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Response of Riesling vines to training system and pruning strategy[1])

by

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Reaktion der Rebsorte Riesling auf Erziehungsform und Schnittsystem

Zusammenfassung: Der Einfluß vier verschiedener Erziehungsformen auf Rieslingreben wurde über einen Zeitraum von 3 Jahren untersucht; hierbei handelte es sich um Flachbogen, niedrigen Kordon (40 cm hoch) und Mosel-Pfahlerziehung. Zwei Schnittsysteme wurden angewandt, entweder „ausgewogener Schnitt" (balanced pruning) mit 30 + 10 Knoten je Rebe oder Schnitt auf 25 Knoten je m der Rebzeile. Die im niedrigen Kordon erzogenen Reben lieferten die höchsten Erträge und entwickelten die dichteste Laubwand. Bei dieser Gruppe waren aber auch die Peridermbildung der Tragruten, Intensität des Weinaromas, Weinqualität und im Jahr 1984 Mostgewicht, Traubengewicht und Anzahl der Beeren je Traube verringert. Erziehungsform und Schnittsystem hatten sehr wenig Einfluß auf die titrierbare Säure und den pH-Wert. Für Rieslinganlagen mit ungeteilter Laubwand wird die niedrige Kordonerziehung empfohlen, da diese höhere und stetigere Erträge, besseren Austrieb und eine ausgeglichenere Laubwand verspricht und außerdem mechanischen Rebschnitt erlaubt.

Key words: training, pruning, growth, shoot, lignification, yield, must quality, wine quality, sensory rating, Canada.

Introduction

Choosing an appropriate training system involves several decisions, including choice of site, cultivar, and associated cultural practices. Furthermore, an appropriate training system can favorably modify growth, yield, and fruit composition by altering vine physiology and microclimate. Viticultural problems with Riesling in British Columbia, such as poor bud survival associated with a lack of winter hardiness, low yields, delayed fruit maturity and high incidence of *Botrytis* bunch rot may be partially rectified by modifying training systems.

Numerous investigators have established the benefits of canopy division over conventional training (Shaulis *et al.* 1966; Carbonneau *et al.* 1978; Cargnello 1984; Smart *et al.* 1985 a and b). Furthermore, many have asserted that training systems associated with high trunks consistently lead to higher yields and improved fruit quality over those encountered in their low trunk counterparts (Blaha 1966; Babrikov 1976; Yonev 1976; Reynolds *et al.* 1985). In all cases, alterations in canopy microclimate were either demonstrated or implied.

Densely-planted vineyards do not lend themselves to major modifications in training without removal of vines or entire rows. However, desirable manipulations in canopy microclimate, yield, and fruit quality are possible within an existing vine spacing and trellis system via alterations in cane disposition and orientation, length of bearing unit, and amount of perennial wood (Morris *et al.* 1984; Reynolds *et al.* 1985; Koblet and Perret 1986). For instance, Peyer (1960) in Switzerland reported that 'drahtbau'

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training, involving a 0.8 m trunk height and two 6-node canes tied bilaterally at that height, improved most yield components over those of 'stickelbau'- (looped cane) and Lenz Moser-trained Blauburgunder and Müller-Thurgau.

Among investigations in Germany, Weiss (1962) indicated that 'halbbogen' training (two 10- to 12-node canes trained upwards, bent across a wire at 1.1 m , and tied to a 0.7 m-high wire) outyielded 'flachbogen'- (similar to 'drahtbau') and 'weitraum'- (1.3 m-high bilateral cordon) trained Müller-Thurgau and Gutedel weiss, in addition to maximizing °Brix and minimizing titratable acidity. Pfaff (1976) tested 'flachbogen' and 'pendelbogen' (canes bent at a greater angle than 'halbbogen') training for four cultivars, and found 'pendelbogen' to be superior in terms of yield and °Brix. Kiefer (1979) tested 'flachbogen', 'halbbogen', 'pendelbogen', and 'silvoz' (1.1 m-high unilateral cordon with several 6- to 8-node canes tied downwards) training for Riesling and Spätburgunder. 'Halbbogen' and 'pendelbogen' appeared superior, although there were some inconsistencies in the data. 'Flachbogen' outyielded 'halbbogen'- and 'umkehr'- (similar to 'silvoz' but with shorter canes) trained vines of four cultivars, as well as maximizing °Brix and minimizing titratable acidity (Weiss 1981). Kiefer and Weber (1985) found minor impact of 'halbbogen' and 'pendelbogen' training on yield and fruit composition of several cultivars, although 'pendelbogen'-trained vines tended to yield highest and 'halbbogen' training led to fruit with lowest titratable acidity.

