variety to show a significant difference ($p<0.05$) in fertility between vineyard sites (Table 4.6), perhaps indicates that genetically, Cabernet Sauvignon fertility is more sensitive to temperature during inflorescence primordium initiation than either Chardonnay or Shiraz. In addition and perhaps more likely, Cabernet Sauvignon fertility was affected to a greater extent than either Shiraz or Chardonnay, by cultural practices adopted at each of the vineyard sites. These cultural practices include irrigation scheduling affecting water stress (Buttrose, 1973 and 1974b; Dunn, 2005), carbohydrate levels (Peacock et al., 2005), nutrition (Matviasvili, 1964), canopy management related to shading (May et al., 1976; Smart et al., 1982a,b) and number of fruiting zones (Dry, 2000). Of these cultural practices, irrigation scheduling and associated vine stress, carbohydrate levels and vine nutrition were likely to have had the largest influence on fertility differences between the vineyard sites.

If temperatures during inflorescence primordium initiation and differentiation were solely responsible for the number of bunches per node at each vineyard site, climatically-warmer vineyards would always show higher fertility. This was not the case in this study, as Padthaway and Bordertown fertility was not significantly higher than Coonawarra for any of the three varieties (Table 4.6).

4.3.1.4 Effect of vineyard site on fertility (bunches per node) and yield components

Across all varieties, Robe generally showed the highest fertility of any vineyard for each variety, but this result was not matched by flower number per inflorescence (Tables 4.6). Watt et al. (2008) noted that, for cool climate Chardonnay, the extent of inflorescence primordia secondary branching prior to winter dormancy is less than in a hot environment, which suggests that the size of these inflorescences is 'less committed' prior to budburst, and therefore, more sensitive to environmental conditions, principally temperature, during budburst. Therefore, it is possible that ambient temperatures during budburst, for at least the two 'cooler' vineyards of Coonawarra and Robe, may contribute strongly to the relative number of flowers formed during budburst. Due to the Robe vineyard's close proximity to the ocean (Figure 4.1) and associated modifying effects of the ocean on ambient temperature, temperatures at Robe vineyard during budburst are higher, on average, than those of the other three vineyards situated more inland. It is suspected that these higher ambient temperatures may be reducing the potential number of flowers formed on an inflorescence at Robe vineyard compared with the other vineyards in the study (Dunn and Martin, 2000; Petrie and Clingeleffer, 2005). Robe vineyard's relatively high fertility compared to the other vineyard sites may also be a direct result of the single wire trellis type used in the vineyard as well as hand pruning to tightly regulate bud numbers. These attributes are likely to have led to canopies which are more open and thus readily intercepted by light (Sanchez and Dokoozlian, 2005), compared with mechanically-pruned hedge canopies (with approximately three times the node number compared to Robe hand-pruned system) common to the other three vineyards in the study.

4.3.1.5 Effect of vineyard site and variety on bunch weight

When each variety was analysed separately by vineyard site, the fertility of Robe Cabernet Sauvignon was significantly higher ($p<0.05$) than Padthaway Cabernet Sauvignon (Table 4.6). Conversely, there was no significant difference in fertility between vineyards for either Chardonnay or Shiraz (Table 4.6), yet there were some notable significant differences ($p<0.05$) in bunch weight between the sites. Bunch weight of Robe Chardonnay was significantly higher ($p<0.05$) than Coonawarra Chardonnay (Table 4.6). This result was predominantly due to higher berry weight for Robe —a direct result of either pruning (hand pruning as opposed to mechanical pruning, which with more buds retained and therefore more sinks, results in smaller berry size) (Clingeleffer et al., 2003; Ashley, 2004) and/or irrigation management by applying more water to increase berry size (Freeman, 1983; Clingeleffer, 1991). Bunch weight of Bordertown Shiraz was significantly higher ($p<0.05$) than either Coonawarra or Padthaway Shiraz (Table 4.6). This result

was potentially due to higher fruit set as a direct result of warmer temperatures over the fruit set period for Bordertown compared to Coonawarra (Table 4.9). However, Bordertown's fruit set temperatures were very similar to those recorded at Padthaway and therefore most likely did not contribute to the difference in Shiraz bunch weights between these two sites (Table 4.9). It is possible, however, that pruning style, node numbers retained at pruning and vine age may have contributed to the differences in bunch weight at these three vineyard sites. Flower numbers per inflorescence were higher for the younger Bordertown Shiraz vines than either Coonawarra or Padthaway (Table 4.6). This was likely a direct result of retaining fewer nodes per vine during hand pruning, resulting in less competition for carbohydrates and other nutrients for each retained node. In addition, hand pruning to a single cordon at Bordertown as opposed to the mechanical hedge pruning system utilised at both Coonawarra and Padthaway, not only resulted in vastly fewer nodes per vine retained (30-35 nodes per vine compared to 80-100+ nodes per vine), but each of these nodes was likely exposed to a more favourable light and temperature environment during inflorescence initiation and differentiation because of the smaller canopy size, resulting in higher fruitfulness (Table 4.6) and larger inflorescences (Table 4.6). With a higher number of flowers per inflorescence and fruit set similar between all three sites, berry number per bunch for Bordertown was significantly higher than either of the other two vineyards (Table 4.6).

