

Paclobutrazol Affects Growth and Fruit Composition of Potted Grapevines

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Abstract. Paclobutrazol applied as a soil drench at 0, 1, 10, 100, or 1000 µg a.i./g soil reduced vegetative growth of 'Seyval blanc' grapevines (*Vitis* spp.). At all rates, there was a reduction in internode length, while at rates higher than 10 µg a.i./g soil, there was also a reduction in node count. Leaf area produced following treatment declined in response to increasing rates, but specific leaf weight increased. Treatment with paclobutrazol delayed senescence and increased the retention of basal leaves that were nearly fully expanded at the time of treatment. Paclobutrazol application had no effect on fruit set or berry size, but the reduction in vegetative growth following treatment decreased the ability of the vine to supply sufficient photoassimilates for fruit maturation. Chemical name used: β[(4-chlorophenyl)-methyl]-a-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol (paclobutrazol).

Paclobutrazol retards vegetative growth in many plant species, including grapes (Hunter and Proctor, 1990; Intrieri et al., 1986; Reynolds, 1988), by inhibiting gibberellin biosynthesis (Davis et al., 1988). Paclobutrazol has usually been applied as either a foliar spray or a soil drench. With foliar spray applications, absorption through mature leaves is limited and paclobutrazol may be taken up through stem absorption (Barrett and Bartuska, 1982) or from excess that drips onto the soil. Elfving and Proctor (1986) have reported that protecting the soil from foliar drip reduced the paclobutrazol-induced inhibition of extension growth in apple. When applied to the soil, a continuous supply of paclobutrazol taken up by the roots is translocated acropetally via the xylem, thus maintaining the concentration of paclobutrazol above the threshold required for the inhibition of gibberellin biosynthesis (Davis et al., 1988). Within a few days after application of paclobutrazol, growth of the main-shoot apex and of axillary buds and shoots is inhibited (Davis et al., 1988; Hunter and Proctor, 1990; Reynolds, 1988; Shaltout et al., 1988). Demand for photoassimilates normally used for extension growth of both main and axillary shoots is reduced, and photoassimilates produced by the leaves may then be diverted to alternate sinks.

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Developing fruit clusters are the dominant sink for photoassimilates (Fisher et al., 1977; Hale and Weaver, 1962; Kaps and Cahoon, 1989), especially between fruit set and veraison (Hale and Weaver, 1962; Hunter and Visser, 1988), during which time the rate of vegetative growth decreases (Winkler et al., 1974). After veraison, photoassimilates are diverted primarily to carbohydrate reserves in the wood (Hunter and Visser, 1988; Winkler et al., 1974).

The present trial was initiated to determine whether paclobutrazol-induced control of vegetative growth in fruiting 'Seyval blanc' grapevines increases the partitioning of photoassimilates into the fruit clusters.

In early Feb. 1987, dormant 2-year-old 'Seyval blanc' grapevines that had been grown outside in pots in 1986 were repotted using a greenhouse soil mix [3 sandy to sandy-loam soil : 2 peatmoss (v/v)]. After having

been pruned to leave a two-node spur, these vines were grown in a greenhouse at the Agriculture Canada Research Station, Harrow, Ont. The greenhouse was set at 27 ± 2C during the day and 22 ± 2C at night. Supplementary lighting was provided by high-pressure sodium lamps for a 16-h photoperiod. Vines were watered daily, and dilute 20N-20P-20K solution was applied bi-weekly.

A single fruitful shoot was retained on each vine, the shoot being supported as necessary. All other shoots and buds were removed before initiation of treatments, and any shoots that subsequently developed from the retained spur were removed. Shoot lengths and node counts were recorded at intervals throughout the course of this experiment.

Two (occasionally three) flower clusters per shoot developed on the retained fruitful shoot. Vines were cluster-thinned to retain only the basal cluster. On 27 Mar. 1987, ≈17 days after bloom, all axillary shoots were removed. The node subtending the youngest leaf to have separated from the shoot apex was marked. Paclobutrazol (250 g·liter⁻¹ flowable) was applied in 500 ml of water to provide 0, 1, 10, 100, or 1000 µg a.i./g soil mix.

Fruit clusters were harvested on 2 June 1987 and weighed separately for each vine. The number and weight of berries in each cluster were determined. Juice was extracted by crushing the berries by hand, followed by squeezing them through cheesecloth. Soluble solids concentration (SSC) was determined with a hand-held TC-10430 refractometer (Reichert, Buffalo, N.Y.). Titratable acidity (TA) was determined by titrating 7.5 ml of juice in 100 ml of distilled water to a pH 8.2 endpoint using 0.1 N NaOH. Juice pH was measured with a model 811 laboratory pH meter (Orion Research, Cambridge, Mass.).

Two weeks after fruit harvest, the shoot was harvested at the node subtending the basal cluster (usually node three to five above the base of the shoot) for leaf area measurements using a LI-3000 leaf-area meter (LI-COR, Lincoln, Neb.) and fresh- and dry-weight determinations. The shoot was separated into three sections: 1) axillary growth from the entire shoot; 2) the upper shoot, being that

Table 1. Effect of paclobutrazol concentration (microgram a.i. per gram soil) applied 17 days after bloom on plant height, node count, axillary growth, and shoot dry weights of greenhouse-grown 'Seyval blanc' grapevines, as determined 2 weeks after fruit harvest.