Studies with vertical cordon training in Austria (Bauer 1985), Czechoslovakia (Kraus 1985) and Germany (Kiefer *et al.* 1985; Slamka 1985) have provided an alternative approach to modification of training systems within the confines of an existing trellis and vine spacing. Kiefer *et al.* (1985) found vertical cordon trained Riesling vines outyielded those trained to the 'einzelpfahl' ('stickelbau') system, but the latter treatment led to better fruit composition. Vertical cordon was inferior to 'pendelbogen' training in terms of yield and fruit composition.

Optimum vine performance within a given training system cannot be achieved unless an appropriate pruning strategy is implemented. Pruning recommendations for *Vitis vinifera* based on the balanced pruning concept of Partridge (1925) are followed throughout most viticultural regions of North America that experience cold winters, such as New York (Jordan *et al.* 1981), Ontario (Fisher *et al.* 1980) and British Columbia (B.C.M.A.F. 1986). Pruning *V. vinifera* based on an intended shoot density has been the subject of many European investigations (Kiefer 1979; Kiefer and Weber 1985), and this concept is now being endorsed in North America (Adelsheim 1983; B.C.M.A.F. 1987).

'Pendelbogen' training is the present system of choice for *V. vinifera* in British Columbia, Ontario, and parts of New York and Oregon. However, the utilization of long canes associated with this system leads to difficulties in terms of apical dominance, as well as severe bud damage during cold winters. Sparse canopies and low yields often result. The objective of this study was to compare the effects of three other training systems with those of 'pendelbogen' on growth, yield, fruit composition, and wine quality of Riesling within the confines of the existing German trellis system. Since the effectiveness of balanced pruning relative to pruning based on shoot density has thus far not been reported, this question was also addressed.

Materials and methods

Experimental design and plant material

Experiments were initiated in February 1984 on 5-year-old pendelbogen-trained Riesling vines (clone 21B Weis) grafted to 5C rootstock, located in Similkameen Vineyards, Cawston, British Columbia. Soil was a gravelly Similkameen silt loam. Vines were spaced 1.4 m within east-west oriented rows 2.4 m apart. A randomized complete block was used, containing four training systems: 'flachbogen' (FB); 'pendelbogen' (PB); low cordon (LC); and Moselle loop (ML). Two pruning strategies, balanced pruning using a 30 + 10 formula, or 25 nodes/m of row were combined with these training systems in a factorial arrangement. (A 30 + 10 balanced pruning designation indicates that 30 nodes/vine are retained for the first 0.5 kg of cane prunings removed, and 10 nodes/vine retained for each 0.5 kg thereafter.) Each of the four blocks comprised a single row of vines, while each treatment replicate consisted of a 5-vine plot, with observations taken on individual vines.

The trellis was similar to that described by PFAFF (1976). FB vines were pruned to four 8- to 12-node canes which were tied bilaterally along wires at 0.7 and 1.1 m heights. Shoots originating from the lower and upper canes were positioned downwards and upwards, respectively. Shoots on all other treatments were positioned upwards through moveable catch wires. PB vines were pruned to two or more 12- to 15-node canes with subsequent treatment as per descriptions of PFAFF (1976). LC vines were trained to 0.4 m high bilateral cordons and pruned to upward-oriented 3-node bearing units, while ML vines were pruned to two or more 15- to 20-node canes which were bent around in a complete bow and tied. All cane-pruned treatments were augmented by one 2-node renewal spur/cane at the head of the vine. Vines were topped to approximately 18 leaves during mid-stage I of berry growth. Necessary irrigation was supplied throughout the season by overhead sprinklers. All pest control and soil management practices were carried out according to current recommendations (B.C.M.A.F. 1987).

Growth and yield

Pruning was carried out in late March of each year, with weight of cane prunings and the number of retained nodes recorded for each vine. Periderm formation, based on the number of canes per vine having 0—3, 3—5, 5—10, or > 10 internodes containing mature periderm, was recorded for each vine in 1985—1987. Shoots arising from retained nodes as well as basal shoots were counted each year.