4.3.2 Fruit set

4.3.2.1 Effect of fertility (bunches per node) on flower number per inflorescence

Fruit set has been defined by Coombe (1962) as the changeover from the static condition of the flower ovary to the rapidly growing condition of the young fruit. From a viticultural standpoint, fruit set is a process that quantitatively determines how many of the flowers become berries (May, 2004). Results from this study have shown that bunch number per node was related to bunch weight, flower number per inflorescence and berry number per bunch (Table 4.1). All these correlations indicate that conditions conducive to the development of bunches also lead to the development of larger bunches and vice versa, as reported by Palma and Jackson (1981) and Dunn and Martin (2007). Mean flower number per inflorescence and fertility were both significantly lower ($p<0.05$) for Cabernet Sauvignon, Shiraz and Chardonnay in season 2002/03 than other seasons (Table 4.5) and this was combined with lower initiation and differentiation temperatures for vintage 2003 than for all subsequent years of the study (Table 4.4).

For Cabernet Sauvignon, when flower number per inflorescence was significantly higher in seasons 2003/04 and 2006/07 than in 2002/03, fruit set was significantly lower in 2003/04 and

2006/07 than in 2002/03 (Table 4.5). Although this trend for flower number per inflorescence and fruit set was not as marked for Shiraz and Chardonnay as it was for Cabernet Sauvignon, season 2002/03 still showed the highest or close to the highest fruit set for both varieties compared with the other seasons (Table 4.5). Whilst temperatures for fruit set were not recorded by variety, an average of fruit set temperatures across the four vineyard sites in the study (Table 4.9) showed that during the fruit set period of 2002, temperatures were cooler than those in 2003 and 2006. Therefore, it appears that flower number per inflorescence was more strongly correlated with the resultant fruit set in this study, than the effect of temperatures during fruit set on the resultant fruit set percentage.

4.3.2.2 Effect of flower number per inflorescence on fruit set

Flower number per inflorescence for Cabernet Sauvignon was higher than that of both Shiraz and Chardonnay, regardless of growing season and vineyard site (Tables 4.2, 4.5 and 4.6). When each variety was separated by growing season (Table 4.5), the apparent relative strength of the genetic makeup of the varieties versus growing season effects on bunch size was evident. Genotype appears to pre-determine the potential range of flower numbers per inflorescence that Cabernet Sauvignon may carry, for example, compared with Chardonnay or Shiraz, whilst the growing season determines the actual number of flowers per inflorescence expressed by each variety (Table 4.5). As a result, genotype predetermines the theoretical maximum of flowers per inflorescence by variety, but the actual number of flowers per inflorescence (below this theoretical maximum) is determined by temperatures during inflorescence primordium differentiation (when branching occurs) and during budburst (when the actual flowers are formed on these branches) (Barnard and Thomas, 1933; Snyder, 1933; Winkler and Shemsettin, 1937; Scholefield and Ward, 1975; Srinivasan and Mullins, 1981).

When blocks were pooled for all vineyards and seasons in the study, Cabernet Sauvignon flower number per inflorescence was significantly higher and fruit set significantly lower, than that of both Shiraz and Chardonnay (Table 4.2). This effect of flower number per inflorescence on fruit set was also evident within all growing seasons for each variety (Table 4.5) and within all vineyard sites for each variety (Table 4.6). These observations potentially highlight a survival mechanism of the grapevine, whereby its capacity to reproduce annually is maximised, but not to the detriment of the plant itself.

In seasons when flower number per inflorescence is at the lower end of the genetically pre-determined 'range' for a given variety, fertility is also generally low (Table 4.3). Higher fruit set which generally eventuates when flower number per inflorescence is low (Table 4.5) thus allows the variety to maximise yield for that season. On the other hand, in seasons where flower number per inflorescence is at the upper end of the genetically pre-determined 'range' for a given variety, the lower fruit set which generally eventuates (Table 4.5) prevents the variety from excess yield for that season which may then lead to excessive stress for the plant, because the number of bunches per node (sinks) were presumably at the upper end for the variety because of the positive correlation between fertility and bunch size.

Percentage fruit set is therefore not pre-determined for each variety and season. It is a measure which is regulated annually by the number of flowers per inflorescence present pre-flowering; the levels of which are generally correlated with fertility. Other factors apart from flower number per inflorescence that can influence fruit set include solar radiation, air temperature, rainfall and nutrition (May, 2004). These factors predominantly reduce the level of fruit set below the upper potential determined by the pre-flowering level of flowers per inflorescence.

Despite the fruit set level of a particular season, the relative number of flowers per inflorescence largely influences final bunch weight, in terms of berries per bunch. For all three varieties, when flowers per inflorescence were significantly lower in season 2002/03 compared with other seasons, berries per bunch were also low, despite a significantly higher fruit set (Table 4.5).

4.3.2.3 Effect of vineyard on flower number per inflorescence

Based on previous findings in this study, this positive correlation between flower number per inflorescence and berry number per bunch should hold, except for where fruit set is negatively affected by environment or other factors. Flower number per inflorescence and berry number per bunch were strongly and positively correlated for all Robe varieties (Table 4.8). This was not the case for other vineyard sites in the study for which conditions over set possibly affected berry number per bunch to a greater extent than flower number per inflorescence pre-flowering. Irrespective of the significance of the differences in fruit set between seasons, mean fruit set was the most consistent between seasons at Robe than at the other vineyard sites (Table 4.12). The difference between highest and lowest mean flower number per inflorescence over time was also smallest for Robe compared with the other sites (Table 4.12). These factors support the finding of the strong correlation between flower number per inflorescence and berry number per bunch at Robe.

