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Influence of Temperature and Ethephon Concentration on Growth and Composition of Cabernet Sauvignon Grapevines*

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Abstract. Potted Cabernet Sauvignon grapevines were acclimated to two different temperature regimes (25°C/15°C and 35°C/25°C day/night temperatures, respectively) until 100% bloom, when the vines were treated with either 0, 250, 500, or 750 ppm ethephon (Ethrel®). Three days after ethephon application all vines were combined and held at 25°C/15°C in a phytotron room for 15 weeks. Growth was suppressed by a greater range of ethephon concentrations at the cool temperature, but effects were shorter-lived than at the high temperature. Generally, the 500 ppm treatment reduced vigor most effectively. The degree to which ethephon influences vine growth is mediated by temperature. Ethephon and temperature treatments caused significant differences in the concentrations of potassium, calcium, and magnesium in leaves.

The primary mode of action of the plant growth regulator ethephon (2-chloroethylphosphonic acid) is through its base-catalyzed degradation and concomitant release of ethylene (Biddle et al. 1976, Cooke and Randall 1968, Warner and Leopold 1969, Yang 1969). In order to control excessive vegetative growth, ethephon was compared with several growth regulators on various cultivars and was found to be the most efficient chemical for regulating growth (Hirschfeld and Lavee 1980, Lavee et al. 1977, Shulman et al. 1980).

The effects of ethephon are influenced by external factors. Significant interactions exist between ethephon and vine water status on fruit development and

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composition in grapes (Hardie et al. 1981). Interactions between ethephon and temperature have been reported in tulip bulbs (Moe et al. 1978), tomato fruit and foliage (Lougheed and Franklin 1972), cherries (Wittenbach and Bukovac 1973), and cherry leaves (Olien and Bukovac 1978). Italian workers (Quaglino et al. 1979) reported that the most marked effects of ethephon on grapevines occurred when it was applied during the warmest part of the day. Temperature affected the ethephon-induced abscission response of *Vitis labrusca* grapes (Clore and Fay 1970). Since the rate of decomposition of ethephon is temperature dependent (Biddle et al. 1976, Klein et al. 1979), some responses may be directly linked to the effect of temperature on the ethephon rather than to the effect of temperature on the responses.

Ethephon increased the respiratory rate of Barlinka grape berries, but without an accompanying rise in membrane permeability (Steenkamp et al. 1977). The effects of ethephon are also influenced by the presence and concentrations of magnesium and calcium ions (Biddle et al. 1976).

The main purpose of this investigation was to determine how temperature influences growth responses and mineral status of grapevines to different concentrations of ethephon applied at full bloom.

Materials and Methods

Plant material used in this study consisted of 64 two-year-old, own-rooted, potted Cabernet Sauvignon grapevines grown under controlled conditions in two separate phytotron rooms. The containers, growth medium, and procedures used in growing, handling, and maintaining the vines have been described (Kliewer 1968, 1970a). Half the vines were held under day/night temperatures of 25°C/15°C (LT), while the other half were acclimated to a day/night temperature of 35°C/25°C (HT) until vines were in full bloom (100% capfall). At approximately 100% capfall, vines within each temperature regime were subjected to one of four ethephon (Ethrel®) treatments, consisting of an unsprayed control, 250, 500, and 750 ppm. Vines were sprayed utilizing a 12-liter Hudson hand-held sprayer without the addition of a wetting agent. This completely randomized design represents eight different treatments, each treatment replicated eight times with single

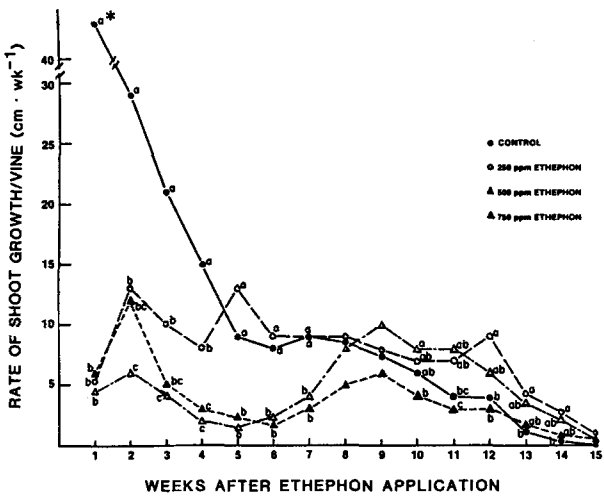

Fig. 1. Effects of ethephon concentration on rate of shoot growth with temperature treatments combined. *Within a week, means followed by the same superscript are significantly different by ±2 SE.

replicates. Three days after the 35°C/25°C vines were treated with ethephon, they were permanently transferred to the 25°C/15°C temperature room. All vines were then maintained at this temperature for the remainder of the experiment.

