Canopy Management to Improve Grape Yield and Wine Quality - Principles and Practices*

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This paper reviews the subject of canopy management with an attempt to develop principles. These principles provide guidelines for canopy surface area amount; spacing between canopies; within canopy shade, especially for the fruiting/renewal zone; balance between fruit and shoot growth; and uniformity of location of fruit/renewal zones, shoot tips and cane bases. Field techniques of point quadrat analysis and canopy scoring are introduced as an aid to defining problem canopies. These techniques are cheap, quick and effective. A set of twenty-one numeric indices and descriptors to assess winegrape canopies is then presented as a winegrape canopy ideotype, which can be further used as management guidelines. Recent publications are reviewed from various aspects of canopy management. These include vigour control, shoot trimming, leaf removal in the fruit zone and training system responses. The paper concludes with presentation of the authors' unpublished data on the effects of canopy microclimate on yield and wine quality. The trial was conducted with the cultivar Cabernet franc on a deep, fertile soil in a cool, high rainfall region. Canopy division using the Ruakura Twin Two Tier doubled yield compared to dense, vertical shoot positioned canopies which are common in New Zealand. Shade caused reduction in all yield components, and also delayed fruit ripening and reduced wine quality. Similar results were obtained by comparing fruit production at different heights with the Te Kauwhata Three Tier trellis system, where lower tiers were shaded at the canopy exterior. The results confirm that grape yield and wine quality can be simultaneously increased by improved canopy management of shaded vineyards.

Canopy management is now an active area of research, especially in the New World winegrowing countries. It is generally accepted that Dr Nelson Shaulis of New York State pioneered canopy studies, especially with publication of the Geneva Double Curtain trellis (Shaulis *et al.*, 1966). However, many of the principles that have emerged from recent research on canopy management are consistent with empirical observations and practices long since employed in Old World vineyards.

The adoption of technological advances, especially post World War Two has created a common situation of excessive vineyard vigour. This is particularly the case in the New World, where the benefits of improved soil preparation, irrigation, nutrition, fertilization and pest, disease and weed control practices have resulted in increased vigour. Further, there are many New World situations where vineyards have been planted on deep and fertile soils. The result of increased vine vigour is typically increased within-canopy shade. Recent research into canopy management has provided techniques to avoid shade.

This paper aims to condense existing knowledge by developing principles of canopy management. These principles are presented along with a series of quantitative indices which permit diagnosis of problem canopies. Field techniques to assess canopies are also presented in detail. The paper concludes with presentation of recent experimental evidence which further supports the principles proposed. This paper can be viewed as an extension of recent reviews on the same subject (Smart, 1985a; Smart 1987c).

DEFINITIONS

A **Canopy,** is defined as the leaf and shoot system of the vine (Shaulis & Smart, 1974). It is described by dimensions of the boundaries in space (i.e. width, height, length etc), and also by the amount of shoot system within this volume (typically leaf area). Canopies are **continuous** where the foliage from adjacent vines down the row intermingle, and where there are no large gaps. If canopies are separated from vine to vine they are **discontinuous**. Where canopies of one vine (or

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adjacent vines) are divided into discrete foliage walls the canopy is termed **divided.** Canopies are **crowded** or **dense** where there is much leaf area within the volume bounded by canopy surfaces - for example a high value of the ratio leaf area: canopy surface area (LA/SA, Smart, 1985a), or of leaf layer number (LLN, Smart, 1985a) or shoot density (shoots/m canopy, Smart, 1988).

The term **canopy management** includes a range of techniques which can be applied to a vineyard to alter the position or amount of leaves, shoots and fruit in space, and so as to achieve some desired arrangement (i.e. canopy microclimate). These techniques include winter and summer pruning, shoot positioning, leaf removal, shoot vigour control and use of improved training system. Canopy management techniques can be used to improve production and/or wine quality, reduce disease incidence, and facilitate mechanisation. Open canopies also lead to more efficient distribution of applied agricultural chemicals (Travis, 1987).

CANOPY MICROCLIMATE

Grapevine leaves as for other plants are strong absorbers of solar radiation, especially in the waveband 400-700 nm of photosynthetically active radiation (Smart, 1987a). Since only about 6% of light in this waveband is transmitted by a leaf (Smart, 1987b), light levels at the centre of dense canopies are very low, less often than 1% of above canopy values (Smart, 1985a).

With high yields, fruit may also cause shade. For example Palmer & Jackson (1977) have quantified this effect for apple canopies. Similar results for grapevine canopies will be presented here. Light encountered in shade conditions has altered quality as well as quantity (Smart, 1987a; Smart, 1987b) with important physiological implications for leaves and fruit in shade conditions (Smart, 1987a). Studies to be detailed later have indicated that shade causes reductions in yield and quality. Therefore an aim of canopy management is to produce a canopy with minimal shade.

When the canopy microclimate is altered by canopy management techniques, it is not only sunlight levels that change. Temperature, humidity, wind speed and evaporation are also modified (Smart, 1985a). Altered evaporation rates are of significance to fungal disease incidence, (English *et al.*, 1989), and exposure can alter thermal relations of grape berries with implications for their composition (Kliewer & Lider, 1968; Smart & Sinclair, 1976; Crippen & Morrison 1986a, 1986b). However, the most significant feature of altered microclimate is for light quantity and quality levels within the canopy, from both a yield and fruit composition viewpoint (Champagnol, 1984; Smart, 1985a; Smart, 1987a).

Shade is avoided by reducing leaf area and increasing the proportion of canopy gaps (Smart, 1988). However, too high a proportion of canopy gaps allows sunlight to be 'lost', falling on the vineyard floor. What is required is a balance between excessive gaps (and hence waste of sunlight energy) and insufficient gaps (and the creation of shade).

PRINCIPLES OF CANOPY MANAGEMENT

Listing of principles: Five principles will be briefly stated and justified by literature reference. Recent results are presented at the end of the paper to further support the first four of these principles.

Principle 1. A large canopy surface area well exposed to sunlight is desirable, and this surface area should develop as quickly as possible in spring: Sunlight interception is increased (Smart, 1973), and canopy density reduced (Shaulis & Smart, 1974; Smart, 1985a) with large exposed canopy surface area. Biomass production and yield potential is increased as more solar energy is trapped by foliage. Rapid development of canopy surface area in spring promotes solar energy interception. Clingeleffer (1989) argues that rapid canopy development is part of the reason for increased yield of minimal pruned vines. Tall, thin, relatively closely spaced, vertical, north-south foliage walls provide maximum exposure for a canopy surface (Smart, 1973; Jackson & Palmer, 1972). Note however that very high values of canopy surface area are not possible without violating principle 2. Overhead canopies, and wide row, low vigour vineyards have low values.