Yield per vine and clusters per vine were recorded at commercial harvest. Cluster weight was calculated from these values. A sample of 100 berries was retained from each vine for berry weight determination; berries per cluster was calculated from cluster weight and berry weight data.

Fruit composition

A 50-g subsample from each 100-berry sample was subjected to the extraction procedure of MATTICK (1983), and titratable acidity (TA) was measured on the extracts according to AMERINE and OUGH (1980) on a Brinkmann 672 Titroprocessor. The remainder of each 100-berry sample was macerated in an Acme Model 6001 Supreme Juicerator and centrifuged for 3 min. Centrifuged samples were used for determination of °Brix and pH on an Abbé refractometer (AO Scientific Instruments) and digital pH meter (Fisher Accumet 825 MP), respectively.

Canopy characterization

Each 5-vine treatment replicate was subjected to point quadrat analysis (SMART *et al.* 1985 a and b) in 1985 and 1986 to assess canopy density. 25 random insertions per treatment replicate were made by passing a 1-m needle through the canopy in the vicinity of the fruit zone at a 30 ° angle to the soil surface. Total canopy contacts as well as the nature of each contact were recorded.

Table 1

Influence of training system and pruning strategy on vine size and cane periderm formation of Riesling · 1984—86

Einfluß von Erziehungsform und Schnittsystem auf Schnittholzproduktion und Peridermbildung bei der Rebsorte Riesling · 1984—86

Factor	Wt of cane prunings (kg)			Percentage of canes/vine in each maturity category											
				0—3 internodes[2])			3—5 internodes[2])			5—10 internodes[2])			>10 internodes[2])		
	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986
Training system															
Flachbogen	0.68	0.77	0.99	23.9	21.0	27.5	16.5	8.3	6.4	17.9	15.8	13.0	41.7	55.0	53.1
Pendelbogen	0.80	0.81	1.13	24.9	21.9	30.3	13.6	9.1	5.7	17.0	15.8	16.5	44.5	53.2	47.5
Low cordon	0.77	0.90	1.02	37.9	24.5	30.8	12.8	10.8	7.2	19.5	17.9	16.1	29.8	46.8	45.9
Moselle loop	0.85	0.81	1.11	26.7	22.7	31.1	12.0	9.2	6.4	15.1	14.4	16.6	46.3	53.7	45.9
Standard error	0.04			2.2			1.3			1.6			2.3	2.3	2.7
Significance[1])	***	NS	NS	***	NS	NS	**	NS	NS	*	NS	NS	***	**	*
Pruning strategy															
30 + 10	0.78	0.79	1.06	29.1	23.1	30.8	14.1	9.8	5.8	16.8	16.1	15.3	40.0	51.1	48.1
25 nodes/m row	0.77	0.86	1.05	27.5	22.0	30.0	13.3	8.9	7.1	17.9	15.8	15.7	41.2	53.3	48.2
Significance[1])	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction[1])	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	**	NS

[1]) *, **, ***, NS: Significant at the 5 %, 1 %, or 0.1 % levels, or nonsignificant, respectively.
[2]) Mature internodes/cane.

Degree of cluster exposure was assessed in 1985 and 1986. 25 clusters per treatment replicate were randomly sampled for incoming photosynthetic photon flux density (PPFD) using a LI-COR LI-199B photometer equipped with a LI-190SB quantum sensor. Sampling was done on cloudless days at 9.30, 11.45, and 14.45 h in 1986, and at 11.30 h in 1985. The sensor was held parallel to that face of the cluster most likely to receive insolation.

Wine composition and quality

Approximately 10 kg of fruit were retained per treatment replicate for subsequent vinification. Pruning strategy treatments were pooled within each training system, and fruit within training treatments from blocks 1 and 3 was combined with that of 2 and 4, respectively, to provide two fermentation replicates. Grapes were stored 16 h at 2 °C, crushed in a standard destemmer-crusher, given 24 h skin contact at 13 °C, and pressed in a hydraulic rack-and-cloth press. Juice was sulfited to 50 mg/l free SO_2 and allowed to settle 24 h at 2 °C. Following racking and 24 h storage at 13 °C, ST61 yeast *(Saccharomyces cerevisiae)* was added, and the fermentation was allowed to proceed at that temperature for approximately 30 d. Wines were cold-stabilized for 28 d at −2 °C, filtered through a 0.4 µm filter, and bottled.

