# The Effect of Partial Defoliation on Growth Characteristics of *Vitis vinifera* L. cv. Cabernet Sauvignon II. Reproductive Growth

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**The effect of partial defoliation over the whole canopy on the reproductive growth of *Vitis vinifera* L. cv. Cabernet Sauvignon was investigated. The 33% defoliation treatment prior to pea size and the 66% defoliation treatment prior to véraison adversely affected fresh mass per berry and yield at harvest. The 33% defoliation treatment from véraison increased fresh berry mass. Partial defoliation had no effect on berry water content. Dry matter started to accumulate rapidly only from after pea size stage.**

**The fresh berry mass:cane mass ratio increased with partial defoliation from véraison. Leaf area/g fresh mass results indicated that control vines carried excess foliage which prevented maximum photosynthetic activity.**

**Partial defoliation of the canopy improved budding percentage, generally increasing with increasing defoliation, whereas bud fertility was improved only by 33% defoliation. In general, leaf removal from bud break and berry set was more effective in improving budding, whereas bud fertility was favoured by partial defoliation from bud break.**

A clear definition of physiological balances in grapevines requires measurements relating to the capacity of the vine, a term which represent vegetative growth, crop yield and grape composition (Winkler *et al.,* 1974). The capacity of a grapevine is determined by its genetic potential for $CO_2$-assimilation (Kriedemann, 1977). Genetic information is used to direct increases in size (growth) and changes in form (development) (Weier, Stocking & Barbour, 1974). According to Ho (1988) the potential sink strength is also determined genetically and can be expressed fully only when the supply is sufficient to meet the demand and the environmental conditions for the metabolic activity of the sink organ are optimal. Research concerning canopy microclimate, however, indicates leaf area, especially the percentage of effective leaf surface, as a major factor determining the capacity of a grapevine (Koblet, 1984; Schneider, 1985; Smart, 1985; Smart *et al.* 1985a; Smart, 1987).

The magnitude of a harvest is dependent, among other factors, on the proportion of assimilates diverted towards fruit development rather than vegetative growth (Kriedemann, 1977). Maggs (1964) stated that future crop plants could be expected to convert a greater proportion of their assimilates into economic end-products and less into mere plant machinery. This would lead to greater yield per plant and, owing to reduced foliage, to more plants per hectare. It is, therefore, necessary to minimise vegetative dominance without reducing assimilate supply to the fruit. Concomitantly, it is essential that an optimum canopy microclimate be created for maximum budding and bud fertility (May, 1965; Shaulis, Amberg & Crowe, 1966; Shaulis & May, 1971; Smart, Shaulis & Lemon, 1982; Archer & Swanepoel, 1987) as well as grape quality (Smart, 1982; Smart *et al.,* 1985b; Kliewer & Bledsoe, 1987; Bledsoe, Kliewer & Marois, 1988; Kliewer *et al.,* 1988; Koblet, 1988). Consequently, research regarding grapevine management is aimed progressively at finding the perfect balance between the accumulation of reserves, vegetative growth, canopy microclimate, and optimal fruit quantity and quality.

Owing to excessive growth and canopy density, problems generally occurring in South African vineyards, research concerning the manipulation of foliage is of special importance. This investigation was, therefore, conducted to determine the effect of different levels of defoliation, implemented from different developmental stages of the vine, on the reproductive growth of *Vitis vinifera* L. cv. Cabernet Sauvignon. The effect of partial defoliation on vegetative growth was discussed by Hunter & Visser (1990).

## MATERIALS AND METHODS

**Experimental vineyard:** An eight-year-old *Vitis vinifera* L. cv. Cabernet Sauvignon vineyard (clone 4/R46) (*CS 46), situated at Nietvoorbij experimental farm in the Western Cape, was used (Hunter & Visser, 1988a).

**Experimental design:** The experiment was laid out as a completely randomized design, as previously described by Hunter & Visser (1990).

**Defoliation treatments:** Defoliation treatments (0%, 33%, 66%) were done as previously described (Hunter &

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Visser, 1990).