At the time of spray treatment, shoots were tagged at the point where the last leaf was fully expanded, defining the basal and apical portions of the shoots. Shoot extension was measured weekly for 15 weeks. The vines were then pruned and the leaves removed in order to determine leaf fresh and dry weights, leaf moisture content, average shoot internode length, number and length of lateral shoots, total shoot growth, and pruning weights. Further, the apical leaf blades, the basal leaf blades, and the petioles were digested with concentrated HNO_3 and 30% H_2O_2, followed by analysis for calcium, magnesium, and potassium status with a Perkin-Elmer 2380 Atomic Absorption Spectrophotometer.

Statistical analyses were performed utilizing two-way analysis of variance followed by means separation by Duncan's Multiple Range Test.

Results and Discussion

Effects of Ethephon and Temperature on Rate of Growth

With both temperature treatments combined, all ethephon concentrations significantly reduced growth to differing points in time (Fig. 1). The 500 ppm treatment provided greatest growth suppression, while the 250 ppm treatment exhibited the least growth suppression. Ethephon at 750 ppm showed the greatest suppression of early growth, but a striking resumption of growth occurred beginning about 8 weeks after application. Growth for all treatments essentially ceased by 15 weeks after ethephon application.

Temperature effects for each growth regulator treatment are expressed in Figs. 2–5. The unsprayed controls (Fig. 2) followed similar patterns with relevant differences apparent only between weeks 3 and 6. The HT, 250 ppm ethephon-treated vines (Fig. 3) showed a slow, steady growth reduction beginning 2 weeks after ethephon application. The corresponding LT vines exhibited an entirely different response to the same concentration of ethephon, with an

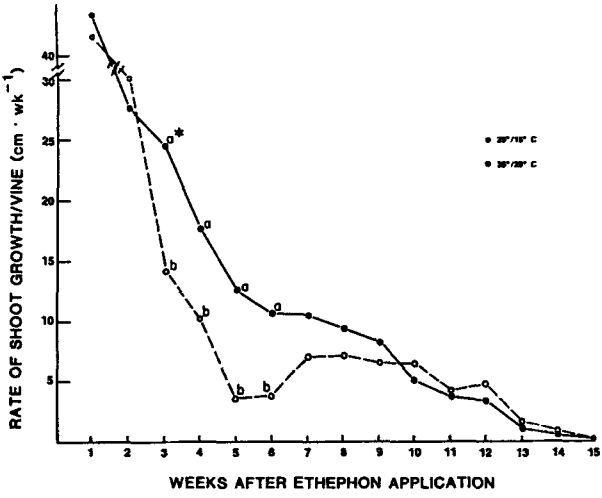

Fig. 2. Rate of growth response to 0 ppm ethephon under two temperature conditions. *Within a week, means followed by different superscripts are significantly different by ±2 SE.

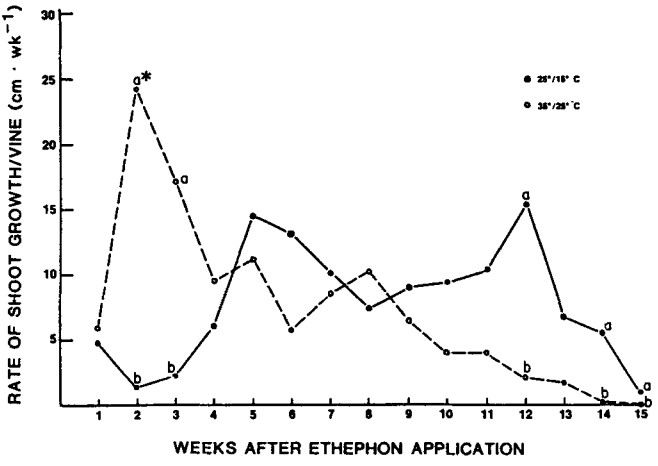

Fig. 3. Rate of growth response to 250 ppm ethephon under two temperature conditions. *Within a week, means followed by different superscripts are significantly different by ±2 SE.