Principle 2. Canopies should not be so close together as to cause excessive shade at the base of adjacent canopies. Vertical canopies are preferred and the ratio of canopy height to alley width should not exceed about 1:1: Where canopies are close together penetration of both direct and diffused sunlight into the enclosure formed by canopy walls and the ground surface is impaired, as is demonstrated by calculation (Jackson & Palmer, 1972; Smart, 1973) and by field measurement (Smart, 1985b; Intrieri, 1987). Photosynthesis is inhibited for exterior leaves at the base of closely-spaced canopies. Figure 1 shows calculated values of sunlight flux densities over summer down the side of vertical canopy

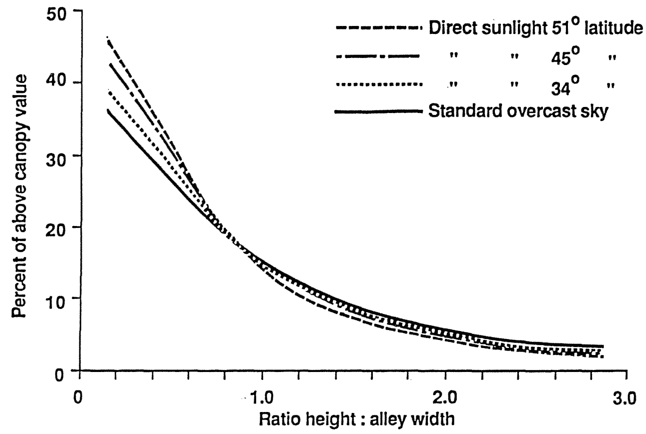

FIGURE 1

Solar radiation flux density estimated at various positions down the vertical walls of canopies, expressed as a percentage of that received by a horizontal surface above the canopy. Position on the wall indicated by the ratio of canopy height: alley width. Data are for seven summer months, direct sunlight on north south walls, 34°, 45° and 51° latitude, and standard overcast sky (data from Jackson & Palmer, 1972).

walls for direct sunlight (north-south rows) at 34°, 45° and 51° latitude and for a standard overcast sky (from Jackson & Palmer, 1972). Note the similarity between all curves, and that values corresponding to height: alley width ratio of 1:1 are about 15% of above canopy values.

Principle 3. Canopy shade should be avoided, especially for the cluster/renewal zone. Leaves and fruit should have as uniform a microclimate as possible: Adequate fruit exposure to sunlight promotes wine quality, though effects of leaf and fruit exposure are not often separated experimentally. Shaded canopies produce fruit of increased K, pH, malic acid and Botrytis bunch rot incidence, and reduced sugar, tartaric acid, phenol and anthocyanin levels (reviewed by Smart, 1985a; Shaulis, 1982; Smart *et al.,* 1988; Kliewer & Smart, 1988; Kliewer *et al.,* 1988). Morrison (1988) has shown that leaf shading affects berry size, sugar, K and pH while cluster shading lowers fruit anthocyanin levels and phenols. Shading reduces fruit monoterpenes (Reynolds & Wardle, 1988, 1989a, 1989c) and induces herbaceous characters in wine (Pszczolkowski *et al.,* 1985). Also, Carbonneau *et al.* (1978) note that excessive fruit exposure may increase phenol concentrations beyond desirable levels. It is likely that high quality wine results from processing fruit of relatively homogeneous composition. Preliminary studies indicate that shaded fruit shows more variation in composition (S. Smith, unpublished data). Since fruit composition responses to microclimate are already evident by veraison (Smart, 1982), it is likely that pre-veraison canopy microclimate has a significant impact on wine quality. Botrytis incidence is increased by high canopy density as fruit exposure is reduced (Gubler *et al.,* 1987; Savage & Sall, 1984). Similar effects of shading are noted for *Oidium* incidence (Pearson & Goheen, 1988). Improved spray penetration also assists disease control (Travis, 1987).

The light microclimate of the renewal zone (base of the shoot which is retained at winter pruning) is important for yield expression (Shaulis 1982; Shaulis & Smart, 1974). Located in this zone are the nodes retained at winter pruning, as well as grape clusters. Shading of this zone causes reduced cluster initiation, bud break, fruit set and berry size (Shaulis & Smart, 1974; Shaulis, 1982; Smart *et al.,* 1982b). Basal leaves are also known to be important for fruit ripening processes (Hunter & Visser, 1988). The effect of shade on fruit set is little studied but poor fruit set in the centre of dense canopies is commonly observed. Recently Jackson & Coombe (1988) suggested this could be due to a physiological disorder Early Bunch Stem Necrosis (EBSN). Shade leaves contribute little to canopy photosynthesis (Smart, 1974; Smart, 1985b) and in time turn yellow and abscise.

Principle 4. Photosynthate partitioning between shoot and fruit growth should be appropriate to avoid either excess or deficient leaf area relative to the weight of fruit. The number of active vegetative growing points per shoot should be limited: Grapevine shoots are potentially indeterminate, and excessively large shoots are a common feature of vigorous vineyards. Vigorous shoots have relatively large diameter, long internodes and large leaves, and there is a marked propensity for active lateral growth; such features are undesirable and indicate an imbalance between vegetative and fruit growth (Smart *et al.,* 1989). Vineyards of high yield demonstrate a balance between shoot and fruit production (e.g. Lavee & Haskal, 1982), an indication that photosynthate is partitioned appropriately between shoot and fruit production. Shoot devigoration can be achieved by a combination of light pruning and improved canopy microclimate, the so-called 'big vine' effect (Smart *et al.,* 1989). Long shoots represent photosynthate diversion into superfluous leaf area, which in turn generally contributes to canopy shading. Long shoots cause high must and wine pH (Smart, 1982). Partial defoliation improves photosynthetic efficiency of remaining leaves (Hunter & Visser, 1988). Shoots that are too short may have insufficient leaf area to adequately ripen fruit (i.e. Peterson & Smart, 1975; Koblet, 1987a). Shoot growth may be regulated by summer trimming (Reynolds & Wardle, 1989b), though for vigorous shoots the lateral buds near the shoot apex burst and continue extension growth (Solari *et al.,* 1988). The balance between shoot and fruit production can be assessed by the ratio yield: pruning mass, sometimes termed 'crop load'. Bravdo *et al.* (1985) found in Israel that values of this ratio greater than 10 with Cabernet Sauvignon led to reduced quality, with no quality effect for values less than 10. Studies by Reynolds (1989) with Riesling in cooler British Columbia found values less than 10 desirable.

There have been few studies of shoot length heterogeneity and its effect, though it is likely that uniform populations are desirable (Smart *et al.,* 1989).

Principle 5. Arranging locations of individual organs in restricted zones in space facilitates mechanisation i.e. of shoot tips for summer pruning, of cane bases for winter pruning and of fruit for mechanical harvesting. Training system design should as much as possible create fruiting/renewal zones at a similar height for any one vine: For vines trained with renewal zones at various heights, the highest buds burst preferentially before those of lower vine parts. This effect is presumably gravimorphic though in many situations low renewal zones are also shaded, which effect reduces bud break. Thus Van den Ende (1984) found most of the fruit production of Sultana vines on the Tatura trellis was at the top of the canopy after a few years cropping, though originally vines had replacement zones at six heights.

DIAGNOSIS OF PROBLEM CANOPIES

This section comprises two parts. The first presents in detail field methods for evaluating winegrape canopies. In the second, quantitaive indices are presented as guidelines to canopy assessment.

The techniques we have developed for diagnosing problem canopies are designed for practical field use by researchers and growers. The techniques are easy to learn and interpret, quick to use and also inexpensive.

Point quadrat: This technique was first applied to vineyard canopy studies in 1980 (Smart, 1982) though the presentation of results is now modified. This simple method describes the distribution of leaves and fruit in space, and provides quantitative canopy description. A sharpened thin metal rod is passed at fixed inclination into the canopy (normally in the fruit zone) and contacts with leaves, clusters and

TABLE 1
Sample point quadrat analysis sheet for two contrasting canopies (ex Smart & Sharp, 1989).
Key: L = Leaf contact C = Cluster contact G = Canopy gap