**Measurements:** Leaf area (cm$^2$), cane mass (g), fresh and dry berry mass (g), the water content of the berries (%), budding percentage, bud fertility and light intensity ($\mu$mol/m$^2$/s) were measured. Budding percentage and bud fertility were determined at the end of the season following the season of treatment. Leaf area was determined with a LI-COR LI 3000 portable area meter. The bunches of five randomly selected shoots per vine were harvested and the fresh mass of the berries determined. Berries were frozen at –20°C prior to freeze-drying. The ambient light intensity between the vine rows as well as the light intensity just above the cordon were determined with a LI-COR Line Quantum Sensor during late morning. Light intensity was expressed as a percentage of the ambient light level.

The following equations were used to determine the budding percentage and bud fertility per vine: Budding percentage = Number of shoots/number of buds allocated during pruning x 100. Bud fertility = Number of bunches/number of shoots originating from buds allocated during pruning.

**Statistical analyses:** Depending on the parameter, a one-way analysis of variance or two-way analysis of variance (standard VORI statistical software packages) was performed on the raw data. Statistical analyses for the determination of significant differences between treatment means were carried out using a Scott-Knott analysis. The experiment was conducted over three growth seasons. Since no interactions between growth seasons were found, the data represent the overall means.

## RESULTS AND DISCUSSION

**Fresh berry mass:** The earlier and more severely partial defoliation was applied, the less fresh mass was produced at subsequent developmental stages compared to those of control vines (Table 1). This was also found by Kliewer (1970) for Sultanina vines. A decrease of hormones or hormone precursors, synthesized in leaves and involved in berry growth, was suggested by Kliewer (1970) as a possible reason for the decrease in berry mass. It is evident that 33% defoliation prior to pea size and 66% defoliation prior to véraison severely affected the yield at harvest (Fig. 1). This is also evident from the fresh mass per berry (Table 2) and is in contrast to the results of Bledsoe, Kliewer & Marois (1988), who found no differences in crop mass and bunch mass owing to either the timing or level of leaf removal. Their experiments were, however, conducted during a single growth season, and the defoliation applied was not as severe as in the present investigation. Koblet (1984) stated that an early removal of too many leaves would weaken the vine and could stop fruit development. Since in this study the whole canopy was evenly defoliated during three growth seasons, creating severe stress conditions, the decreases in the yield of vines subjected to long-term defoliation may have resulted from the depletion of reserves. The translocation patterns of photosynthetate in shoots were, however, not different, and the total photosynthetic activity of especially 33% defoliated vines was similar to or even higher than that of control vines (Hunter & Visser, 1988b, 1989), whereas the increases in the number and length of laterals (Hunter & Visser, 1990) were not enough to account for the decreased masses. According to Brown & Coombe (1985), accumulation is controlled primarily by phloem unloading in the berry, and Ho (1988) stated that the import of assimilate might be controlled by energy-dependent processes. Owing to the drastic changes in microclimate, source:sink relationships and metabolic activity, it is possible that changes in enzyme activity in leaves and/or grapes also played important roles in the control of accumulation in berries. This aspect needs to be investigated further. Furthermore, the partial exposure of berries to direct sunlight may also have contributed to the lower fresh berry mass (Kliewer, 1970). Crippen & Morrison (1986), finding

TABLE 1
The effect of defoliation from different developmental stages of the vine on the fresh berry mass (g) per shoot.

| Developmental stage defoliation commenced | Developmental stage measured | Defoliation (%) | | |
|---|---|---|---|---|
| | | 0 | 33 | 66 |
| Bud break | Berry set | $18^h$ | $18^h$ | $15^h$ |
| | Pea size | $67^g$ | $82^f$ | $56^g$ |
| | Véraison | $174^d$ | $151^e$ | $96^f$ |
| | Ripeness | $247^a$ | $215^c$ | $134^e$ |
| Berry set | Pea size | $67^g$ | 82f | $81^f$ |
| | Véraison | $174^d$ | $155^e$ | $133^e$ |
| | Ripeness | $247^a$ | $206^c$ | $163^d$ |
| Pea size | Véraison | $174^d$ | $180^d$ | $150^e$ |
| | Ripeness | $247^a$ | $228^b$ | $195^c$ |
| Véraison | Ripeness | $247^a$ | 256a | $234^b$ |
| Cv (%) | | 16,21 | | |

Values designated by the same letter do not differ significantly ($p \leq 0,05$).
Data represent the means over three growth seasons.

that shaded berries were significantly heavier than sun-exposed berries, attributed it to a higher water content of the former.