Because yield components were averaged over a number of blocks from each vineyard site, it is expected that the correlations between flower number per inflorescence and berry number per bunch in this study may have also been affected by the variability in cultural practices adopted across the blocks included within each variety for the vineyard sites. Target grades for the blocks included for each variety were most similar for Robe vineyard (A-B grade) and therefore it is suggested that this is an additional reason for the tight correlations between flower number per inflorescence and berry number per bunch reported in Table 4.8 for this site. Management strategies employed at Robe are relatively similar across the vineyard blocks of each variety than for other vineyard sites where target grades are more variable (A-D grade). Robe blocks are all hand-spur pruned to a single cordon, with similar node number per vine. Irrigation and nutrition are similarly managed across the site due to the similar target end use of the blocks. Coonawarra, Padthaway and Bordertown vineyard sites, unlike Robe, each have a variety of training systems eg. T-trellis, two wire vertical, single wire resulting in vastly different bud numbers per vine. Pruning methods vary between hand spur, cane and mechanical hedge pruning. Irrigation and nutrition programs are also tailored to accompany these training and pruning methods, to produce the required target end uses. It is possible that these cultural practices are sufficiently variable across the blocks included within each variety of these three vineyard sites, to reduce the strength of the overall correlation between flower number per inflorescence and berry number per bunch.

4.3.3 Variation in Yield

4.3.3.1 Crop Forecasting System

The structured crop forecasting system used to forecast wine grape yields on the vineyards in this study was that developed by Clingeleffer and other researchers, as part of their project funded by the Grape and Wine Research and Development Corporation (Clingeleffer, 2001). This system takes timely measurements of bunches per vine, berries per bunch and weight per berry to predict yield (weight per vine). The aims of my investigation to determine which yield components predominantly affect yield per vine were two-fold. Firstly, to test the theory that approximately 60% of the seasonal variation in yield is due to variation in bunches per vine, approximately 30% is due to berries per bunch and approximately 10% is due to weight per berry (Dunn, 2004; Martin, 2004; Clingeleffer, 2001). The second aim was to determine whether the estimation of any yield components could be omitted from the crop forecasting system for any particular variety or vineyard without affecting the accuracy of the results. The crop forecasting system utilised on the vineyards in my study is very time-consuming and therefore most effort

must be placed on capturing data of those yield components which have the greatest effect on yield. It is expected that if any steps in the yield forecasting process could be removed (based on scientific evidence), then this system could be adopted on more blocks across these vineyards, potentially improving the overall accuracy of yield estimation on the vineyards.

4.3.3.2 Fractions of seasonal variation in yield accounted for by seasonal variation in yield components.

Over the five seasons of the Limestone Coast study, bunches per vine accounted for most of the seasonal variation in yield per vine for almost all vineyard x variety combinations. There were however, some seasons and cultivars for which berries per bunch dominated variations in yield (Tables 4.10 and 4.11). Most similar studies state that variation in bunches per vine generally accounts for 60% of the variation in yield, followed by 30% for berries per bunch and 10% for weight per berry (Dunn, 2004; Martin, 2004; Clingeleffer, 2001). Results presented in Table 4.10 show that bunches per vine accounted for between 24-88% of the seasonal variation in yield per vine, across all varieties and vineyards in the study. These data when averaged by variety, are in agreement with the 60:30:10 finding; especially for berries per bunch and weight per berry. It was expected that seasonal variation in bunches per vine would most commonly affect seasonal variation in yield. In general, if pruning is carried out to the same node level per vine from season to season, if fertility is low in one season, yield will be low and vice versa if fertility is high. This result is exacerbated by the fact that conditions conducive to anlagen conversion to inflorescence primordia also predisposes them to form more branches and therefore to have the capability to carry more flowers (Palma and Jackson, 1981; Dunn and Martin, 2007). So, in general, high yield is usually a consequence of both high bunch number and large bunches.

4.3.3.3 Effect of variety and 'pruning to fertility' on fractions of seasonal variation in yield accounted for by seasonal variation in yield components.

Averaged across all three vineyard sites in the study, variation in bunches per vine most affected Chardonnay yields and least affected Cabernet Sauvignon yields (Table 4.10). In the latter case, variation in berries per bunch made a strong contribution to variation in yield. This finding was different to that of Martin (2004) who found that bunches per vine for Cabernet Sauvignon and Chardonnay more strongly determined the seasonal variation in yield than for Shiraz. The fact that Chardonnay yields (on average) were so strongly driven by bunches per vine in this study was somewhat unexpected. Chardonnay yield (in cool climates) was predicted to be more affected by berries per bunch because of its sensitivity to low temperatures over flowering (May,

2004) which can lead to reduced fruit set and therefore a reduction in berries per bunch – this trend was in fact noted for Coonawarra, not for the warmer Padthaway vineyard (Table 4.10). Temperatures over the fruit set period were however more variable over time for Coonawarra than Padthaway (Table 4.9), which is likely to have contributed to the greater variation in fruit set between seasons for Coonawarra than Padthaway (Table 4.12).