Low density canopy Cabernet franc, TR2T								High density canopy Gewürztraminer, standard							
1	L	13	LC	26	LCC	39	C	1	LLCCL	13	LLL	26	LLLLL	39	LCCCCLL
2	LLC	14	CL	27	LCL	40	G	2	LLL	14	LCLCL	27	LLLLLL	40	CLL
3	LLC	15	L	28	G	41	C	3	LL	15	LLLL	28	LLLLLCLL	41	LC
4	LC	16	L	29	G	42	CLCC	4	LL	16	LLL	29	LLLLL	42	CCLLL
5	L	17	CL	30	L	43	G	5	LLCL	17	LLL	30	LLLL	43	LLL
6	L	18	LL	31	C	44	CC	6	LLCLLL	18	LL	31	LL	44	LLCLL
7	LCL	19	L	32	LL	45	C	7	LLCL	19	LCL	32	LLCCLL	45	LLCLL
8	G	20	L	33	G	46	LC	8	CLLL	20	LLLL	33	LCLL	46	LLCCL
9	G	21	L	34	G	47	G	9	LCLL	21	LCLLLL	34	LLL	47	LLCCL
10	LLC	22	L	35	LCL	48	G	10	LL	22	LLL	35	LCCLL	48	LLLCL
11	G	23	L	36	LLL	49	L	11	LL	23	LLL	36	LL	49	LLLCLLLL
12	L	24	G	37	LL	50	LL	12	LLL	24	CLL	37	LLLLLLC	50	LLCLCL
		25	G	38	L					25	LCC	38	LCLL		

Percent gaps:	13/50 = 26%	0/50 = 0%
LLN:	43/50 = 0,86	167/50 = 3,34
Percent interior leaves:	4/43 = 9%	72/167 = 43%
Percent interior clusters:	6/23 = 26%	36/39 = 92%

canopy gaps noted. Stems are normally ignored. Each insertion takes about 10 seconds. Typically 50-100 passes are made for each canopy to be analysed. The following canopy descriptors can be generated from the data - percent gaps, LLN (leaf layer number), percent interior leaves and percent interior clusters (Smart & Smith, 1988; Smart & Sharp, 1989). Table 1 shows typical data for high and low density canopies, and demonstrates the method to calculate canopy density indices.

Vineyard scoring: The concept of visual canopy assessment to predict winegrape quality was first described by Smart *et al.,* (1985a). Canopy assessment takes place between veraison and harvest using eight characters as presently proposed (Smart & Smith, 1988; Smart & Sharp, 1989). Three of these characters describe microclimate (canopy gaps, canopy density and fruit exposure) and five describe prior growth or physiological status (Table 2). Each character is assessed out of 10 points, giving a total of 80. Note that the scorecard should not be used for diseased, unhealthy or excessively stressed vines.

The scorecard as presented is based on observation and measurement of high quality vineyards in Australia, New Zealand, USA, France and Germany. In particular, detailed studies of Cabernet Sauvignon vineyards in the Graves region of France were most instructive (Smart, Carbonneau & de Loth, unpublished). Development of the scorecard was supported by extensive vineyard microclimate measurements (Smart, 1982; Smart *et al.,* 1982a; Smart *et al.,* 1985a; Smart *et al.,* 1985b; Smart 1987b; Smart 1988; Smart & Smith, 1988). For all of this, some arbitrariness is recognised in the scorecard construction. For example it is difficult to justify only eight characters, and that they should all have equal weighting. The scorecard is suggested as **first approximation** only, and modification to accommodate different cultivars in different regions is encouraged. For Mediterranean climates, the addition of a descriptor for vine water status is considered desirable.

Scoring a canopy takes less than two minutes. Results are presented here to illustrate that little judge training is required. In February 1987 we compared the scores from four judges. Judge A had five years experience with the scorecard, judge B had two years experience, and judges C and D were using the scorecard for the first time. Thirty experimental plots of Cabernet franc were assessed, comprising two rootstocks by five training systems with three replicates. The four judges initially discussed scores for several canopies, then worked separately. Results were analysed to investigate "judge" effects for each character scored.

Analysis of variance showed that trellis treatment was the variable with most significance (8 out of 9), followed by judge effects (7 out of 9), and no rootstock effect. Interaction of judge (with rootstock or trellis) was less frequent, occurring 6 times out of a possible 27. Treatment effects were of less significance or no significance where the range in scores was small i.e. for the characters shoot length and presence of growing tips. Similarly, these same characters correlated poorly when other judges scores were correlated with judge A, and the character fruit exposure had the highest correlation coefficient. There was little apparent effect of prior judge experience. The limited frequency of interactions with judges supports the contention of using several judges and averaging their scores.

Vine growth and yield measurements: Simple measurements at winter pruning of cane number and retained node number and total cane mass, and of yield and bunch number at harvest allows useful indices of vine balance to be determined. There are:

TABLE 2
Vineyard scorecard for assessing vineyard potential to produce quality winegrapes.

NOTE: If majority of shoots are less than 30 cm long, or if these vines are clearly diseased or chlorotic or necrotic, or excessively stressed, DO NOT SCORE VINEYARD.

A.	**Standing away from canopy**	
1	CANOPY GAPS (from side to side of canopy, within area contained by 90% of canopy boundary)	
	*about 40%	10
	*about 50% or more	8
	*about 30%	6
	*about 20%	4
	*about 10% or less	0
2	LEAF SIZE (basal-mid leaves on shoot, exterior). For this variety are the leaves relatively:	
	*slightly small	10
	*average	8
	*slightly large	6
	*very large	2
	*very small	2
3	LEAF COLOUR (basal leaves in fruit zone)	
	*leaves green, healthy, slightly dull and pale	10
	*leaves dark green, shiny, healthy	6
	*leaves yellowish green, healthy	6
	*leaves with mild nutrient deficiency symptoms	6
	*unhealthy leaves, with marked necrosis or chlorosis	2
B.	**Standing at Canopy**	
4	CANOPY DENSITY (from side to side in fruit zone), mean leaf layer number	
	*about 1 or less	10
	*about 1,5	8
	*about 2	4
	*more than 2	2
5	FRUIT EXPOSURE (remember that the canopy has two sides normally - that fruit which is not exposed on your side may be exposed to the other side)	
	*about 60% or more exposed	10
	*about 50%	8
	*about 40%	6
	*about 30%	4
	*about 20% or less	2
6	SHOOT LENGTH	
	*about 10-20 nodes	10
*	about 8-10 nodes	6
*	about 20-25 nodes	6
*	less than about 8 nodes	2
*	more than about 25 nodes	2
7	LATERAL GROWTH (normally from about point where shoots trimmed. If laterals have been trimmed, look at diameter of stubs)	
*	limited or zero lateral growth	10
*	moderate vigour lateral growth	6
*	very vigorous growth	2
8	GROWING TIPS (of all shoots, the proportion with actively growing tips - make due allowance for trimming)	
*	about 5% or less	10
*	about 10%	8
*	about 20%	6
*	about 30%	4
*	about 40%	4
*	about 50% or more	0
	Total point score	____/80 = ____%

TABLE 3
Summary of anova results with four judges of differing experience.

Character assessed	Range of values[a]	Rootstock R	Trellis T	Significance Judge J	RXJ	TXJ	RXTXJ	Correlation with Judge A[c] Judge B	C	D
Canopy gaps	0,6-9,2	–	***b	*				,66	,78	,79
Leaf size	7,3-9,7	–	***	**				,43	,67	,67
Leaf colour	7,1-9,8	–	***	***		**		,33	,60	,67
Canopy density	2,2-8,5	–	***	***	*	***	**	,64	,71	,62
Fruit exposure	2,8-10,0	–	***	–		***		,94	,83	,97
Shoot length	9,6-10,0	–	*	–				-,11	-,14	,07
Lateral growth	5,7-9,8	–	***	***				,69	,62	,71
Growing tips	9,9-10,0	–	–	*				0	0	0
Total	46-76	–	***	***		*		,91	,86	,93

[a] highest and lowest mean score for trellis treatments, an indication of data spread.
[b] significance level * P<,05
**P<,01
*** P<,001
[c] correlation coefficients r>0,35 P<,05
r>0,45 P<,01
r>0,56 P<,001

- average cane mass (total cane mass/cane number) with high values indicating excessive vigour,
- total cane mass (kg/m row or per m canopy) with high value indicating high canopy density,
- yield/cane mass ratio, with low values indicating imbalance due to excessive vigour (Bravdo *et al*, 1984),
- bud burst (shoots per node) and fruitfulness (clusters/shoot) with low values indicating among other things effects of shaded canopies.