TABLE 2
The effect of defoliation from different developmental stages of the vine on the fresh mass (g) per berry at ripeness.

| Developmental stage defoliation commenced | Defoliation (%) | | |
|---|---|---|---|
| | 0 | 33 | 66 |
| Bud break | $1,20^b$ | $1,18^b$ | $1,11^b$ |
| Berry set | $1,20^b$ | $1,18^b$ | $1,08^b$ |
| Pea size | $1,20^b$ | $1,32^a$ | $1,17^b$ |
| Véraison | $1,20^b$ | $1,26^a$ | $1,30^a$ |
| Cv (%) | 8,26 | | |

Values designated by the same letter do not differ significantly ($p \leq 0,05$).
Data represent the means over three growth seasons.

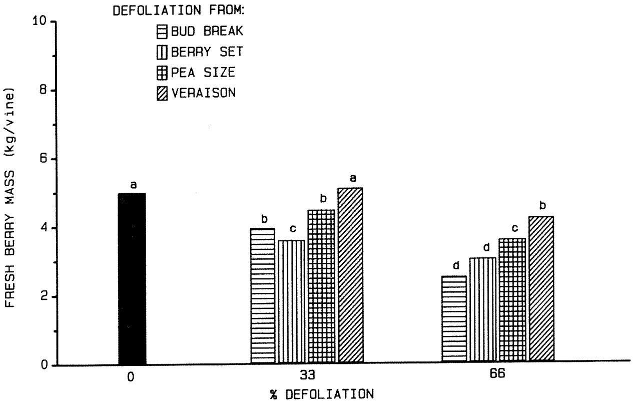

FIGURE 1
The effect of defoliation, implemented from different developmental stages during the growth season, on the fresh berry mass at ripeness. Bars designated by the same letter do not differ significantly ($p \leq 0,05$).

Partial defoliation (33%) from véraison resulted in an apparent higher fresh berry mass (Table 2). Apart from higher photosynthetic activities of remaining leaves, as induced by partial defoliation (Buttrose, 1966; May, Shaulis & Antcliff, 1969; Kliewer & Antcliff, 1970; Kriedemann, 1977; Hofäcker, 1978; Johnson, Weaver & Paige, 1982; Hunter & Visser, 1988b, 1988c), another possible explanation for increased berry mass may be an enhancement of the mobilization of carbohydrate reserves in woody tissues available for accumulation in fruits (Kliewer, 1970). Partial defoliation, however, had no apparent effect on the amount of photosynthetates added to the reserve pool (Hunter & Visser, 1988b). Owing to changes in the canopy microclimate of partially defoliated vines, light composition could also have played a major role in morphological and physiological activity, especially the expression of enzyme activity.

Nevertheless, the improved canopy microclimate due to leaf removal (Hunter & Visser, 1988c, 1990) may also have dramatic effects on grape composition, such as an increased sugar concentration and wine colour and a decrease in the malate and potassium content and pH (Smart, 1982; Smart *et al.*, 1985b; Kliewer & Bledsoe, 1987; Bledsoe *et al.*, 1988; Kliewer *et al.*, 1988, Koblet, 1988).

**Dry berry mass:** Dry mass increased slightly up to pea size, whereafter the accumulation of solutes increased rapidly until harvest (Table 3). In general, it seemed that later leaf removals led to smaller effects on dry mass production. It is, therefore, clear that maintaining enough leaf area to nourish the rapidly dividing cells of young berries is critical for obtaining high yields at harvest. These results are in agreement with the findings of other investigators, i.e. that the removal of the photosynthetic source during the early stages of berry development resulted in lower yields (Coombe, 1959; Kliewer, 1970; Kliewer & Ough, 1970; Kliewer & Fuller, 1973; Sidahmed & Kliewer, 1980).