It is proposed that Cabernet Sauvignon yield was most strongly influenced by berries per bunch and weakly influenced by bunches per vine compared with Chardonnay and Shiraz due to a focus on the production of quality Cabernet Sauvignon in the Limestone Coast as a flagship variety of the region. With the adopted annual practice of adjusting retained node numbers per vine according to predicted inflorescence number per node obtained from bud dissections ('pruning to fertility'), the variability in bunches per vine from year to year, in Cabernet Sauvignon, has reduced. With bunches per vine being relatively stable from season to season, the only other yield component which can determine yield is bunch weight. The component of bunch weight, berries per bunch, more often than weight per berry affected the seasonal variation in yield (Table 4.10). Variability in the yield component berries per bunch (as affected by the conditions over flowering and fruit set and by the number of flowers present pre-flowering) may therefore have a considerable effect on the seasonal variation in yield when 'pruning to fertility' becomes an adopted management practice.

4.3.3.4 Effect of vineyard site on fractions of seasonal variation in yield accounted for by the seasonal variation in yield components.

Robe was the only vineyard for which bunches per vine was the dominant yield component that affected yield variation similarly for all varieties (Chardonnay was excluded due to low sample size) (Table 4.10). This result is perhaps a cumulative effect of several factors. From a macro perspective, target grade levels for Robe vineyard blocks (over the whole vineyard site and those blocks included in this study) cover a smaller range than for either Coonawarra or Padthaway. Robe targets predominantly A and B grade fruit, whilst Coonawarra and Padthaway vineyards target levels ranging from A to D grade. This strategy means that pruning at Robe is carried out to a more consistent node number across vineyard blocks as the targets are similar for each variety or block. A similar level of effort is employed in achieving target node numbers for each vineyard block at Robe, because the target grade levels are alike. At Coonawarra and Padthaway vineyards, however, more attention to detail is employed in high target end-use blocks, and vice versa with blocks for which the target end use is lower. Management practices

are therefore likely to be more varied between blocks at both Padthaway and Coonawarra vineyards. Had the analysis in Table 4.10 been carried out by separately assessing blocks of the same quality level, perhaps the fractions of seasonal variation in weight per vine accounted for by the seasonal variation in bunches per vine, berries per bunch and weight per berry in higher quality blocks at both Coonawarra and Padthaway may have looked similar to those at Robe (insufficient data to perform this analysis). The fact that bunches per vine was the dominant yield component that affected yield variation similarly for all varieties at Robe may also reflect the similarity of vine densities, pruning styles, trellis types and vine ages of the Robe blocks in the study as compared with those at both Coonawarra and Padthaway. In addition, it appears that these cultural practices may have had a stronger effect on seasonal yield component variation than the variability in fruit set temperatures over time. Robe fruit set temperatures were more variable than those of Padthaway over time (Table 4.9) but did not result in greater seasonal variation in berries per bunch than Padthaway (Table 4.10).

4.3.3.5. Effect of growing season on fractions of seasonal variation in yield accounted for by seasonal variation in yield components.

When variety x vineyard combinations were analysed by growing season (excluding 2002/03 due to a lack of data), there was no definitive trend for the seasonal influence on the relative importance of bunches per vine in the seasonal variation of yield per vine (Table 4.11). This result was matched by the lack of difference between seasons (except 2002/03) (Table 4.5). The most obvious conclusion from this finding, as suggested previously, is that temperatures during inflorescence primordium initiation were not different enough between the seasons (excluding 2002/03) to result in variability in bunch number per vine from season to season (Table 4.4).

The vineyard blocks in the study were also pruned to different node levels each season. Based on findings in the previous chapter, the number of nodes retained and the length of the bearers retained affected actual bunch number or fertility (bunches per node). Because of this 'pruning to fertility' practice adopted by the vineyards in the study, variation in actual bunch number per vine from season to season cannot be exclusively equated to variation in predicted fertility from season to season determined by temperature etc. during inflorescence primordium initiation in the season prior to that of the vintage year. Therefore, although the measured differences in temperature during inflorescence primordium initiation between seasons were minimal, 'pruning to fertility' is likely to have changed the relative effects of these temperatures on actual bunch number per vine.

While growing season did not clearly affect the seasonal variation in yield per vine accounted for by the seasonal variation in berries per bunch across all vineyard sites (Table 4.11), there were some growing seasons for which trends were noted, particularly at Padthaway for which there were more data available to analyse. In seasons 2003/04 and 2005/06, berries per bunch were substantially higher than in seasons 2004/05 and 2006/07 (Table 4.12) and therefore, accounted for a comparatively larger proportion of the seasonal variation in weight per vine (Table 4.11). Mean temperatures over the fruit set period for these four seasons were comparatively similar and therefore possibly did not contribute significantly to these noted differences in berry number per bunch (Table 4.9). The high berry numbers per bunch in season 2003/04 were due to high flower number per inflorescence and the high berry numbers per bunch in season 2005/06 were due to high fruit set (Table 4.12).

4.3.3.6 Future yield component data collection from the crop forecasting system

Bunches per vine was, in most cases, the dominant factor which determined seasonal variation in yield per vine; however, there was considerable variation between varieties and between vineyard sites in the study. Because of the relative importance of bunches per vine and berries per bunch in determining the seasonal variation in yield, these components of the currently employed crop forecasting system must continue to be collected for all vineyard sites and varieties. More attention should be focussed on obtaining accurate berry numbers per bunch as this yield component appears to be more important in determining yields in the Limestone Coast than in previous studies. A time frame greater than five years may also be required to determine, with more accuracy, the relative importance of the yield components in determining seasonal yield variability, due to variation in trellis types, pruning styles and vine densities of the blocks involved, as well as the pruning practices not being static over time. Berry weight measurement is a by-product of berries per bunch determination, so despite weight per berry contributing least to the determination of weight per vine, collection of these data can be completed with little additional effort and therefore should also be continued.