Paclobutrazol (µg·g ⁻¹ soil)	Ht (mm)	No. nodes	Axillary growth		Shoot dry wt (g)		
			Total length (mm)	No. ²	Lower	Upper	Axillary
0	1.55	31.6	433	14.2	7.44	13.92	2.09
1	1.34	31.2	390	12.4	7.71	10.90	1.96
10	0.94	28.9	193	11.4	8.27	5.42	1.06
100	0.67	24.4	135	10.8	8.00	1.70	0.64
1000	0.67	19.1	93	8.1	7.81	0.80	0.40
Significance	***	***	***	***	NS	***	***
Linear	***	***	***	***	NS	***	***
Quadratic	***	***	NS	NS	NS	*	NS

¹Shoot includes leaves and stems.

²Shoot length >5 mm.

NS, *, ***Nonsignificant or significant at P = 0.05 or 0.001, respectively.

Table 2. Effect of paclobutrazol concentration (microgram a.i. per gram soil) applied 17 days after bloom on leaf area (LA, square centimeter), leaf count, mean area per leaf (area, square centimeters), and specific leaf weight (SLW, milligrams per square centimeter) of greenhouse-grown 'Seyval blanc' grapevines, as determined 2 weeks after fruit harvest.

Paclobutrazol ($\mu\text{g}\cdot\text{g}^{-1}$ soil)	Lower shoot				Upper shoot				Axillary shoot			
	LA	No.	Area	SLW	LA	No.	Area	SLW	LA	No.	Area	SLW
0	645	8.1	76.3	18.7	1109	18.8	59.2	19.4	354	19.8	17.1	15.8
1	734	9.6	76.1	19.1	1044	18.8	55.4	19.5	327	21.3	14.8	16.1
10	895	11.6	77.3	19.3	596	16.5	34.4	26.7	159	19.3	7.6	19.4
100	861	11.9	72.2	20.1	160	12.6	12.3	29.8	81	19.6	4.0	24.9
1000	873	11.8	73.2	20.0	67	7.6	7.7	40.5	50	12.6	3.9	26.1
Significance	***	***	NS	***	***	***	***	***	***	*	***	***
Linear	***	***	NS	***	***	***	***	***	***	**	***	***
Quadratic	*	*	NS	NS	NS	***	NS	**	NS	*	**	NS

ns,***,****Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively.

Table 3. Effect of paclobutrazol concentration (microgram a.i. per gram soil) applied 17 days after bloom on fruit quality of greenhouse-grown 'Seyval blanc' grapevines.

Paclobutrazol ($\mu\text{g}\cdot\text{g}^{-1}$ soil)	SSC ^z (%)	TA ^y (g/100 ml)	pH	SSC : TA ratio
0	23.4	0.89	3.47	26.9
1	23.6	0.93	3.43	25.6
10	22.8	1.03	3.41	22.5
100	21.9	0.99	3.35	22.4
1000	20.1	0.96	3.34	21.1
Significance	***	**	NS	***
Linear	***	*	**	***
Quadratic	*	**	NS	NS

^zSSC = Soluble solids concentration.

^yTA = Titratable acidity (as tartaric acid equivalents).

ns,***,****Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively.

part of the shoot above the marked node; 3) the lower shoot, from the level of the basal cluster to the marked node. The axillary growth and the upper shoot developed following paclobutrazol application, while the lower shoot was mostly formed before application of the paclobutrazol treatments.

We used a randomized complete block with four vines per treatment in each of four replicates. Shoot lengths measured on 4 Mar. 1987 (≈ 3 weeks after budbreak) were used for assigning vines to replicates (based on apparent vigor), before treatment allocations. Paclobutrazol rates were log-transformed before analysis of the data by means of SAS-General Linear Models (GLM). Treatment degrees of freedom were partitioned into linear, quadratic, cubic, and quartic components using single degree-of-freedom contrasts (Snedecor and Cochran, 1980). Linear and quadratic trends are reported as not significant or as significant at $P = 0.05, 0.01, \text{ or } 0.001$.

Plant height and axillary growth of greenhouse-grown 'Seyval blanc' grapevines trained to a single fruitful shoot were reduced by soil applications of paclobutrazol 17 days after peak bloom (Table 1). The lowest rate of paclobutrazol ($1 \mu\text{g}\cdot\text{g}^{-1}$ soil) inhibited internode elongation in the upper shoot, while at higher rates (10, 100, and $1000 \mu\text{g}\cdot\text{g}^{-1}$ soil), there was also a reduction in node count, again in the upper shoot component. Total length of axillary shoot growth was reduced linearly ($P = 0.001$) by log-

scale increases in paclobutrazol dosage (Table 1). At the lowest paclobutrazol rate; there was a reduction in total axillary shoot length resulting from a reduction in shoot count (data not presented). At higher paclobutrazol rates, the total axillary shoot length was reduced through both a reduction in shoot count and a reduction in mean shoot length.