Other measurements: Light microclimate may be measured with electronic sensors, with due caution exercised for sampling problems. Similarly leaf area may be determined and the vigour index γ calculated (see Smart, 1985a) as well as the leaf area/crop mass ratio. However both of these techniques are considered more complex than is required for most practical vineyard assessment situations (Smart & Sharp, 1989).

PROPOSING A WINEGRAPE CANOPY IDEOTYPE

Following on the ideotype concept of Donald (1968) for an ideal wheat plant description, we now present **a grapevine canopy ideotype**. The ideotype proposed is a series of numeric indices and characters which can be used to assess winegrape canopies. The values presented are believed optimal for winegrape yield and quality with current knowledge, but may be found to require modification for different cultivars or environments. These values should be especially useful as guidelines for canopy management in high vigour situations. Some of the indices presented have not been previously introduced and references from the literature that support the values are included.

Of the indices listed in Table 4, we have found the following to be the most useful for vineyard diagnosis and trellis evaluation; surface area, shoot spacing, shoot length, lateral development, ratios of yield: canopy surface area and yield to pruning mass, and LLN.

YIELD AND QUALITY RESPONSES TO CANOPY MANAGEMENT

This section will briefly review published responses to canopy management techniques, and the next Section will present data for trellis system effects on yield and quality. It should be emphasised that a range of canopy management techniques are available, and the suitability of various techniques depends on vineyard vigour, when considerations of economics and practicability are not considered. As a general principle, the desirability of adoption of a more complex training system is increased as vineyard vigour increases. For low to moderate vigour vineyards, summer trimming (hedging) or fruit zone leaf removal may be sufficient to improve microclimate.

Vigour control: Low shoot vigour helps create open canopies. Examples of this are given by Smart (1985a) and Smart *et al.*, (1989) who reviewed management techniques to achieve devigoration.

Shoot trimming: Unless shoot growth is inhibited, for example, by water stress (Smart & Coombe, 1983) or by light pruning (Clingeleffer, 1989; Smart *et al.*, 1989) shoot growth normally continues beyond optimum length. Summer trimming (hedging) to contain shoot growth is widely used in high humidity environments like Europe and New Zealand, but less frequently in drier climates like Australia and California. As long as trimming is done early, fruit ripening is encouraged (Solari *et al.*, 1988; Koblet, 1987a; Koblet, 1988). Kliewer & Bledsoe (1987) have however found that trimming delayed fruit maturity. Perhaps this result was due to removing exterior, photosynthetically active leaf area and exposing less efficient leaves.

Leaf removal in the fruit zone: Fruit exposure in dense canopies can be enhanced by preveraison leaf removal in the cluster zone. Fruit composition is improved and herbaceous wine characters reduced (Kliewer and Bledsoe, 1987; Smith *et al.*, 1988; Freese, 1988; Kliewer *et al.*, 1988; Iland, 1988). Leaf removal also facilitates control of Botrytis bunch rot (Gubler *et al.*, 1987; Smith *et al.*, 1988).

Training system: The pioneering studies of Shaulis *et al* (1966) demonstrated that within canopy shade was a principle cause for yield and quality reductions, and that this could be overcome by canopy division. Subsequently, a large number of studies with a range of cultivars and environments have confirmed the same principles. Smart (1985a) reviewed earlier work and to this list can now be added Carbonneau (1985), Carbonneau & Casteran (1987), Casteran & Carbonneau (1987), Intrieri (1987), Cullen (1988), Kliewer *et al.*, (1988), and Smart & Smith (1988). More complex training systems typically have more old wood per vine as trunks and cordons, and this also enhances yield (Murisier & Spring, 1987; Koblet, 1987b). The ability of canopy division to improve vine microclimate and performance is dependant on vineyard vigour. This was emphasised by Smart *et al.* (1985a), Smart *et al.* (1985b), Carbonneau & Casteran (1987a), and Casteran & Carbonneau (1987).

RECENT RESULTS FROM CANOPY MANAGEMENT EXPERIMENTS

The paper concludes by presenting recent experimental results from a trellis trail which support principles developed above. Results presented will be limited to three of the five treatments, and to two seasons. The full results of the trial will be the subject of a further report.

A trail with the cultivar Cabernet franc was established in 1983 at Rukuhia, near Hamilton to investigate yield and quality responses to training systems. The soil is deep and fertile (Horotiu silt loam, 80 cm of silt loam over coarse sand and gravel extending for several meters). The climate can be described using the Smart-Dry index (Smart & Dry, 1980) as cool (MJT = 17,3C), maritime (CTL = 9,2C), overcast (SSH = 6,5 hrs/day), not arid (deficit 60 mm), and very humid (RH = 73%). Such conditions are favourable to high vine vigour and restrict maturity for this late season cultivar. The trial compares five training systems and two rootstocks (1202 Couderc (1202C) and Aramon Rupestris Ganzin 1 (ARGI)). There are three replicates, each plot consisting of six vines. Generally, rootstocks have only small effects and these are not discussed here. The training systems are Te Kauwhata Three Tier (TK3T) and Te Kauwhata Two Tier (TK2T) at row spacing 1,8m, and Tatura trellis, Ruakura Twin Two Tier

TABLE 4
Winegrape canopy ideotype to promote high yields and improved fruit composition.

Character assessed	Optimal Value	Justification of optimal value
Canopy characters:		
Row orientation	north-south	Promotes radiation interception Smart (1973) though Champagnol (1984) argues that hourly interception should be integrated with other environmental conditions i.e. temperatures which affect photosynthesis to evaluate optimal row orientation for a site. Wind effects can also be important (Weiss & Allen, 1976a; Weiss & Allen, 1976b).
Ratio canopy height: alley width	~1:1	High values lead to shading at canopy bases, and low values lead to inefficiency of radiation interception. (See literature cited for Principle 2; data in this paper.)
Foliage walls inclination	vertical or nearly so	Underside of inclined canopies is shaded (Smart & Smith, 1988).
Renewal/Fruiting area location	near canopy top	A well exposed renewal/fruiting area promotes yield and, generally, wine quality, although phenols may be increased above desirable levels. (See literature cited for principle 3; data in this paper.)
Canopy surface area (SA)	~21,000 m^2/ha	Lower values generally indicate incomplete sunlight interception, higher values are associated with excessive cross row shading. (See literature cited for principle 1; data in this paper.)
Ratio leaf area/surface area (LA/SA)	<1,5	An indication of low canopy density especially useful for vertical canopy walls. (Smart 1982; Smart *et al,* 1985a and literature cited for principle 3).
Shoot spacing	~15 shoots/m	Lower values associated with incomplete sunlight interception, higher values with shade. Optimal value is for vertical shoot orientation and varies with vigour (Smart, 1988).
Canopy width	300-400mm	Canopies should be as thin as possible. Values quoted are minimum likely width. Actual value will depend on petiole and lamina lengths and orientation.
Shoot and fruit characters:		
Shoot length	10-15 nodes, about 600-900mm length	These values are normally attained by shoot trimming. Short shoots have insufficient leaf area to ripen fruit; long shoots contribute to canopy shade and cause elevated must and wine pH (see literature cited for principle 4).
Lateral development	limited, say less than 5-10 lateral nodes total per shoot	Excessive lateral growth is associated, with high vigour (Smart *et.al.,* 1985a; Smart & Smith, 1988; Smart, 1988, Smart *et al.,* 1989).
Ratio leaf area: fruit mass	about 10 cm^2/g (range 6-15 cm^2/g)	Smaller values cause inadequate ripening, higher values lead to increased pH (Shaulis & Smart, 1974; Peterson & Smart, 1975; Smart 1982; Koblet, 1987a). Value around 10 optimal.
Ratio yield: canopy surface area	1-1,5 kg fruit/m^2 canopy surface	This is value of exposed canopy surface area required to ripen grapes (Shaulis & Smart, 1974). Values of 2,0 kg/m^2 have been found to be associated with ripening delays in New Zealand, but higher values may be possible in warmer and more sunny climates.
Ratio yield: total cane mass	6-10	Low values associated with low yields and excessive shoot vigour. Higher values associated with ripening delays and quality reduction. (See literature cited for principle 4.)
Growing tip presence after veraison	nil	Encourages fruit ripening since actively growing shoot tips are an important alternate sink to the cluster (Koblet, 1987a).
Cane mass (g) (in winter)	20-40g	Indicates desirable vigour level. Leaf area is related to cane mass, with 50-100cm^2 leaf area/g cane mass. Values will vary with variety, shoot length (Smart & Smith, 1988; Smart *et al.,* 1989; also data in this paper).
Internode length	60-80 mm	Indicates desirable vigour level (Smart *et al,* 1989). Values will vary with variety.
Total cane mass: m canopy length	0,3-0,6 kg/m	Lower values indicate canopy is too sparse, higher values indicate shading. Values will vary with variety, shoot length (Shaulis & Smart, 1974; Shaulis, 1982; Smart, 1988; data presented this paper).
Microclimate characters:		
Proportion canopy gaps	20-40%	Higher values lead to sunlight loss, lower values can be associated with shading (Smart & Smith, 1988; Smart 1988).
Leaf layer number (LLN)	1–1,5	Higher values associated with shading, lower values with incomplete sunlight interception (Smart, 1988 and literature cited for principle 3).
Proportion exterior fruit	50-100%	Interior fruit has composition defects (literature cited for principle 3).
Proportion exterior leaves	80-100%	Shaded leaves cause yield and fruit composition defects (literature cited for principle 3).