4.4 CONCLUSIONS

- The hypothesis that in seasons of comparatively high fertility, potential bunch weight is also high can be accepted based on the results from this Limestone Coast study, ie. significant correlations between fertility and bunch weight, fertility and flower number per inflorescence and fertility and berry number per bunch
- When inflorescence primordia initiated and differentiated under cooler conditions, actual bunches per node and flowers per inflorescence were lower and fruit set was higher for Cabernet Sauvignon, Shiraz and Chardonnay.
- Cabernet Sauvignon has inherently more flowers than either Shiraz or Chardonnay which was associated with significantly lower fruit set than the other two varieties.
- Genotype determines the range of flowers per inflorescence that a variety can potentially carry, whereas actual flower number per inflorescence is determined by inflorescence primordium initiation and differentiation temperatures as well as temperatures around budburst.
- Vineyard site did not strongly affect the magnitude of the yield components in general, as compared with growing season or variety, as climate differences between the vineyard sites were minimal. Cultural practices at each vineyard site were sufficiently variable to affect fertility levels between the sites, particularly for Cabernet Sauvignon.
- Robe vineyard showed the highest fertility level and a strong association between flower number per inflorescence and berry number per bunch for each variety, compared to the other vineyard sites. It was also the only vineyard for which the fractions of seasonal variation in yield, accounted for by bunches per vine, berries per bunch and weight per berry, were consistent across varieties. The single wire trellis, tight pruning and similarity in target grade level common to all varieties at the site may have affected this result.
- Flower number per inflorescence at Robe is potentially reduced by warmer ambient temperatures at budburst than at the other sites.
- Fruit set level is inversely related to the number of flowers per inflorescence at pre-flowering for Cabernet Sauvignon, Shiraz and Chardonnay. This is perhaps a survival mechanism for the grapevine as it allows the vine to maximise yield each season without detriment to its longevity.
- The relative number of flowers per inflorescence for Cabernet Sauvignon, Shiraz and Chardonnay largely influences relative bunch weight, despite the inverse relationship between flower number per inflorescence and fruit set.

- Bunches per vine accounted for the majority of the seasonal variation in yield for all vineyard site x variety combinations except for Padthaway Cabernet Sauvignon and Shiraz.
- The use of predicted fertility to set node numbers is likely to be moderating fluctuation in bunch numbers and therefore yield over time. This practice may be increasing the seasonal variation in berries per bunch.
- The magnitude of predicted fertility affected by inflorescence primordium initiation and differentiation temperatures may not be matched completely by actual fertility (bunches per node) from season to season as a direct result of pruning.
- Collection of all yield components in the current crop forecasting system must be maintained.

CHAPTER FIVE
GENERAL CONCLUSIONS

The importance of budburst in yield determination

Budburst determines which node positions on a bearer will produce the shoots on which inflorescences are located and it may act by modifying the potential inflorescence number per node based on the relative location of each node from the apex of the bearer. Node positions with the highest percentage budburst were located at the distal end of each bearer length, at the outer edge of the mechanically-pruned hedge. These nodes were exposed to the most favourable light and temperature environments during initiation and had the highest fertility. The observed hierarchy in budburst on a bearer of any length can be attributed to hormonally-driven apical dominance, the relative sink of the nodes on each bearer length based on their fruitfulness and the influence of the pruning cut.

Effect of node position on a bearer on its relative size of yield components

The position on a bearer at which a node is situated affects its contribution to the total yield of the bearer. Proximal nodes develop earliest in the season when weather conditions are generally least favourable for bunch primordium initiation and differentiation. These node positions have lower budburst, are less fruitful and have smaller inflorescences than distal node positions. Differences in fertility of nodes on a bearer have been predetermined prior to budburst due to the genetically-determined quadratic trend in fruitfulness on a bearer, the unique microclimate of temperature and light surrounding each node on the bearer and the balance between shoot growth in the current season and the development of the uncommitted primordia in the latent buds. Actual fertility of each node also appears to be dependent on bearer length. The closer that an individual node is to the distal end of the bearer, the greater is the likelihood of budburst at that node and thus the greater the average fertility of that node relative to the same node position counted from the base of the bearer on longer bearers.

The relationship between bunch size and node position appeared to be independent of bearer length, unlike that of fertility. The relative location of an individual node from the distal end of the bearer did not appear to affect the number of flowers per inflorescence at that node position. Flower number per inflorescence had not been fully determined at the onset of budburst,

therefore factors such as budburst that affected the magnitude of inflorescence number per node could not affect flower number per inflorescence at this stage.

Confirmation of the co-development of bunch number and bunch size

Fertility was positively correlated with bunch weight, flower number per inflorescence and berry number per bunch. These correlations indicate that the same factors that affect the relative number of bunches that develop will also affect the relative size of the bunches that develop. When yield components of single inflorescences on a shoot were compared with those of multiple inflorescences on a shoot, single inflorescences weighed significantly less with fewer flowers per inflorescence compared with the basal inflorescence of the two-inflorescence shoots. The relative sizes of the individual inflorescence primordia within each node also appear to be directly affected by the number present per node. When there are multiple inflorescence primordia developing at a node, the carbohydrate/nutrient sink of these developing inflorescence primordia appears to be stronger than if only a single inflorescence primordium exists.