Analysis for TA and pH was done according to aforementioned methods. Ethanol concentration was determined on a Hewlett-Packard 5880 gas chromatograph. Wines were evaluated following 8 months of bottle storage at 13 °C for aroma intensity, acidity, astringency, and overall quality by six experienced tasters. Wines were randomized for each taster, with fermentation replicates evaluated in separate flights. A line scoresheet was used. All statistical analyses were performed using analysis of variance by the GENSTAT statistical package (Numerical Algorithms Group, Downers Grove, IL).

Results

Growth and yield

Weight of cane prunings (vine size) was reduced slightly by FB training in 1984 but not subsequently (Table 1). Pruning strategy had no effect that year but 30 + 10 pruning reduced vine size slightly in 1985. No interactions were present between the two factors.

Low cordon training reduced the percentage of canes containing 10 or more mature internodes in 1984 and 1985, and increased the percentage of canes with only 0—3 mature internodes (Table 1). Pruning strategy had no main effect. In 1985, balance-pruned PB vines had a lower percentage of canes with 10 or more mature internodes than LC-trained vines under the same pruning strategy (data not shown).

LC training led to greatest shoot production in all three seasons independent of pruning strategy (Table 2). Much of this difference may have been due to superior non-count shoot production, but budbreak was also higher (Table 2). Pruning strategy had no effect on shoot production and no interactions existed between the two factors (data not shown).

LC training consistently maintained highest yields for all three seasons. This was attended by a reduction in cluster weight, berries per cluster, and berry weight in 1984 (Table 3). An interaction between the two factors existed that season for berry weight, wherein balance-pruned ML vines maintained highest berry weight overall, while PB and FB vines had lowest berry weights among the balance pruned and 25-node vines, respectively. PB-trained vines pruned to 25 nodes/m of row had highest berry weight

Table 2

Influence of training system on shoot growth of Riesling · 1984—86

Einfluß der Erziehungsform auf das Triebwachstum bei der Rebsorte Riesling · 1984—86

Training system	Shoots/vine			Count shoots/ vine	Noncount shoots/vine	% Budbreak
	1984	1985	1986	1986	1986	1986
Flachbogen	33.0	38.4	37.1	26.6	10.6	88.4
Pendelbogen	33.2	33.7	42.4	33.6	8.9	89.0
Low cordon	50.5	44.9	48.0	33.9	14.1	92.5
Moselle loop	34.4	35.0	45.2	36.8	8.4	90.5
Standard error	1.5	1.5	1.2	0.9	0.9	1.3
Significance[1]	***	***	***	***	***	**

[1]) **, ***, NS: Significant at the 1 % or 0.1 % levels, or nonsignificant, respectively.

within that pruning strategy. There was no influence of either factor on cluster weight, berries per cluster, or berry weight in 1985 (Table 3). LC vines had largest clusters in 1986, but this trend was confined primarily to 25-node vines only (data not shown). LC-trained vines also had highest berries per cluster in 1986. Balanced pruning increased yield slightly in 1986 in all treatments but ML.

Fruit composition

An apparent overcropping situation in 1984 may have led to lowest °Brix in LC fruit (Table 4). An interaction between training × pruning was manifested by a maximization of °Brix in balance-pruned ML vines and 25-node FB vines. ML-trained vines had highest °Brix in 1985; the interaction showed balance-pruned FL and 25-node LC vines to have lowest °Brix. Effects on TA were very small; 25-node PB and ML vines had lowest TA in 1984 and 1985, respectively. Balance-pruned FB and 25-node LC vines had highest TA in those same respective years. LC vines produced fruit with lowest pH in 1984 but FB training minimized pH in 1985. Interactions indicated that lowest pH occured in 25-node LC fruit in 1984 and 25-node FB fruit in 1985. No influence of either factor was observed on fruit composition in 1986. No effect was observed in any season on incidence of *Botrytis* (data not shown).

Canopy characterization

Both LC and ML vines produced canopies with the greatest percentage of leaf contacts and fewest cluster contacts or gaps (Fig.). LC-trained vines tended to have a greater percentage of their 5th contacts as clusters, suggesting superior cluster exposure on the north side of the vines. LC vines were also densest when examined in terms of total canopy contacts (Table 5). FB and PB training produced vines of least canopy density.