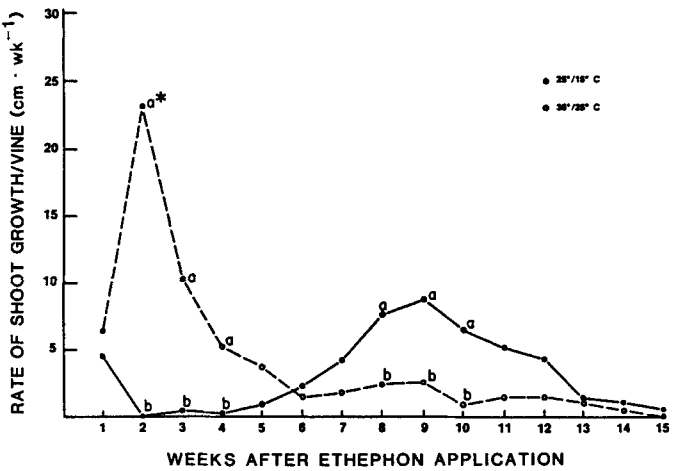

Fig. 4. Rate of growth response to 500 ppm ethephon under two temperature conditions. *Within a week, means followed by different superscripts are significantly different by ±2 SE.

immediate month-long reduction of growth, followed by a recovery of the growth rate.

There was a greater reduction of growth when vines of both temperatures were subjected to 500 ppm ethephon (Fig. 4) compared with 250 ppm, with HT vines once again experiencing early growth, but declining more rapidly than HT at 250 ppm. Growth of LT vines was highly suppressed at 500 ppm with some regrowth later in the season.

For HT vines, 750 ppm caused the greatest early growth suppression (Fig. 5). The regrowth, however, was higher than HT vines at 500 ppm. Similarly, LT vines at 750 ppm experienced greater late growth than did HT vines at 500 ppm.

Generally, suppression of vine growth by ethephon was more effective over a wider range of concentrations at LT than at HT. However, the tendency toward renewed growth under LT indicates the need for a second application approximately 2 months after the first application in order to maintain restricted growth.

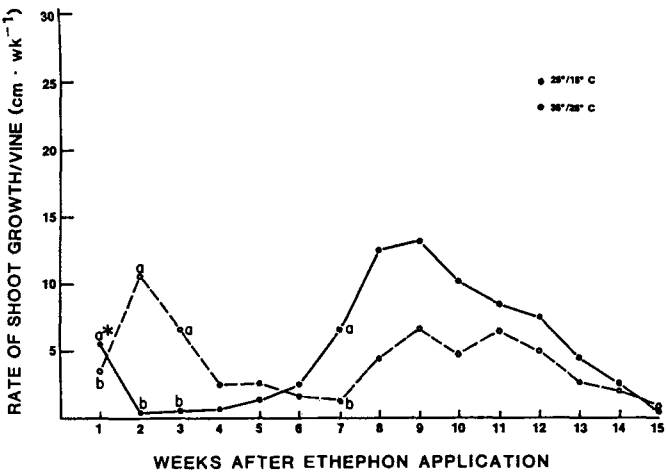

Fig. 5. Rate of growth response to 750 ppm ethephon under two temperature conditions. *Within a week, means followed by different superscripts are significantly different by ±2 SE.

Growth Responses to Ethephon and Temperature

In addition to changes in rate of growth, other differences in growth due to ethephon and temperature treatments were observed (Table 1). Average internode length, another measure of shoot extension, was reduced by all ethephon treatments under LT, whereas under HT, 750 ppm ethephon was required to reduce internode length significantly. The degree to which ethephon decreases internode length was mediated by temperature.

The number and total length of laterals were increased by all ethephon concentrations under LT, but under HT, they increased only at 750 ppm. The induction of laterals by ethephon occurred as though the vines had been physically topped. A single application of ethephon might serve to increase, through heavy lateral growth, foliage around the fruit, precisely the area where foliage reduction is generally most desired.

Total shoot growth, which consists of growth of main and lateral shoots, was increased under LT at higher ethephon concentrations. Under HT, however, total growth remained relatively unchanged from the control, except for the 500 ppm treatment, in which growth was significantly reduced. At LT, ethephon caused the vines to react as though they were topped, with the resulting increase in total growth attributed to the increased number of stimulated growing points. The increase in total growth under HT by 750 ppm over 500 ppm indicates a similar trend; however, higher ethephon concentrations than those tested would be required to verify this pattern. Thus in cooler climates, multiple ethephon applications applied at 6- to 8-week intervals would likely be necessary for continued suppression of lateral growth and reduction of total shoot growth. In warmer climates, a single application of 500 ppm was effective; however, 750 ppm could require multiple applications.