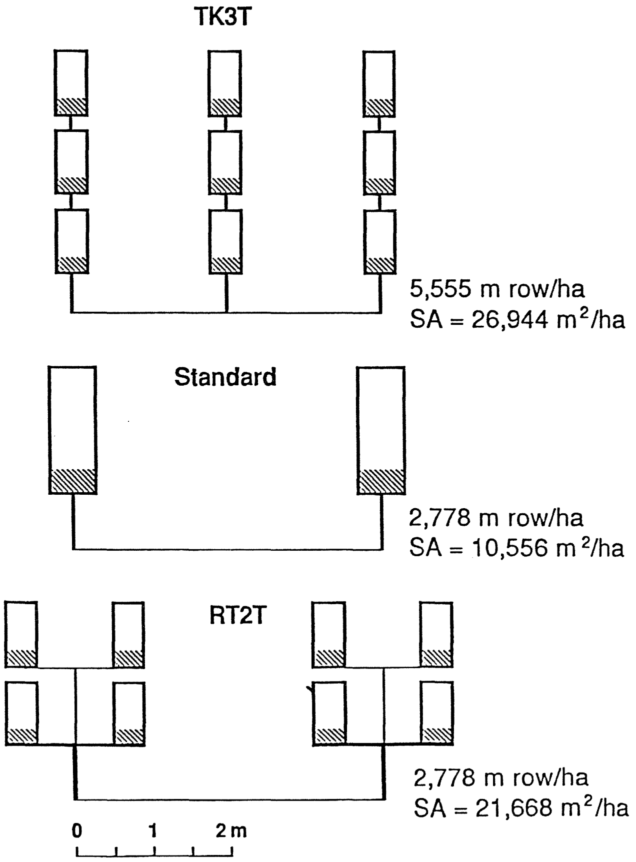

FIGURE 2

Cross-sectional dimensions of three training systems drawn to scale, along with calculations of row length/ha and canopy surface area. TK3T is Te Kauwhata Three Tier; Standard is vertically shoot positioned, non divided canopy, and RT2T is Ruakura Twin Two Tier.

(RT2T) and 'Standard' vertically shoot positioned (STD) with 3,6m row spacing. The RT2T system was designed with the before listed principles 1 to 5 in mind. Within row spacing is 2,0m. The first harvest was 1985, and since the 1987 vintage yields have been relatively stable as canopies have filled their allotted space.

Results will be presented here for three treatments only - TK3T, RT2T and STD, (see Figure 2) with fruit composition and wine quality assessments for the 1988 vintage and yield components for the 1989 vintage. In general, yields for the 1989 vintage were higher than for 1988, due to higher cluster numbers for the top tier of RT2T and TK3T.

Experimental wine was made from each replicate using 20-40 kg fruit lots fermented on skins to dryness and sterile filtered to avoid confounding effects of malolactic fermentation. Wine sensory assessment was carried out when the wines were 7 months old, using 7 experienced industry judges. The judges were evaluated for consistency and discrimination ability. The scorecard used in the sensory evaluation used six characters (colour density and hue, fruit character on nose and palate, palate structure and overall acceptability), each assessed out of 7 points. Results from this card correlated well with the three character card assessing colour (ex 3), nose (7), palate (10), and total (20) normally used in New Zealand and Australia (Gravett & Smart, unpublished data). Standard wine analyses were made and included spectral analysis by Somers & Evans (1977) method.

Figure 2 shows the dimensions of the three systems to be discussed, along with the calculated canopy surface area. The TK3T system has a SA greater than the optimum cited in Table 3, while the RT2T was at the optimum and the non-divided STD canopy with wide row spacing was about half the optimum value.

Effect of tier height on yield, growth and quality: The TK3T trellis provides unique insight into effects of shade on yield, growth, fruit composition and wine quality. The TK3T was included in this trial as a test for principle 2, in that the ratio of canopy height to alley width is 1,8:1, in obvious violation of the 1:1 guideline. Thus lower tiers are shaded at the canopy exterior. It is possible to see the effect of varying the height to alley width ratio on vine performance by comparing different tier heights. Individual vines with 6m cordon length were trained to each height and pruned to 80 nodes (13,3 nodes/m) to minimise within-canopy shading (see Table 4).

The top tier produced five times the yield and four times the pruning mass and three times cane mass, of the lowest tier (Table 5). The middle tier was intermediate. These differences are of similar order to the calculated mean light flux density at the midpoint of the fruiting zone, taken from Figure 1. Also shown in Table 5 are the height: alley width ratios calculated at the fruit zone midpoint. All the yield components bud break, fruitfulness (clusters/shoot), berry number and berry mass were reduced for lower tiers, with the last two being the most sensitive to shading.

Trends in fruit composition were similar to yield (Table 6) with top tier showing advanced maturity. Sugar accumulation was delayed for the lower tiers with the effect evident already at veraison and persisting till harvest. Maximum differences from top to bottom were 2,9° Brix at veraison and 4,2° Brix at harvest. There were smaller differences with acidity and pH, with maximum differences of 1,1° Brix and 0,07 pH units at harvest. Berry mass differences were substantial between tiers, a maximum of 0,68 g at harvest. As denoted by the proportion of red berries at veraison sampling, the top tier fruit commenced colouring earlier than both middle and lower tiers.

Fruit composition trends between tiers were further reflected in wine analyses (Table 7). Lower tiers had higher wine K and pH, and lower titratable acidity and tartaric acid. The difference from top to bottom tier respectively was 300 mg/l K, 0,15 pH units, 1,3 g/l titratable acidity and 0,4 g/l tartaric acid. Wine colour density was higher for the top tier as was also the concentration of anthocyanins, ionised anthocyanins and phenols. In turn these differences were expressed in the sensory scores, with all components except 'fruit on the nose' showing significant effect of tier position. Wines from the top tier scored 4,9 ex 7 for overall acceptability, 4,6 for the middle tier and 3,8 for the bottom tier. Lower and more shaded tiers produced wine with less colour and fruit character, and less full palate.