Mean PPFD received by clusters was greatest in LC-trained vines in 1985 and 1986 (Table 5). FB vines pruned to 25 nodes/m row displayed a higher degree of cluster exposure than their LC-trained counterparts during late afternoon. Use of this pruning strategy increased cluster exposure within FB-trained vines at both the afternoon samplings (Table 5).

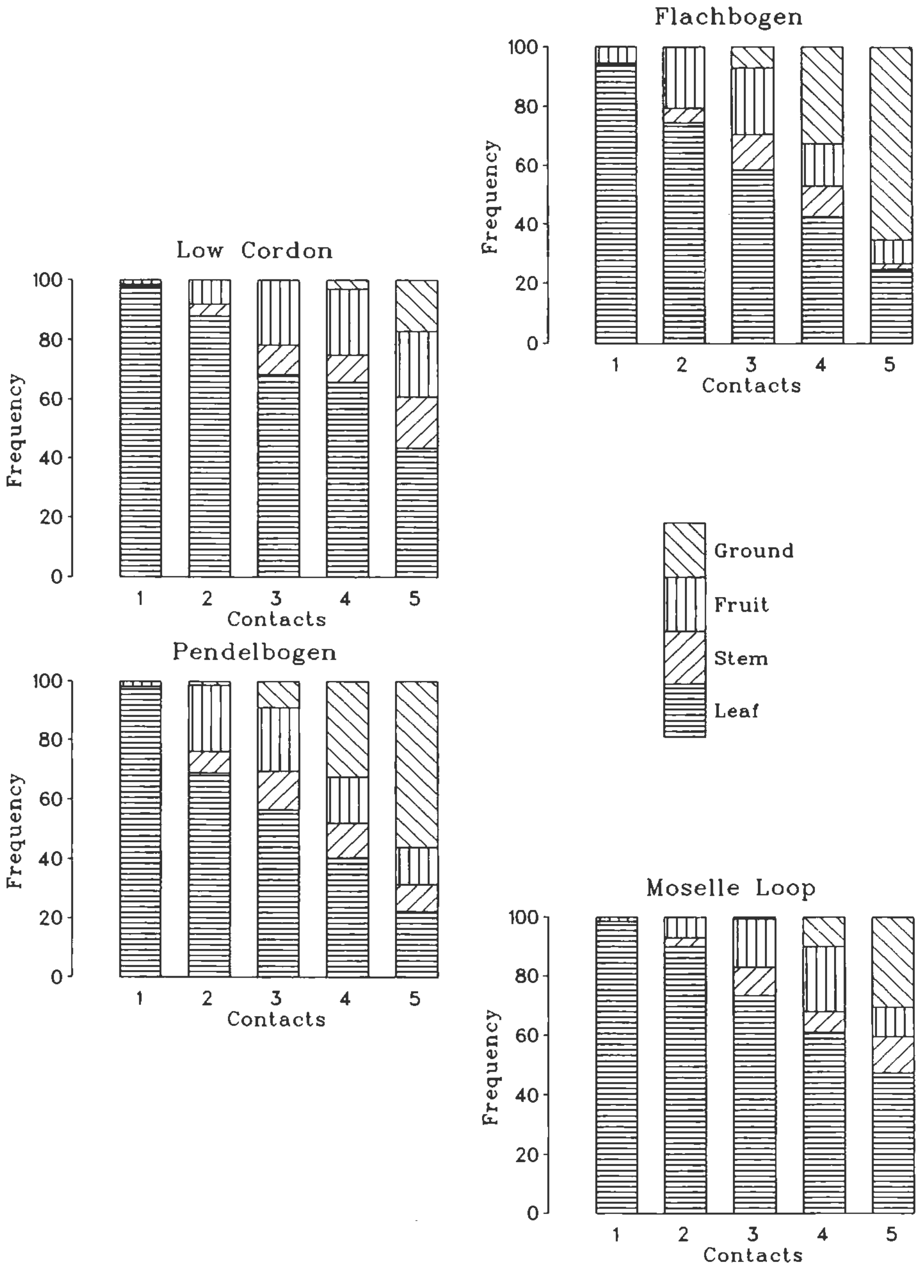
Table 3

Influence of training system and pruning strategy on yield components of Riesling · 1984—86