Total pruning weights were reduced by all ethephon concentrations under both temperature regimes with the greatest reduction at 500 ppm (Table 1). The reduction in pruning weight for treatments with increased total shoot growth was due to the inclusion of numerous long, thin lateral shoots that were stimulated by the ethephon treatments.

Table 1. Growth responses to ethephon and temperature of Cabernet Sauvignon grapevines.

Temp day/night (°C)	Ethephon conc (ppm)	Avg apical[a] internode length (mm)	No. of laterals	Total lateral growth (cm)	Total shoot growth[c] (cm)	Pruning wt (g)
	0	51e[b]	4.2a	14.5a	185bc	94.0d
25/15	250	37cd	24.9bc	43.6ab	173bc	63.6ab
	500	27a	33.4c	113.6d	213cd	55.6a
	750	34bc	38.1c	87.5cd	266d	80.9c
	0	41d	3.4a	10.0a	152bc	74.0bc
35/25	250	37cd	10.8ab	13.9a	125ab	58.4a
	500	38cd	11.4ab	22.5a	84a	51.5a
	750	30ab	38.6c	76.5bc	152bc	60.0a

[a] The term apical denotes that portion of the shoot that contained leaves not fully formed at time of ethephon application and that subsequently developed growth.
[b] Mean separation within columns by Duncan's Multiple Range Test, 5%.
[c] Total shoot growth includes length of lateral shoots plus main shoots.

Table 2. Leaf responses to ethephon and temperature of Cabernet Sauvignon grapevines.

Temperature day/night (°C)	Ethephon conc (ppm)	Basal leaves[a]			Apical leaves[a]		
		Fresh wt (g)	Dry wt (g)	Moisture (%)	Fresh wt (g)	Dry wt (g)	Moisture (%)
	0	56.0ab[b]	21.4ab	61.9bcd	54.5e	22.6e	58.3ab
25/15	250	56.6ab	22.0ab	60.8abcd	34.3bc	13.6bc	61.6cd
	500	66.2bc	26.5cd	60.1abc	18.8a	6.9a	62.9d
	750	75.1c	27.4d	63.2d	29.0abc	10.5b	63.8d
	0	53.6a	19.8a	63.1d	46.5de	18.8d	59.4abc
35/25	250	61.7ab	22.9bc	62.8cd	37.8cd	14.5c	61.1bcd
	500	53.4a	21.5ab	59.6ab	24.6ab	10.5b	56.8a
	750	58.5ab	24.4bcd	58.3a	27.2abc	11.1b	58.9abc

[a] The point at which the last leaf was fully formed at the time of ethephon application defines the division between basal and apical.
[b] Mean separation within columns by Duncan's Multiple Range Test, 5%.

Leaf Responses to Ethephon and Temperature

Statistical analysis of basal leaf response to both treatment variables revealed significant interactions between the two for fresh weight and moisture responses, while significant differences in dry weight of basal leaves were due to temperature and growth regulator treatments independently.

The fresh weight of basal leaves increased with increasing ethephon concentrations under LT. This increase did not occur under HT (Table 2). The increase in fresh weight was due to an increase in dry weight. The latter has been directly correlated to leaf surface area (Kliewer 1970, Kliewer and Fuller 1973, Kliewer et al. 1972, Kliewer and Weaver 1971). The restriction of shoot growth, coupled with the increase in leaf surface area, reinforces the evidence that reduction of leaf area increases the photosynthetic efficiency of the remaining leaves (Kliewer 1970 Am J Enol Vitic).

The increase in dry weight of basal leaves under HT with increasing ethephon concentration was considerably less dramatic than under the LT condition. This again indicates a greater range of ethephon effectiveness under LT than under HT. Apical leaves, however, experienced the greatest decrease in fresh and dry weight at 500 ppm ethephon, regardless of temperature treatment (Table 2).

There was a strong interaction between ethephon and temperature on the moisture content of basal and apical leaves. This was primarily due to the decreasing moisture levels of basal leaves with increasing ethephon concentrations under HT but not under LT. This confirms the visual observation that vines subjected to high growth regulator concentrations under HT use less water. These results are in agreement with findings that water uptake was reduced and leaf chlorophyll contents were increased in barley and tobacco plants treated with ethephon (Frommhold 1980).