TABLE 5
Effect of tier height of TK3T on yield and yield components and growth. Cabernet franc, Rukuhia, 1988-1989 season.

Character assessed	Top	Middle	Bottom	LSD
Cordon length/vine	5,68	5,72	5,69	–b
Yield (kg/vine)	21,8	8,2	4,3	3,8
Clusters/vine	169	120	89	9
Berry mass (g)	1,40	0,99	0,88	0,11
Nodes retained/vine	80	80	79	–
Shoots/vine	87	72	70	3
Total cane mass (kg vine)	4,1	1,3	1,0	0,3
Percent bud break	109	91	89	4
Clusters/shoot	1,94	1,67	1,29	0,12
Bunch mass (g)	129	68	48	19
Berry number	92	69	54	11
Yield (g)/node retained	273	102	55	47
Yield (g)/shoot	249	114	63	42
Yield/pruning ratio	5,4	6,8	4,6	1,3
Cane mass (g)	47,5	17,3	14,1	4,6
Nodes retained/m cordon	14,1	13,9	13,8	–
Shoots/m cordon	15,4	12,6	12,3	0,6
Clusters/m cordon	29,8	21,0	15,7	1,8
Yield (kg)/m cordon	3,85	1,43	0,76	0,70
Total cane mass (kg)/m cordon	0,73	0,22	0,17	0,05
Berries/m cordon	2740	1440	860	430
Calculated light (relative)[a]	100	57	31	NA
Height: alley ratio at fruit zone midpoint	0,40	0,88	1,43	NA

[a] calculated from Fig. 1 for midpoint of fruit zone.
[b] not significant indicated by –
NA = not applicable
Note: Data for ARG 1 and 1202 C rootstocks combined.

TABLE 6
Effect of tier height of TK3T on fruit composition.
Cabernet franc, Rukuhia, 1987-1988 season.

Character assessed	Top	Middle	Bottom	LSD
Veraison 3 March 1988[1]				
Sugar (°Brix)	12,1	9,5	9,2	0,8
Titratable acidity (g/l)	24,9	24,0	24,0	–a
pH	2,72	2,65	2,67	0,05
% red berries	95	69	38	20
Berry mass (g)	1,39	1,07	0,86	0,19
Harvest 20 April 1988[1]				
Sugar (°Brix)	19,3	15,9	15,1	1,6
Titratable acidity (g/l)	10,4	9,6	9,3	0,9
pH	2,95	2,95	3,02	0,05
Berry mass (g)	1,67	1,22	0,99	0,17
Yield (kg/vine)	13,2	10,4	7,3	1,8
% rot	5,2	0,2	0,4	1,9
Must composition[2]				
Sugar (°Brix)	19,5	17,0	16,7	1,4
Titratable acidity (g/l)	10,0	9,7	9,5	–
pH	3,02	2,98	3,04	–
Malic acid (g/l)	4,5	3,9	3,9	0,4

[a] not significantly different indicated by –
[1] Data for ARG1 and 1202C rootstocks combined.
[2] Data for 1202C rootstock only.

Effect of RT2T training: The trial allowed comparisons between RT2T and STD trellis systems, but also comparisons were made within the RT2T plots. For each RT2T plot of six vines, there were two 'big' vines and four 'small' vines arranged in a 2 x 2 factorial combination with tier position ('up' and 'down'). Any one vine was trained to only one height. 'Big' vines had 12m of cordon and 160 nodes retained, while 'small' vines had 6 m of cordon and 80 nodes retained, both at 13,3 nodes/m cordon. Shoot growth was devigorated on big vines because of high node number retained at winter pruning (Smart *et al.*, 1989). Thus despite similar shoot spacing, the canopy of big vines was less dense than for small vines (Smart & Smith, 1988). Data for these comparisons are shown in Tables 8, 9 and 10, and where height by vine size interactions are significant these data are shown in Table 11.

Table 8 presents the effect of vine size and tier height on yield and growth and also compares RT2T plots including both big and small vines with STD. RT2T more than doubles yield of STD due to greater cordon (canopy) length, more nodes retained (by 28), higher bud break (by 24%), clusters per shoot (by 0,1), and berry number per bunch (by 21). Large differences in yield per retained node (by 90g) and per shoot (by 50g) between RT2T and STD result. These yield responses are in accord with responses noted previously (Smart & Smith, 1988), and correspond to the STD vines having a dense shaded canopy with the RT2T canopy being open. STD vines are 'unbalanced' with excessive vegetative growth as indicated by low yield/ pruning ratios and high cane mass.

The yield, yield component and growth differences between the two tier heights for the RT2T are similar to those recorded for the top two tiers of TK3T and require no further discussion. There was less effect on yield components of 'big' versus 'small' vines. Percent bud break of small vines was slightly higher (by 17%), as is expected with fewer retained nodes per vine (Smart & Smith, 1988). 'Big' vines showed better balance between vegetative growth and fruit than 'small' vines, as indicated by higher yield per shoot (by 21 g), lower yield to pruning ratio (by 2,7), and lower cane mass (by 7 g). There was little interaction between level and size. Lower tier big vines had more clusters per shoot, and lower total cane mass per m of cordon (Table 11).

Fruit composition was similar for RT2T and STD vines at veraison (Table 9). Fruit from small vines had higher acidity than big vines at veraison by 1,3 g/l. Interactions between size and tier position in the RT2T are explained by lower tier small vines having higher pH, and berry size differences were less for the bottom tier than the top (Table 11). At harvest there were significant differences in fruit composition. STD vines had more sugar (by 0,9° Brix), higher pH (by 0,13) and higher bunch rot (by 18%). Top tier vines had higher sugar

TABLE 7
Effect of tier height of TK3T on wine analysis and sensory scores. Cabernet franc, Rukuhia 1987-1988 season.

Character assessed	Top	Middle	Bottom	LSD
Wine analysis:				
% alcohol (v/v)	10,8	9,7	8,9	–a
Titratable acidity (g/l)	8,6	7,9	7,3	0,4
pH	3,22	3,23	3,37	0,04
Tartaric acid (g/l)	2,5	2,9	2,1	0,4
Potassium (mg/l)	570	630	870	170
Malic acid (g/l)	3,0	2,8	3,2	–
Acetic acid (g/l)	0,18	0,15	0,19	–
Extract (g/l)	20,2	20,0	18,8	–
Sugar free extract (g/l)	18,9	18,4	17,1	–
Wine colour density	7,7	6,5	5,0	2,7
Wine hue	0,51	0,49	0,56	0,05
α^b	40,3	37,2	32,0	–
α'	37,4	36,4	30,9	–
Total anthocyanins (mg/l)	150	135	103	45
Ionised anthocyanins (mg/l)	60	49	33	14
Phenols (a.u.)	27,7	21,7	18,7	2,9
Sensory scores: (Ex 7 maximum)				
Colour density	5,8	5,2	4,3	0,5
Colour hue	5,9	5,6	4,8	0,5
Fruit on nose	4,9	5,0	4,4	0,5
Fruit on palate	5,3	5,0	4,3	0,4
Palate structure	5,2	4,7	3,9	0,6
Overall acceptability	4,9	4,6	3,8	0,6

[a] not significantly different indicated by –
[b] α proportion ionised anthocyanins
α' proportion ionised anthocyanins without SO_2
Note: Data for 1202C rootstock only.

TABLE 8
Effect of tier height and vine size of RT2T compared with standard trellis on yield, yield components and growth. Cabernet franc, Rukuhia, 1988-1989 season.