Einfluß von Erziehungsform und Schnittsystem auf die Ertragskomponenten bei der Rebsorte Riesling · 1984—86

Factor	Yield (t/ha)			Cluster wt (g)			Berries/cluster			Berry wt (g)		
	1984	1985	1986	1984	1985	1986	1984	1985	1986	1984	1985	1986
Training system												
Flachbogen	15.1	19.6	19.8	85.1	112.5	103.5	75.5	79.4	72.8	1.14	1.42	1.42
Pendelbogen	14.9	16.7	20.9	83.4	109.1	99.5	74.1	77.6	70.9	1.13	1.41	1.41
Low cordon	17.8	19.3	24.9	67.3	110.3	105.5	61.1	77.3	76.3	1.10	1.43	1.38
Moselle loop	16.0	16.9	19.1	85.1	111.4	91.0	71.4	78.3	65.1	1.20	1.42	1.40
Standard error	0.7	0.9	0.9	3.0		3.5	2.7		3.0	0.02		
Significance[1]	***	**	***	***	NS	***	***	NS	**	***	NS	NS
Pruning strategy												
30 + 10	16.2	18.2	22.0	80.1	111.3	100.9	70.1	78.6	72.9	1.14	1.42	1.39
25 nodes/m row	15.8	18.2	20.4	80.4	110.3	98.8	70.9	77.7	69.7	1.14	1.42	1.42
Significance[1]	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction[1]	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS

[1]) *, **, ***, NS: Significant at the 5 %, 1 %, or 0.1 % levels, or nonsignificant, respectively.



Effect of training system on the first 5 canopy contacts assessed by point quadrat analysis (SMART *et al.* 1985 a and b), August 26, 1985.

Einfluß der Erziehungsform auf die 5 ersten Kontakte einer Sonde mit der Laubwand, 26. August 1985. Methode von SMART *et al.* (1985 a und b).

Table 4

Influence of training system and pruning strategy on fruit composition of Riesling · 1984—86

Einfluß von Erziehungsform und Schnittsystem auf die Mostqualität bei der Rebsorte Riesling · 1984—86

Factor	°Brix			Titr. acidity (g/l)²)			pH		
	1984	1985	1986	1984	1985	1986	1984	1985	1986
Training system									
Flachbogen	17.4	22.4	20.7	12.5	11.9	11.4	3.40	3.18	3.26
Pendelbogen	17.5	23.0	20.7	12.2	11.9	11.4	3.39	3.23	3.25
Low cordon	16.8	23.1	20.5	12.4	12.2	11.8	3.37	3.20	3.22
Moselle loop	17.3	23.6	21.0	12.5	12.0	11.4	3.39	3.21	3.24
Standard error	0.1	0.2		0.1	0.1		0.01	0.01	
Significance¹)	***	***	NS	*	*	NS	**	***	NS
Pruning strategy									
30 + 10	17.2	22.9	20.9	1.24	1.20	1.15	3.39	3.21	3.23
25 nodes/m row	17.3	23.1	20.6	1.24	1.20	1.15	3.38	3.20	3.26
Significance¹)	NS	NS	NS	NS	NS	NS	*	NS	NS
Interaction¹)	***	**	NS	***	***	NS	***	***	NS

¹) *, **, ***, NS: Significant at the 5 %, 1 %, or 0.1 % levels, or nonsignificant, respectively.
²) Tartaric acid equivalents.

Wine composition and quality

Wine acidity and pH were not affected by any treatment in 1985. Ethanol was highest in the LC and ML wines. Wines vinted from FB fruit were judged superior to other systems in terms of intensity of varietal character and overall quality (Table 6). LC wines had least-intense aroma and lowest quality.