**Water content:** The water status of the berries of defoliated vines were almost similar (Table 4). It is, therefore, evident that the improved light conditions in the canopy (Hunter & Visser, 1990) had no effect on the water content of berries. This is in contrast to the findings of Crippen & Morrison (1986). This finding is very important because of the well-known effect of water in the regulation of solute concentration in the berry (Coombe, 1987). The mean berry water content over defoliation treatments was 90%, 90%, 80% and 72% at berry set, pea size, véraison and ripeness, respectively. It was evident that the components of dry matter started to accumulate rapidly only from after pea size until harvest. According to Coombe, Bovio & Schneider (1987) this constitutes principally glucose and fructose.

**Fresh mass:cane mass ratio:** Except for defoliation from bud break, no significant differences were found between the fresh mass at ripeness:cane mass ratio of the non-defoliated and 33% defoliated vines (Fig. 2). Defoliation prior to berry set (33%) and prior to véraison (66%) led to the most marked

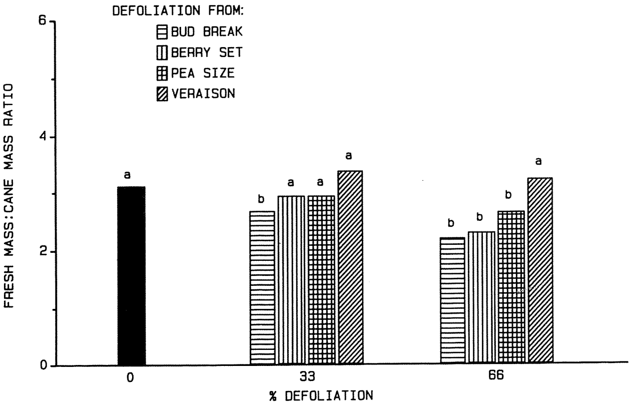

FIGURE 2
The effect of defoliation, implemented from different developmental stages during the growth season, on the fresh mass:cane mass ratio. Bars designated by the same letter do not differ significantly ($p \leq 0,05$).

TABLE 3
The effect of defoliation from different developmental stages of the vine on the dry berry mass (g) per shoot.

| Developmental stage defoliation commenced | Developmental stage measured | Defoliation (%) | | |
|---|---|---|---|---|
| | | 0 | 33 | 66 |
| Bud break | Berry set | $2^{i}$ | $2^{i}$ | $2^{i}$ |
| | Pea size | $6^{h}$ | $8^{h}$ | $5^{h}$ |
| | Véraison | $37^{e}$ | $34^{e}$ | $21^{g}$ |
| | Ripeness | $69^{a}$ | $57^{b}$ | $37^{e}$ |
| Berry set | Pea size | $6^{h}$ | $8^{h}$ | $6^{h}$ |
| | Véraison | $37^{e}$ | $32^{e}$ | $28^{f}$ |
| | Ripeness | $69^{a}$ | $58^{b}$ | $45^{d}$ |
| Pea size | Véraison | $37^{e}$ | $35^{e}$ | $28^{f}$ |
| | Ripeness | $69^{a}$ | $59^{b}$ | $51^{c}$ |
| Véraison | Ripeness | $69^{a}$ | $69^{a}$ | $61^{b}$ |
| Cv (%) | | 18,65 | | |

Values designated by the same letter do not differ significantly ($p \leq 0,05$).
Data represent the means over three growth seasons.

reductions in fresh mass:cane mass ratios. When implemented from véraison, however, the ratio apparently increased, compared to control vines.

**Leaf area/fresh mass and fresh mass/leaf area:** Generally, the later and more severe the defoliation, the more the leaf area per gram of fresh mass was reduced, compared to that of control vines (Table 5). The larger leaf areas with early defoliation resulted mainly from the still low berry masses at the early stages. The stimulation in lateral growth and concomitant leaf area (Hunter & Visser, 1990) could also have contributed to larger leaf areas. Considering the 10 $cm^2$ to 12 $cm^2$ leaf area generally required to ripen one gram of fruit (Winkler, 1930; Kliewer, 1970; Kliewer & Antcliff, 1970; Kliewer & Ough, 1970; Kliewer & Weaver, 1971; Archer & Beukes, 1983; Jooste, 1983), it is evident that the control vines carried excess foliage. The fresh berry mass per leaf area clearly showed that the metabolism and photosynthesis of the remaining leaves of partially defoliated vines were more effective, having the ability to support much higher berry masses throughout the growth season (Table 5). It is, therefore, of the utmost importance to create a microclimate and physiological condition that would allow the optimal photosynthetic activity of all grapevine leaves. This would prevent them from functioning below their maximum efficiency.