Character assessed	Trellis			Tier height			Vine size			Interaction (height + size)
	STD	RT2T	LSD	UPPER	LOWER	LSD	BIG	SMALL	LSD	
Cordon length/vine (m)	1,91	7,82	0,84	7,63	8,0	-	12,10	5,68	0,69	–a
Yield (kg/vine)	8,9	21,5	1,8	29,6	13,4	2,0	31,5	16,5	2,1	0,001
Clusters/vine	116	214	12	254	173	22	306	167	23	–
Berry mass (g)	1,24	1,24	-	1,37	1,04	0,07	1,23	1,17	0,07	–
Nodes retained/vine	79	107	NA	107	107	NA	160	80	NA	NA
Shoots/vine	65	111	5	120	102	85	153	90	5	0,001
Total cane mass (kg/vine)	3,7	3,1	0,3	3,9	2,2	0,2	3,7	2,8	0,3	–
Percent bud break	83	107	4	115	99	5	96	113	5	–
Clusters/shoot	1,79	1,89	0,07	2,11	1,67	0,16	2,00	1,84	–	,04
Bunch mass (g)	77	97	7	117	78	9	100	96	–	–
Berry number	60	81	13	87	75	10	80	81	–	–
Yield (g)/node retained	113	203	18	280	126	18	197	206	–	–
Yield (g)/shoot	137	187	15	244	130	13	201	180	15	–
Yield/cane mass ratio	2,5	6,8	0,3	7,6	6,0	0,8	8,6	5,9	0,9	–
Cane mass (g)	58	28	3	34	22	3	24	31	3	–
Nodes retained/m cordon	41,4	13,9	1,2	14,1	13,4	-	13,4	14,2	–	–
Shoots/m cordon	34,1	14,9	1,1	16,2	13,5	0,8	12,8	15,9	0,9	–
Clusters/m cordon	60,7	28,3	3,1	34,3	22,2	2,7	25,7	29,6	2,8	–
Yield (kg)/m cordon	4,67	2,84	0,52	3,95	1,72	0,25	2,66	2,92	–	–
Total cane mass (kg)/m cordon	1,97	0,43	0,13	0,56	0,31	0,03	0,31	0,49	0,03	0,004
Berries/m cordon	3666	2259	406	2879	1638	307	2102	2415	–	–

[a] not significantly different indicated by –
NA = not applicable
Note: Data for ARG1 and 1202C rootstocks combined.

TABLE 9
Effect of tier height and vine size on fruit composition of RT2T compared with standard. Cabernet franc, Rukuhia, 1987-1988 season.

Character assessed	Trellis			Tier height			Vine size			Interaction (height + size)
	STD	RT2T	LSD	UPPER	LOWER	LSD	BIG	SMALL	LSD	
Veraison 3 March 1988[1]										
Sugar (Brix)	10,6	10,4	–	10,9	9,3	0,8	10,2	9,9	–	–a
Titratable acidity (g/l)	23,6	23,6	–	22,5	22,9	–	22,0	23,3	1,1	–
pH	2,52	2,78	–	2,19	2,67	0,04	2,44	2,42	–	0,03
% red berries	88	82	–	96	66	–	84	78	–	–
Berry mass (g)	1,17	1,24	–	1,39	1,08	0,14	1,27	1,19	–	0,03
Harvest 20 April 1988[1]										
Sugar (Brix)	18,5	17,6	1,2	18,7	16,5	1,9	17,3	17,9	–	–
Titratable acidity (g/l)	9,6	9,5	–	9,5	9,5	–	9,5	9,4	–	–
pH	3,08	2,95	0,06	2,95	2,96	–	2,94	2,97	–	–
Berry mass (g)	1,21	1,43	0,08	1,60	1,26	0,10	1,38	1,48	–	–
Yield/vine (kg)	17,7	9,5	1,5	19,1	16,2	1,7	25,6	13,7	1,8	0,02
% rot	20	2	9	4	0	1	2	2	–	–
Must composition[2]										
Sugar (Brix)	19,5	18,6	–	19,1	16,5	1,4	17,2	18,3	–	–
Titratable acidity (g/l)	9,8	9,5	–	9,5	9,4	–	9,5	9,4	–	0,03
pH	2,98	3,21	0,14	2,99	2,97	–	2,95	3,01	,03	–
Malic acid (g/l)	5,0	4,5	0,5	4,6	4,1	0,4	4,3	4,5	–	0,04

[a] not significantly different indicated by –
[1] Data for ARG1 and 1202C rootstocks combined.
[2] Data for STD vs RT2T for ARG1 rootstock only, remainder for 1202C

TABLE 10
Effect of tier height and vine size of RT2T compared with standard on wine analysis and sensory scores. Cabernet franc, Rukuhia, 1987-1988 season.

Character assessed	Trellis			Tier height			Vine size			Interaction (height + size)
	STD	RT2T	LSD	UPPER	LOWER	LSD	BIG	SMAAL	LSD	
Wine analysis:										
% alcohol (V/V)	10,7	10,2	–	10,8	8,9	0,9	9,5	10,2	–	–[a]
Titratable acidity (g/l)	7,7	8,4	–	8,5	8,1	0,3	8,4	8,2	–	0,03
pH	3,40	3,19	0,13	3,18	3,20	–	3,13	3,25	0,05	–
Tartaric acid (g/l)	1,7	2,9	0,7	2,7	2,8	–	3,0	2,4	0,3	–
K (mg	920	720	130	680	660	–	570	770	100	–
Malic acid (g/l)	3,3	2,7	0,3	3,1	3,0	–	2,9	3,2	–	–
Acetic acid (g/l)	0,23	0,18	–	0,17	0,17	–	0,18	0,17	–	–
Extract (g/l)	23,8	20,3	–	20,8	18,8	1,6	18,7	20,9	1,6	–
Sugar free extract (g/l)	22,1	19,0	–	19,3	17,4	1,5	17,3	19,4	1,5	–
Wine colour density	3,9	7,0	2,7	7,0	5,5	1,0	6,1	6,5	–	–
Wine hue	0,77	0,49	–	0,53	0,52	–	0,49	0,56	0,02	0,003
α^b	17	37	11	38	40	–	42	36	–	–
α'	25	37	5	38	39	–	40	36	–	0,04
Total anthocyanins (mg/l)	161	165	–	158	105	12	125	138	12	0,05
Ionised anthocyanins (mg/l)	28	60	29	59	41	5	50	50	–	–
Phenols (a.u.)	22	24	–	25	17	2	21	22	–	–
Sensory scores:										
Colour density	3,8	4,6	0,6	5,5	5,2	–	5,1	5,6	–	–
Colour hue	3,6	5,9	0,7	5,8	5,5	0,2	5,7	5,6	–	0,01
Fruit on nose	3,7	5,1	0,5	5,2	5,2	–	5,0	5,4	0,1	0,01
Fruit on palate	3,9	5,5	0,6	5,4	5,1	0,2	5,0	5,6	0,2	0,04
Palate structure	3,8	5,2	0,4	5,2	4,8	0,2	4,7	5,2	0,2	–
Overall acceptability	3,5	5,1	0,6	5,0	4,6	0,3	4,5	5,0	0,3	–

[a] α proportion ionised anthocyanins.
α' proportion ionised anthocyanins after removing SO_2 effect.
[b] not significantly different indicated by –
Note: Data for standard vs RT2T for ARG1 rootstock, remainder for 1202C rootstock.

TABLE 11
Details of significant tier hight X vine size interactions, RT2T. Cabernet franc, Rukuhia, 1987-1988 and 1988-1989 seasons.