Discussion

Results indicate that LC training has potential for use with *V. vinifera* cultivars grown in British Columbia as well as other viticultural areas which experience cold winters. Most notable are the sustainable high yields associated with this system that were observed over this 3-year investigation (Table 7). These high yields can be attributed mainly to a greater number of clusters per vine, made possible by the high shoot numbers resulting from superior budbreak and significant basal shoot production in LC vines. Slight reductions in cluster weight, berries per cluster, and berry weight (Table 7) were largely reflective of the response of LC vines during the 1984 season, during which the cordons were being established. The increase in canopy density identified in LC-trained vines was a likely consequence of their high shoot production. A resultant evaluation in intra-canopy shading could explain the poor periderm formation in the canes of LC vines. The significance of this latter response was inconsequen-

Table 5

Influence of training system and pruning strategy an canopy characteristics of Riesling · 1985—86

Einfluß von Erziehungsform und Schnittsystem auf die Beschaffenheit der Laubwand bei der Rebsorte Riesling · 1985—86

Factor	Cluster PPFD (µE/m²/s) 1985[2])	Cluster PPFD (µE/m²/s) 1986[2])			Canopy contacts 1986[3])
	11.30 h	9.30 h	11.45 h	14.45 h	
Training system					
Flachbogen	542	241	255	321	4.0
Pendelbogen	467	364	288	286	4.1
Low cordon	639	454	401	397	4.5
Moselle loop	446	341	285	277	4.4
Standard error	61	58	45		0.2
Significance[1])	**	**	**	NS	***
Pruning strategy					
30 + 10	553	346	310	327	4.2
25 nodes/m row	494	354	305	313	4.3
Significance[1])	NS	NS	NS	NS	NS
Interaction[1])	NS	NS	*	**	NS

[1]) *, **, ***, NS: Significant at the 5 %, 1 %, or 0.1 % levels, or nonsignificant, respectively.
[2]) Mean of 100 random determinations/sampling/treatment.
[3]) Mean of 100 random insertions with a point quadrat/treatment.

Table 6

Influence of training system on wine composition and quality of Riesling · 1985

Einfluß der Erziehungsform auf Zusammensetzung und sensorische Eigenschaften des Weines bei der Rebsorte Riesling · 1985

Training system	Wine composition			Taster score[3])			
	Ethanol (%)	Titr. acidity (g/l)[2])	pH	Aroma	Acidity	Astringency	Quality
Flachbogen	9.03	12.5	3.32	90.4	73.2	73.4	91.6
Pendelbogen	9.24	11.9	3.25	76.2	73.0	68.8	86.1
Low cordon	9.74	11.7	3.30	75.9	69.3	71.2	80.4
Moselle loop	9.73	11.8	3.29	81.8	71.3	71.8	86.0
Standard error	0.26			2.7			2.0
Significance[1])	***	NS	NS	*	NS	NS	*

[1]) *, ***, NS: Significant at the 5 % or 0.1 % levels, or nonsignificant, respectively.
[2]) Tartaric acid equivalents.
[3]) Possible 160 points on a line scoresheet.

Table 7

Influence of training system and pruning strategy on vine size, yield and fruit composition of Riesling · 3-year means 1984—86

Einfluß von Erziehungsform und Schnittsystem auf Schnittholzproduktion, Traubenertrag und Mostqualität bei der Rebsorte Riesling · Mittelwerte 1984—86

Response variable	Training system				Standard error	Significance[1]	Pruning strategy		Significance[1]
	Flachbogen	Pendelbogen	Low cordon	Moselle loop			30 + 10	25 nodes/m	
Wt of cane prunings (kg)	0.81	0.91	0.90	0.92		NS	0.88	0.89	NS
Yield components									
Yield (t/ha)	18.2	17.5	20.7	17.3	0.8	***	18.8	18.1	*
Cluster wt (g)	100.4	97.3	94.4	95.8	3.5	**	97.4	96.5	NS
Berries/cluster	75.9	74.2	71.6	71.6	2.8	**	73.9	72.8	NS
Berry wt (g)	1.33	1.32	1.30	1.34	0.02	*	1.32	1.33	NS
Fruit composition									
° Brix	20.2	20.4	20.1	20.6	0.3	**	20.3	20.3	NS
Titr. acidity (g/l)[2]	11.9	11.8	12.1	12.0	0.2	*	12.0	12.0	NS
pH	3.28	3.29	3.26	3.28	0.02	**	3.28	3.28	NS

[1]) *, **, ***, NS: Significant at the 5 %, 1 %, or 0.1 % levels, or nonsignificant, respectively.
[2]) Tartaric acid equivalents.

tial, however, insofar as 3- to 4-node bearing units were retained at pruning. Since the first 5 basal nodes were, in most cases, well-matured, and tend to be hardiest anyway (HOWELL and WOLPERT 1978; HOWELL and SHAULIS 1980) no negative effects of inferior periderm formation were manifested in LC-trained vines.