**Budding percentage and bud fertility:** The partial defoliation of canopies improved the budding percentage, which generally increased with increased defoliation (Fig. 3). Leaf removal from bud break and berry set was generally more effective in improving budding. Though not sig-

TABLE 4
The effect of defoliation from different developmental stages of the vine on the water content (%) of the berries.

| Developmental stage defoliation commenced | Developmental stage measured | Defoliation (%) | | |
|---|---|---|---|---|
| | | 0 | 33 | 66 |
| Bud break | Berry set | $90^{b}$ | $90^{b}$ | $89^{b}$ |
| | Pea size | $90^{b}$ | $90^{b}$ | $90^{b}$ |
| | Véraison | $80^{c}$ | $78^{d}$ | $79^{d}$ |
| | Ripeness | $72^{f}$ | $72^{f}$ | $71^{f}$ |
| Berry set | Pea size | $90^{b}$ | $90^{b}$ | $91^{a}$ |
| | Véraison | $80^{c}$ | $80^{c}$ | $79^{d}$ |
| | Ripeness | $72^{f}$ | $71^{f}$ | $72^{f}$ |
| Pea size | Véraison | $80^{c}$ | $80^{c}$ | $80^{c}$ |
| | Ripeness | $72^{f}$ | $73^{e}$ | $73^{e}$ |
| Véraison | Ripeness | $72^{f}$ | $73^{e}$ | $72^{e}$ |
| Cv (%) | | 1,16 | | |

Values designated by the same letter do not differ significantly ($p \leq 0,05$).
Data represent the means over three growth seasons.

TABLE 5
The effect of defoliation from different developmental stages of the vine on the leaf area ($cm^2$) per fresh berry mass (g) and fresh berry mass (mg) per leaf area ($cm^2$).

| **Developmental stage defoliation commenced** | **Developmental stage measured** | **Defoliation (%)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0** | | **33** | | **66** | |
| | | $cm^2/g$ | $mg/cm^2$ | $cm^2/g$ | $mg/cm^2$ | cm2/g | $mg/cm^2$ |
| Bud break | Berry set | $176^{a}$ | $6^{h}$ | $177^{a}$ | $7^{h}$ | $134^{b}$ | $9^{h}$ |
| | Pea size | $62^{c}$ | $17^{h}$ | $42^{d}$ | $27^{g}$ | $37^{d}$ | $30^{g}$ |
| | Véraison | $27^{e}$ | $41^{f}$ | $23^{e}$ | $48^{f}$ | $24^{e}$ | $46^{f}$ |
| | Ripeness | $18^{e}$ | $60^{e}$ | $15^{e}$ | $79^{c}$ | $15^{e}$ | $73^{d}$ |
| Berry set | Pea size | $62^{c}$ | $17^{h}$ | 37d | $29^{g}$ | $25^{e}$ | $44^{f}$ |
| | Véraison | $27^{e}$ | $41^{f}$ | $23^{e}$ | $49^{f}$ | $18^{e}$ | $61^{e}$ |
| | Ripeness | $18^{e}$ | $60^{e}$ | $15^{e}$ | $73^{d}$ | $12^{e}$ | $86^{c}$ |
| Pea size | Véraison | $27^{e}$ | $41^{f}$ | 18e | $62^{e}$ | $12^{e}$ | $89^{c}$ |
| | Ripeness | $18^{e}$ | $60^{e}$ | $12^{e}$ | $90^{c}$ | $11^{e}$ | $111^{b}$ |
| Véraison | Ripeness | $18^{e}$ | $60^{e}$ | $12^{e}$ | $90^{c}$ | $8^{e}$ | $134^{a}$ |
| Cv (%): $cm^2/g$<br>$mg/cm^2$ | | 35,12<br>21,57 | | | | | |