Character assessed	Upper – big	Upper – small	Lower big	Lower – small	LSD
From Table 8:					
Yield (kg/vine) 1989	43,0	22,9	20,0	10,1	3,0
Shoots/vine	168	96	137	84	7,2
Clusters/shoot	2,10	2,12	1,89	1,56	0,24
Total cane mass (kg/m cordon)	0,40	0,64	0,22	0,35	0,05
From Table 9:					
pH, veraison	2,23	2,16	2,65	2,68	0,07
Berry mass (g), veraison	1,51	1,26	1,03	1,12	0,20
Yield/vine (kg) 1988	28,7	14,3	22,6	13,0	2,6
Must titratable acidity (g/l)	9,3	9,7	9,7	9,0	0,6
Must malic acid (g/l)	4,3	4,9	4,2	4,0	0,6
From Table 10:					
Wine tritratable acidity (g/l)	8,4	8,6	8,4	7,8	0,5
Wine hue	0,49	0,58	0,50	0,53	0,02
a'	37,4	38,2	43,0	34,8	5,8
Total anthocyanins (mg/l)	157	158	92	118	18
Sensory score - hue	5,9	5,5	5,4	5,6	0,4
Sensory score - fruit on nose	5,2	5,3	4,6	5,4	0,5
Sensory score - fruit on palate	5,3	5,7	4,6	5,4	0,4

(by 1,2° Brix) and berry weight (by 0,34 g), and there was no effect of vine size. Interactions are due to lower tier large vines having higher titratable acidity, while there was little effect of vine size for the bottom tier in malic acid compared to the top tier (Table 11).

The fruit composition effects carried through to the wine, with STD wines having higher pH (by 0,21), K (by 200 m/ℓ) and malic acid (by 0,6 g/ℓ) and lower tartaric acid (by 1,2 g/ℓ), see Table 10. Wines made from fruit from the top tier had more acidity and extract, while wines from big vine fruit had lower pH, K and extract and higher tartaric acid than for wine from small vines. Interactions were caused by low values of titratable acidity for lower tier small vines (Table 11). Wine spectral analysis showed RT2T wines had more colour density (by 3,1 units), and ionised anthocyanins (by 32 mg/ℓ) than wines from the STD. Similar patterns were evident when wines from the top and bottom tiers were compared. Big vines produced wine with lower hue values and lower anthocyanins. There was little effect from vine size in the bottom tier on colour hue, however small vines in the bottom tier had lower α' and higher total anthocyanins (Table 11).

Judges recorded a clear preference for RT2T wines over STD in all characters assessed. These wines had better colour, more fruit character and were fuller on the palate. Overall acceptability rating was 5,1 ex 7 for RT2T and 3,5 for STD. Wines from the top tier were preferred to those from the bottom tier, and from small vines to big vines. These differences were however small. Interactions were due to lower values for bottom tier big vines in colour hue, and fruit on nose and palate (Table 11).

Yield and quality relationship: The relationship between yield and quality for RT2T and TK2T vines is presented in Figures 3a and b. Figure 3a shows the relationship between yield and sensory score for overall acceptability for different tier heights for TK3T and up-down and big-small comparisons for RT2T all using 1202C rootstock. Figure 3b shows the relationship for wines made from all vines in the plot (i.e. composite over tier height and vine size, all ARG1 rootstock). Note that as shading is decreased, yield and sensory score are simultaneously improved.

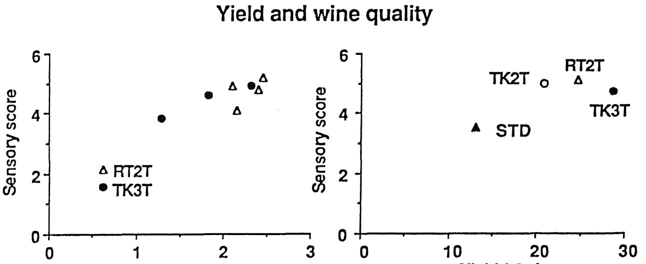

FIGURE 3

Relationship between yield and sensory evaluation score ex 7 for overall acceptability. Figure on left is data for three tiers of TK3T, and four combinations of vine size and tier height for RT2T. Yield results expressed per m canopy length. Figure on right is for STD, TK2T, RT2T, TK3T with composite fruit samples taken over two heights for TK2T, three heights for TK3T, and four combinations of vine size and tier height for RT2T. Cabernet franc, Rukuhia, 1988 vintage.

Shading caused by fruit: For vertically shoot positioned canopies where the fruit is within a constricted region there is a possibility that clusters may contribute to shading of the renewal zone. For the productive RT2T trellis for example, while the canopy is of low density (15 shoots/m) the shoots are very fruitful (190 g/shoot) and the basal shoot zone is literally a wall of fruit. Measurements were made in April 1989 on the Cabernet franc trial to determine cluster projected area in relation to canopy surface area. Cluster shape was approximated as a truncated triangle, and characteristic dimensions measured on a sample of 20 clusters. The average cluster projected area was 102 cm^2, and so for average cluster mass of 114 g, this corresponds to 0,89 cm^2 projected area/g fruit mass. The fruit zone height was on average 26 cm high, or 2620 cm^2/canopy surface area per m cordon. The area sampled had 31 clusters per m cordon, or 3190 cm^2 projected cluster area per m cordon. Therefore, the average cluster layer number (CLN, ratio cluster area: canopy fruit zone area) was 1,21. Since clusters are opaque, the clusters themselves can contribute significantly to shade in the cluster region. For the value of 1,5 kg fruit/m^2 canopy surface area of Table 4, the cluster surface area would be about 1340 cm^2/m^2 canopy surface area, or 13%.

CONCLUSIONS

This paper has condensed results of recent studies into guidelines for canopy management. These are presented as five 'principles'. Optimal values of 21 performance indices and character shave been incorporated into a winegrape canopy ideotype. Along with the field techniques of point quadrat and canopy scoring which are described, these measurements will assist in diagnosing problem canopies.

Recent research results are also presented which serve to confirm some of the principles that introduced this paper. Results presented from the Te Kauwhata Three Tier trellis system reinforce principle 2, which deals with the spacing of vertical foliage walls. The recommendation is that the height to alley width ratio should not exceed about 1:1. Provided this value is not exceeded, light levels at the canopy exterior should not drop below about 15% of ambient on a horizontal plane (Figure 1). Results presented for the TK3T comparison show that as the height: alley width ratio increases, so does yield and wine quality decrease. All yield components are affected by shade, with berry number and berry mass most sensitive. Fruit maturation was delayed by shade, and judges scored a clear preference for wines produced from top tier fruit which had least shading. These data gave further clear evidence for the negative effects of shade on yield and wine quality.

The Ruakura Twin Two Tier system was designed with the principles and canopy ideotype listed above in mind. Results presented here confirmed the importance of these principles. Yield is doubled, fruit composition is improved and wine quality increased. The bottom tier however, has less yield and lower quality than the top tier. We are now evaluating a modified form of the RT2T with the bottom tier of shoots growing downwards. In this configuration, the two fruiting/renewal zones will be closer together, and at mid canopy height, which will reduce yield, fruit composition and wine quality differences between the two tiers (Smart *et al.*, unpublished data).

The RT2T trial also permitted an evaluation of the effect of vine size. That is, vines with large retained node numbers (160) were compared with those pruned to 80 nodes, but where canopy length was proportional to retained node number. Use of large vines caused desirable shoot devigoration, assisting in achieving a desirable canopy microclimate for these vigorous vines. The results suggest that a preferred planting arrangement would be to have large vines on the top tier and small vines on the bottom tier, which will help reduce fruit composition and wine quality differences between tiers. The large vine will tend to counter the tendency of the top tier to promote vigour and fruit ripening as will the small vines counter the tendency of bottom tier to reduce vigour and delay ripening. The results are encouraging further research into the use of low vine density and complex trellis systems on high fertility sites.

Adoption of the canopy management techniques outlined here will have a major impact on winegrape production, fruit composition and wine quality from vigorous vineyards. This viewpoint is supported by literature citation and recent experimental data presented here. While these results are contradictory to the common opinion that high yield causes reduced wine quality, they demonstrate that improving canopy microclimate for dense canopies can simultaneously improve yield and quality.

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