Flower number per inflorescence and fruit set

Flower number per inflorescence is genetically determined. Cabernet Sauvignon has significantly more flowers per inflorescence than either Chardonnay or Shiraz, regardless of growing season or vineyard site. Genotype appears to predetermine the theoretical maximum of flowers that a variety may carry, whilst temperatures during inflorescence primordium differentiation and during budburst of each season, determine the actual number of flowers expressed by each variety. Robe vineyard's relatively high node fertility was not matched by flower number per inflorescence when compared with the other vineyards sites. Temperatures at budburst may be sufficiently high at this cool climate site to cause a reduction in the number of flowers per inflorescence.

The proportion of flowers on an inflorescence that become berries (per cent fruit set) is not predetermined for each variety. It is a measure which is regulated predominantly by the number of flowers per inflorescence present pre-flowering in each season. Other factors, such as low temperatures over flowering and water stress, act to reduce fruit set below the upper potential determined by the pre-flowering level of flowers per inflorescence. For Cabernet Sauvignon, Shiraz and Chardonnay, small inflorescences which are common at proximal node positions on a bearer tend to set higher proportions of these flowers into berries and vice versa with inflorescences that carry a larger flower number, commonly found at distal node positions on a bearer and on the basal inflorescences of two-inflorescence shoots. This is a survival mechanism

that allows the vine to annually reproduce to maximum capacity but not to the detriment of the plant itself.

Effect of climate and cultural practices on yield components

When inflorescence primordium initiation and differentiation occurred under cool conditions for vintage 2003; that is in the spring of 2001, the magnitude of all yield components (fertility, bunch weight, flower number per inflorescence and berry number per bunch) was low compared with other seasons. Temperatures during inflorescence primordium initiation and differentiation were, however, not solely responsible for actual fertility at each vineyard site—as climatically warmer vineyards did not always show higher fertility in this study. Trellis type and pruning style, irrigation scheduling, carbohydrate levels, nutrition and canopy management also affected fertility.

Practical guide to manage yield through pruning

Pruning is the cheapest tool for crop regulation and can affect both bunch number and bunch size. The most effective method to maximise yield based on results from this study is to retain longer bearers at pruning as a positive relationship between average yield per bearer and bearer length was found. As a word of caution, when bearer length is increased, the proportion of blind nodes on the bearer also increases and the proportion of fruitful and non-fruitful nodes decreases. The node positions with the highest budburst and fruitfulness will be those at the most distal node positions on the bearer. Maintaining the shape of the canopy may therefore be difficult if long bearers are retained at pruning in successive seasons as the positions of the fruiting nodes become more distal to the cordon each successive season. Canopy shape is important (especially in narrow-row vineyards) to allow access for machinery down vine rows, maintenance of good airflow through the canopy to reduce disease pressure and especially to allow optimum light interception for the developing inflorescence primordia.

As the relationship between yield per bearer and bearer length was found to be non-linear, retention of bearers of three nodes or longer did not significantly increase yield. Therefore, to increase yield but still maintain canopy shape, leaving an average of three nodes in length per bearer can result in a 38% increase in yield above that which would have occurred by retaining bearers of an average of two nodes in length. As this trial was only performed over a single growing season with one variety, quantification of yield differences due to the retention of different length bearers in a canopy are expected to vary from season to season as node fertility, both on average and at different node positions, changes.

In practice, adjustment of average bearer length retained in the canopy during the mechanical hedge-pruning process is relatively simple, but does require a formalised approach of accurate and frequent assessments to ensure accuracy of the result. The steps outlined below should be followed by growers to facilitate pruning bearers of a hedged canopy to three nodes in length.

Tools required: Mechanical pruner
Measuring tape
Rod or stick pre-cut to 0.3m
Paper and pen
Calculator

Protocol:

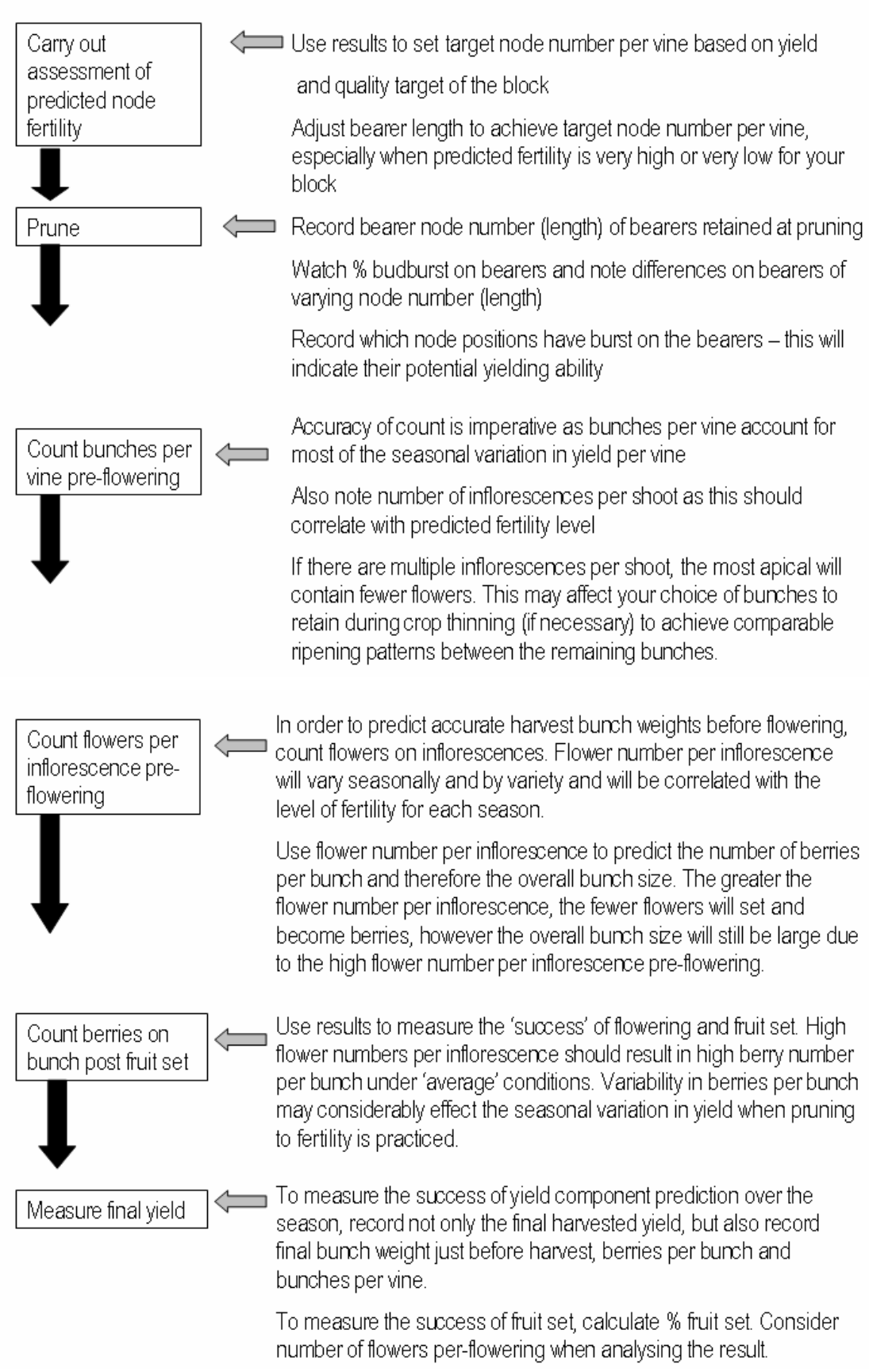
1. Measure the distance from the top of the cordon vertically to the spot half way between nodes three and four and repeat horizontally for both sides of the canopy.
2. At the start of the row, align your horizontal and vertical cutter bars (or saws) to the heights as measured above.
3. Prune down the row for at least ten bays or thirty vines.
4. To facilitate randomised assessments of your pruning, throw a rod or stick pre-cut to a 0.3m segment length back down the midrow of the pruned section and then pickup the rod and place horizontally into the pruned canopy in line with the row direction.
5. On a sheet of paper, record the sample number. Locate each bearer that has its base within the segment. Count the number of nodes on each of these bearers and record the number of bearers of each bearer length against that sample number.
6. Repeat steps 4 and 5 until you have recorded bearers within ten random segments.
7. For each of your ten segments, calculate the median bearer length and then average these values for the ten segments.
8. Adjust your pruning in or out and up or down to reach an average bearer length of three nodes. By examining average internode length you can judge how far you need to adjust your pruning cuts after your initial assessment.
9. To ensure your adjustments have resulted in an average of three node bearers in the pruned canopy, repeat your 10 random segments.
10. Once you are satisfied that you have adjusted your pruning to reach your target bearer length, continue to prune the whole block to the same specifications.

Crop Forecasting

The ability of Australia's grapegrowers to accurately forecast winegrape yield has been relatively poor to date and the implications for this poor crop forecasting have been documented in this thesis. The comprehensive crop forecasting system developed by Clingeleffer and other researchers, documented in Clingeleffer (2001) is currently being used by many Australian grapegrowers with success. However, inaccurate crop forecasting is still adversely affecting the wine industry as a whole.

Growers need to measure their ability to forecast yields on an annual basis, as well as measure seasonal yield variation, to understand the enormity of financial and other impacts as a direct result of inaccurate crop forecasting. To improve the accuracy of crop forecasts, growers need to record the magnitude of a number of yield components each season. In addition, growers need to understand how they can affect their yields through the cultural practices that they adopt, and to understand the effect that the climate of their vineyard site has on grapevine yield components. In this way, growers will be better able to apply various forms of management to their vines at targeted times during the season in order to adjust their cropload. They should then be better able to meet their yield and quality goals, which will benefit not only the grower, but also the winery and ultimately the whole Australian Wine Industry.

The following flowchart illustrates the main components associated with final yield which should be measured in the vineyard. Each step is conducted to improve yield forecasts as the season progresses and to give the grower confidence in manipulating yield through the season to meet the final yield target. Many adjustments also need to be made to the yield components collected in the vineyard, to account for such things as bunch gain, berry loss and harvesting style. A number of additional documented factors also need to be considered by growers, to help them understand the development of, and interaction between, the measured yield components.