Values designated by the same letter do not differ significantly ($p \leq 0,05$).
Data represent the means over three growth seasons.

nificantly, bud fertility was improved by 33% defoliation as well as 66% defoliation from bud break (Fig. 4). According to May (1965), shading may reduce the import of assimilates into the bud and, therefore, reduce fruitfulness. Smart *et al.* (1982) suggested that the leaf subtending the bud may be the principal source of photosynthetates for the bud. Although light intensity at the basal parts of the shoots was improved (Table 6), 66% defoliation was probably too servere, especially as regards the availability of nutrients for the initiation and differentiation of inflorescence primordia. This was also evident from the lower yields (Fig. 1) as well as the lesser total photosynthetic activity of the 66% defoliated vines compared to those of control vines (Hunter & Visser, 1988b, 1989). According to Shaulis & May (1971), the yield of grapevines is determined by, amongst other factors, the growth of buds and their inflorescence primordia as well as the accumulation of photosynthetates in the season preceding harvesting.

Bud fertility was favoured by partial defoliation from bud break. This coincided with the period for the formation of inflorescence primordia and their initiation and differentiation (Swanepoel & Archer, 1988). It is, therefore, evident that the exposure of basal buds to higher light intensities during this period only, affected the fruitfulness of the buds. Smart *et al.* (1982) found a positive relationship between the radiation microclimate of the leaf subtending a bud and the productivity of the shoot from that bud in the following growth season. The correlation was also the highest with an improved microclimate in the pre-flowering period. The

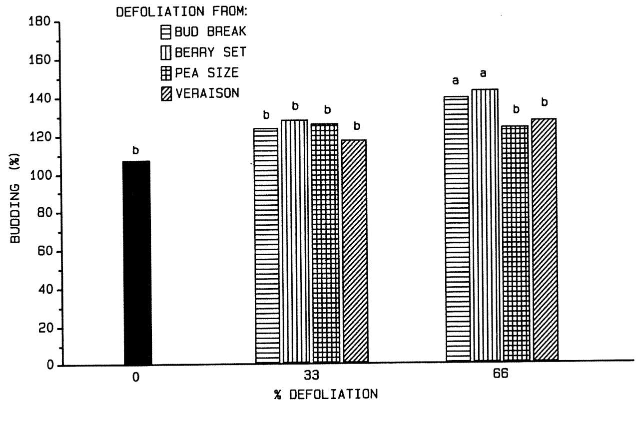

FIGURE 3
The effect of defoliation, implemented from different developmental stages during the growth season, on budding percentage. Bars designated by the same letter do not differ significantly ($p \leq 0,05$).

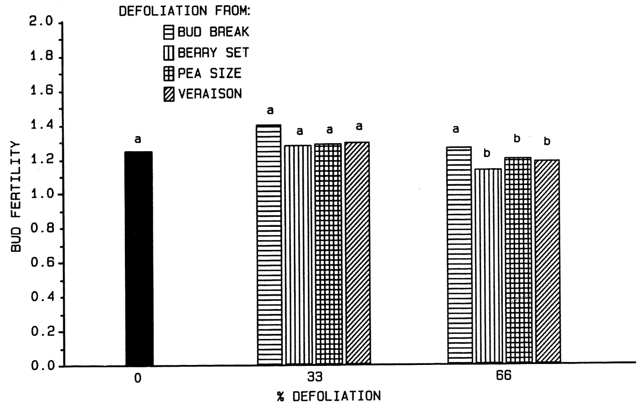

FIGURE 4
The effect of defoliation, implemented from different developmental stages during the growth season, on bud fertility. Bars designated by the same letter do not differ significantly ($p \leq 0,05$).