The long (12—15 node) canes retained in PB training often lead to poor budbreak in the central portion of the cane due to apical dominance (ADELSHEIM 1983). Sparse canopies often result. This problem was addressed within this investigation by reducing cane length (FB and LC) or increasing cane bending (ML), since both of these features may lead to improvements in budbreak through reductions in apical dominance. As already discussed, high shoot production in LC-trained vines may have been associated with superior hardiness of retained nodes more so than through a reduction of apical dominance. Since percent budbreak of ML-trained vines in 1986 was nearly that associated with LC training, it can be assumed that this phenomenon was due to apical dominance suppression. This was reflected by denser canopies in ML-trained vines during 1985 and 1986 relative to those associated with FB or PB training. Shoot growth along the length of ML canes was considerably stronger than that in either of the other two cane-pruned systems.

LC-trained vines were associated with relatively high cluster exposure in comparison to other systems. This likely resulted from death and senescence of many shaded basal leaves in LC vines throughout the summer. High cluster exposure encountered in 25-node FB vines was attributable to the open canopies associated with this treatment.

Effects of training system on fruit composition were small and difficult to interpret. High yields associated with LC training may have led to an overcropping situation in 1984 and 1985, hence fruit maturity was delayed somewhat in this system in terms of °Brix under both pruning strategies in 1984, and within the 25 nodes/m of row pruning level in 1985. High °Brix associated with balance-pruned ML vines in 1984 and both ML treatments in 1985 seem also to be yield-related. Open canopies may help explain low TA in 25-node ML and PB fruit in 1984 and 1985, respectively, while dense canopies associated with 25-node LC vines can justify observations of high TA in fruit from that treatment despite indications of high fruit exposure in 1985 and 1986. High TA is often associated with inferior canopy microclimate (SMART 1982; REYNOLDS *et al.* 1985; SMART *et al.* 1985 b). It is unlikely that the high pH observed in 25-node PB vines in 1984 and 1985 relative to other treatments was due to inferior fruit exposure, since canopy density in these vines was low, and high pH is usually associated with shaded fruit (SMART 1982; SMART *et al.* 1985 b). Low pH in fruit from LC-trained vines in 1984 suggests that this was a function of delayed fruit maturity, as observed previously in New York-grown, cordon-trained Seyval blanc vines in which fruit microclimate was poor (REYNOLDS *et al.* 1985). 3-year means for fruit composition (Table 7) suggest that LC training delayed fruit maturity very slightly.

Training system had no major effect on wine composition but LC training tended to reduce varietal intensity and quality (Table 6). Effect of pruning strategy throughout this investigation was very small, and this factor could not, by itself, be associated with a modification in any parameter of growth, yield, fruit composition, or canopy density. At present, pruning of Riesling at 25 nodes/m of row appears to be a safe recommendation, and is within range of pruning levels recommended for *V. vinifera* in Germany (KIEFER and WEBER 1985). No major impact of pruning strategy on yield or fruit composition was observed in the present study (Table 7). Further experimentation is required to ascertain optimal shoot density for Riesling grown in British Columbia.

LC training appears to be a viable option for *V. vinifera* on non-divided canopies. Consistently high yields were observed in LC-trained vines during the course of this experiment, attended by a very small impact on fruit composition (Table 7) and wine quality. Inadequate canopy density associated with cane pruning was markedly improved, and no winter injury to trunks or cordons was observed despite three consecutive seasons of unusually cold winters. Reduction in pruning cost, potential for mechanization, sustainable yields and adequate fruit quality dictate that LC training be considered for *V. vinifera* cultivars in viticultural regions of North America which experience cold winters.

Summary

Riesling vines were subjected over a 3-year old period to four training systems ('flachbogen'; 'pendelbogen'; low cordon; Moselle loop) in combination with two pruning strategies (30 + 10 balanced pruning; 25 nodes/m of row). Low cordon-trained vines yielded highest and maintained densest canopies, but were also characterized by a reduction in cane periderm formation, wine aroma intensity, wine quality, and, during 1984, °Brix, cluster weight, and berries per cluster. Effects of both training and pruning strategy on titratable acidity and pH were very small. Due to large and consistent gains in yield, improved budbreak and canopy fill, as well as potential for mechanization of pruning, low cordon training is recommended for Riesling on non-divided canopies.

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