Carry out assessment of predicted node fertility
Use results to set target node number per vine based on yield and quality target of the block
Adjust bearer length to achieve target node number per vine, especially when predicted fertility is very high or very low for your block
Prune
Record bearer node number (length) of bearers retained at pruning
Watch % budburst on bearers and note differences on bearers of varying node number (length)
Record which node positions have burst on the bearers – this will indicate their potential yielding ability
Count bunches per vine pre-flowering
Accuracy of count is imperative as bunches per vine account for most of the seasonal variation in yield per vine
Also note number of inflorescences per shoot as this should correlate with predicted fertility level
If there are multiple inflorescences per shoot, the most apical will contain fewer flowers. This may affect your choice of bunches to retain during crop thinning (if necessary) to achieve comparable ripening patterns between the remaining bunches.
Count flowers per inflorescence pre-flowering
In order to predict accurate harvest bunch weights before flowering, count flowers on inflorescences. Flower number per inflorescence will vary seasonally and by variety and will be correlated with the level of fertility for each season.
Use flower number per inflorescence to predict the number of berries per bunch and therefore the overall bunch size. The greater the flower number per inflorescence, the fewer flowers will set and become berries, however the overall bunch size will still be large due to the high flower number per inflorescence pre-flowering.
Count berries on bunch post fruit set
Use results to measure the 'success' of flowering and fruit set. High flower numbers per inflorescence should result in high berry number per bunch under 'average' conditions. Variability in berries per bunch may considerably effect the seasonal variation in yield when pruning to fertility is practiced.
Measure final yield
To measure the success of yield component prediction over the season, record not only the final harvested yield, but also record final bunch weight just before harvest, berries per bunch and bunches per vine.
To measure the success of fruit set, calculate % fruit set. Consider number of flowers per-flowering when analysing the result.

The above recommended set of yield measurements, whilst perhaps considered extensive, are especially important in practice for calculating yield of winegrapes contracted to corporate wineries. A number of sequential yield forecasts for each block of winegrapes are required to be submitted to these wineries, upon which many strategic decisions are made to ensure product requirements are met.

In order to ensure yield samples are collected sufficiently across all parts of a block of unknown variability, a random number generation system should be used to identify 60 positions in a block. Each measurement should occur within a pre-marked 0.6m 'slice' across a vine row (segment) at these 60 randomised positions across the block. Over time, segment number per block can be reduced if variability across the block is found to be low. For further details on best practice crop forecasting methods, refer to Martin, Dunstone and Dunn's 'How to forecast winegrape deliveries Version 7 October 2003.

Future Research

There has been considerable research into specific environmental effects on vine growth and reproduction; however, there has been only limited study into the interactions between climate and cultural factors on a range of vineyard sites and varieties. This is an important area for future research.

In terms of climate-related research, the work of Watt et al. (2008) warrants extension over a range of climates, grapegrowing regions and varieties. This work will then determine the extent of secondary branching prior to dormancy that the inflorescence primordium undergoes under this range of conditions; in order to evaluate 'how committed' the size of the inflorescence primordium is prior to budburst and therefore its relative sensitivity to environmental conditions over budburst. This research will improve understanding of yield development and ultimately may change the pruning strategies that growers adopt in order to meet their yield targets. Especially when faced with poor node fruitfulness (bunch number), growers may choose to retain ''kicker canes''[4] at pruning as an insurance method for achieving a target yield, but also to combat the prospect of even smaller bunches developing if temperatures at budburst are unfavourable for secondary branching. As an extension to this research, further work is also required to quantify the influence

[4] Also known as sacrificial canes, these are commonly canes of 8-10 nodes retained at pruning in addition to the target node number for a vine. These canes are then removed at or prior to veraison in attempt to devigourate the vine, or in case of bad set, they can be retained until harvest (Clancy, 2001).

of budburst temperature on flower number per inflorescence under a range of budburst temperatures.

In terms of research related to cultural factors, an extension of this thesis is warranted to investigate, side-by-side, the effects of varying pruning methods in altering yield over time based on predicted fruitfulness levels and target yields. Financial implications of pruning to a range of styles and attempting to maintain canopy shape over time would also warrant analysis, as would measurement of wine quality. Pruning styles that might be investigated are pruning to a specific bearer length over the whole canopy, finger and thumb pruning, spur pruning by retaining 'doubles' in order to increase total node number and mechanical hedge pruning.

Other research that may be beneficial to industry would be a study of best practice guideline levels of carbohydrates, nutrition and water stress for optimum development of inflorescence primordium in the latent buds. In addition, further analysis into yield component variation over a longer time period than five years is also warranted over a range of varieties and grapegrowing regions to further our understanding of the contribution of bunch number per vine and berry number per bunch to the seasonal variation in grapevine yield.

APPENDICES

Appendix 1 – Minitab output on the correlations between fruitfulness type (fruitful as assigned by a '1', non-fruitful as assigned by a '2' or blind as assigned by a '3') and bearer length and fruitfulness type and bearer cross-sectional area pre-flowering.

A1.1 General Linear Model: Fruitfulness type versus bearer length

Factor	Type	Levels	Values
bearer length	fixed	5	1 2 3 4 5

Analysis of Variance for fruitfulness, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	**P**
bearer length	4	26.3062	26.3062	6.5765	7.45	**<0.001**
Error	1333	1177.3478	1177.3478	0.8832		
Total	1337	1203.6540				

Least Squares Means for fruitfulness

bearer length	Mean	SE Mean
1	1.698	0.07699
2	1.552	0.06485
3	1.710	0.05698
4	1.903	0.05089
5	1.929	0.04912

A1.2 One-way ANOVA: Bearer cross-sectional area vs fruitfulness type

Analysis of Variance for bearer cross-sectional area

Source	DF	SS	MS	F	**P**
fruitful	2	26400	13200	11.27	**<0.001**
Error	1329	1556332	1171		
Total	1331	1582732			

Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
1	765	99.21	34.75	(---*--)
2	76	86.26	32.34	(----------*----------)
3	491	91.12	33.66	(---*----)
		Pooled StDev =	34.22	84.0 91.0 98.0

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