Effects of Ethephon and Temperature on Major Cation Status

Ethephon at concentrations of 500 ppm and 750 ppm significantly increased the concentration of calcium in basal leaf blades and in petioles under both LT and HT (Table 3). Calcium levels in basal leaf blades and in petioles increased with increasing levels of ethephon, except in basal leaf blades at LT. The concentration of calcium in basal leaf blades and in petioles was generally higher at LT than at HT; however, the differences were not always significant. The data in Table 3 indicate that little holdover effect of ethephon application on calcium levels exists in the apical leaf blades, which developed after ethephon application.

Ethephon significantly reduced the concentration of potassium in basal leaf blades, with HT vines having lower levels than LT vines (Table 3). Levels of potassium in HT petioles were also less than in LT petioles for all ethephon treatments. For both temperatures, the greatest decrease in petiole potassium concentration was at 500 ppm, and the greatest increase was at 750 ppm. In apical leaf blades, a strong interaction took place in which high ethephon and LT resulted in the greatest potassium accumulation (Table 3). At HT, ethephon had no significant effect on the level of potassium in apical leaf blades.

Magnesium level differences (Table 3) in basal leaf blades were primarily due to temperature effects, while petiole magnesium differences were due to effects by both experimental variables, with no interaction. The significant interaction between temperature and ethephon on apical leaf blade magnesium was due to the striking decrease found in HT vines treated with 750 ppm.

Many investigators have shown that ATPases may function as energy transducers in the transport of ions, particularly cations, across the plasma membrane or tonoplast of plant cells (Hodges 1976). Studies with tobacco revealed that ethephon affected the activity of several enzyme systems including ATPase (Henry and Richard 1979). The role of ATPases in the uptake and exchange of cations in grapevines has been postulated (Boulton 1980). Cytoplasmic ATP is proposed as the substrate for and primary influence on trans-

Table 3. Effect of ethephon concentration and temperature on the levels of calcium, potassium, and magnesium in leaf blades and petioles of Cabernet Sauvignon grapevines.

Temperature day/night (°C)	Ethephon conc (ppm)	Calcium (% dry wt)			Potassium (% dry wt)			Magnesium (% dry wt)		
		leaf blades		petioles	leaf blades		petioles	leaf blades		petioles
		basal[a]	apical[a]		basal[a]	apical[a]		basal[a]	apical[a]	
25/15	0	1.73a[b]	1.56a	1.51a	1.18c	0.80a	1.35bc	0.85ab	0.92b	2.69a
	250	2.20d	1.84bc	2.26c	0.88a	0.81a	1.56c	0.84ab	0.75a	3.10bc
	500	2.13cd	1.76abc	2.30c	0.82a	1.07c	1.35bc	0.86ab	0.74a	3.16bc
	750	1.95bc	1.64ab	2.39c	0.92ab	0.94b	1.57c	0.81a	0.70a	2.96ab
35/25	0	1.72a	1.71ab	1.47a	1.07bc	0.70a	1.33bc	1.03c	1.03c	2.99abc
	250	1.84ab	1.71ab	1.70a	0.78a	0.72a	1.22b	0.94bc	0.91b	3.10bc
	500	1.95bc	1.93c	1.96b	0.79a	0.69a	0.83a	1.02c	1.00bc	3.53d
	750	2.00bc	1.68ab	2.32c	0.79a	0.82a	1.48bc	0.88ab	0.76a	3.36cd

[a] The point at which the last leaf which was fully formed at the time of ethephon application defines the division between basal and apical.

[b] Mean separation within columns by Duncan's Multiple Range Test, 5%.

port of cations across the plasma membrane of leaf and berry cells, with secondary effects due to temperature.

It is postulated that the effects of ethephon and temperature on the cation status of grape tissues can be attributed, at least in part, to the mediating response of membrane-bound ATPase activity. Further studies are needed in order to more fully understand the mechanism of action and subsequent effects of ethephon on grapevines.

Conclusions

The data presented in Figs. 1–5 and in Tables 1–3 indicate that there was an interrelationship between ethephon and temperature, which was expressed as differences in growth and leaf responses, as well as in mineral status.

The data show that a wider range of ethephon concentrations is effective under lower temperatures. However, a second application of ethephon 6 to 8 weeks after the initial application would be necessary to maintain growth suppression. Generally, 500 ppm ethephon was most effective in reducing excessive vegetative growth in Cabernet Sauvignon grapevines.

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