TABLE 6
The effect of defoliation and developmental stage of the vine on the canopy light intensity, expressed as a percentage of the ambient light intensity.

| **Developmental stage** | **Defoliation (%)** | | | **Mean** |
|---|---|---|---|---|
| | **0** | **33** | **66** | |
| Berry set | 7,65 | 10,84 | 21,35 | 13,28$^{c}$ |
| Pea size | 11,60 | 21,74 | 25,45 | 19,60$^{b}$ |
| Véraison | 14,02 | 27,67 | 36,45 | 26,05$^{a}$ |
| Ripeness | 24,33 | 26,56 | 38,34 | 29,74$^{a}$ |
| Mean | 14,40$^{c}$ | 21,70$^{b}$ | 30,40$^{a}$ | |
| Cv (%) | 46,87 | | | |

Values designated by the same letter do not differ significantly ($p \leq 0.05$).
Data represent the means over three growth seasons.

duration of exposure, as well as the quality (specific wavelengths) of light, may also have been important (Morgan, Stanley & Warrington, 1985; Archer & Swanepoel, 1987). May (1965), however, found that the effect of shading on fruitfulness was not related to light quality, but rather to the reduction in total light intensity. Nevertheless, the results of this study indicated that no direct relationship existed between the fruitfulness of buds and the yield per vine. This may be attributed partly to the decrease in cane mass for especially the long-term severe defoliations (Hunter & Visser, 1990), resulting in lower bud loads per vine and, consequently, lower yields per vine over the three growth seasons of the investigation. It is possible that the high budding percentage further deprived the already severely stressed vines of essential nutrients and reserves, possibly resulting in the apparently reduced shoot lengths and cane masses reported by Hunter & Visser (1990). Nevertheless, the budding percentage was apparently directly affected by the improved light intensity resulting from partial defoliation (Table 6).

## CONCLUSIONS

The 33% defoliation treatment prior to pea size and 66% defoliation prior to véraison adversely affected the fresh mass per berry and yield at harvest, whereas 33% defoliation from véraison increased the fresh berry mass compared to that of non-defoliated vines. When applied from véraison, partial defoliation increased the fresh berry mass:cane mass ratio. The leaf area/fresh mass and fresh mass/leaf area results implied that non-defoliated vines carried excess foliage, preventing maximum metabolism and photosynthetic activity, but that the remaining leaves of partially defoliated vines were able to support substantially higher berry masses throughout the growth season. Furthermore, partial defoliation improved budding, especially when applied from bud break and berry set. Bud fertility was improved only by 33% defoliation, which was more favourable when applied from bud break.

It is clear that the early removal of highly active, newly matured leaves will deprive the vine of essential nutrients, with a deleterious effect on its longevity and health. The even defoliation applied in this study over the whole grapevine canopy was, however, too severe and is not recommended as a canopy management practice. It is, however, essential that the leaves of the grapevine be maximally exploited to benefit vegetative as well as reproductive growth during the growth season. The present results, together with previous results, suggest that an even removal of 33% of leaves opposite and below bunches may be applied during the period from flowering or berry set to pea size. The results further suggest than in practice an even partial defoliation of 33% from as early as pea size may be safely applied to the lower half of the grapevine canopy. This will not only facilitate the prevention of the potentially deleterious effects of excessive vegetative growth and a dense canopy-interior, but improve the canopy microclimate and stimulate metabolic activity and the contribution of photosynthetates to the developing berry. This, as well as the effect of partial defoliation on fruit quality, is currently being investigated further.

An improved canopy microclimate to secure the maximum photosynthetic activity of leaves as well as fruit development before pea size should be obtained by other canopy management practices such as suckering, shoot positioning, tipping and topping. If at all necessary, topping must preferably be carried out before pea size to leave enough time for leaves on sprouting lateral shoots to become active and contribute to the berry during the period véraison to ripeness. Owing to the multidirectional translocation in the shoot, which is still evident before pea size, it is expected that the effect on fruit development would be more dramatic. Topping during the period pea size or véraison to ripeness must be avoided because of the importance of young and recently matured, active leaves on the upper half of the shoot in terms of photosynthesis, the accumulation of reserves, and the translocation of photosynthetic products to the grapes. Photosynthetic products are translocated to bunches mainly during this period. Except in cases of excessive growth. shoots should be tipped only if active growth continues. To prevent the canopy from becoming too dense when topping prior to pea size has been carried out, leaf removal is a necessity during the period pea size to ripeness.

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