Intrieri et al. (1986) reported a proportional reduction in shoot and axillary growth of grapevines following spray applications of paclobutrazol. Wample et al. (1987) and Reynolds and Wardle (1990) attributed the paclobutrazol-induced reduction in shoot growth to an effect on internode elongation, while Hunter and Proctor (1990) and Intrieri et al. (1986) also reported a reduction in node count.

The dry weights of the upper shoot and axillary shoot components exhibited a significant ($P = 0.001$) linear response to log-scale increases in paclobutrazol dosage (Table 1). The upper shoot component showed the highest degree of growth inhibition, the reduction in dry weights exceeding 90% at the highest rate of paclobutrazol, while the reduction in axillary shoot dry weights was $\approx 80\%$. While the effect of paclobutrazol application was not significant for the lower shoot component, dry weights for this component were lowest for control plants (Table 1) as a result of fewer leaves being retained to harvest (Table 2).

The total leaf area from the lower shoot increased in response to paclobutrazol application, primarily because more leaves were harvested (Table 2), but the mean area per leaf was not affected by treatment. Total leaf area, leaf count, and mean area per leaf from the upper shoot component were reduced by paclobutrazol application (Table 2). While leaf area from the axillary shoot component was reduced by increasing paclobutrazol dosages, the number of leaves harvested from this component was reduced only at $1000 \mu\text{g}$ paclobutrazol/g soil (Table 2). These reductions in area for leaves developing under the influence of paclobutrazol are consistent with those of earlier reports (Intrieri et al., 1986; Reynolds and Wardle, 1990; Wample et al., 1987).

Vines not treated with paclobutrazol were taller with a larger leaf area in the upper shoot and axillary components; consequently, there was more shading of the lower

stem section of control vines. Shading of basal leaves can lead to early senescence and abscission (Ueda and Nakagawa, 1977), which may be attributed, at least in part, to the unsuccessful competition by these shaded basal leaves for carbohydrates. Photoassimilates exported from photosynthetically active leaves are preferentially distributed to the shoot apex and to developing fruit clusters rather than to mature leaves (Hale and Weaver, 1962). Leaf retention in the lower shoot component of paclobutrazol-treated vines may also have resulted from the overall demand for photoassimilates, since the reduction in total leaf area contributes to a reduction in total assimilate supply (De Jong and Doyle, 1984). A paclobutrazol-induced delay in the onset of leaf senescence has been reported to prolong the period of active photosynthesis (Davis et al., 1988).

The specific leaf weight (SLW, i.e., fresh weight per unit leaf area) of all components increased in response to paclobutrazol application (Table 2). This increase in SLW was particularly strong for those leaves harvested from the upper shoot, and SLW of these leaves was always higher than for leaves harvested from other components. It was only at paclobutrazol rates of 100 or $1000 \mu\text{g}$ a.i./g soil that the SLW of the axillary leaves exceeded that of leaves from the lower shoot (Table 2). The SLW of leaves on the lower shoot, which were formed before paclobutrazol application, also increased in response to increasing paclobutrazol dosage. However, some of these lower leaves were not fully expanded at the time of paclobutrazol application and may, therefore, have developed at least partially under the influence of the growth regulator. Most of the leaves that abscised before harvest of the vines were basal leaves that were fully expanded at the time of treatment.

Typically, leaves that formed after paclobutrazol treatment were smaller and darker green than leaves that developed before treatment or on control plants. They also exhibited a downward curling of leaf margins and a thickened appearance that has been described for other plant species (Jaggard et al., 1982; Steffens et al., 1985). Visual observations suggested that growth of the leaf veins may have been reduced by paclobutrazol application to a greater extent than expansion of interveinal tissues (Wample and Culver, 1983), leading to a crinkled or roughened appearance (Intrieri et al., 1986). Coleman (1986) indicated that the midrib and major veins mature acropetally in the lamina, minor veins and mesophyll tissue mature basipetally from the lamina tip, and the lamina tip matures some time before the leaf base. It appears that this order of leaf development may contribute to the effect of paclobutrazol and other inhibitors of gibberellin biosynthesis on leaf appearance.

Paclobutrazol, applied 17 days after peak bloom when most of the natural berry drop had already occurred, had no effect on cluster size, berry count, or mean berry weight (ranges: 32-36 g, 23-26 g, 1.1-1.3 g, respectively). With prebloom paclobutrazol

applications, Shaltout et al. (1988) observed an increase in fruit set in 'Roumi Red' grapes, the increase in berry count per cluster contributing to an increase in cluster weight. However, paclobutrazol applied to 'Riesling' vines \approx 4 weeks after peak bloom did not lead to increased cluster weight (Reynolds, 1988). Williams et al. (1989) reported no effect of soil-injected paclobutrazol applied at budbreak or at bloom on the yield of 'Thompson Seedless' in the year of treatment.

Under greenhouse conditions, fruit yields and components of yield (i.e., berry count and mean berry weight) were also low (Table 3). Flower clusters on greenhouse-grown vines were smaller than those expected on field-grown vines, but poor fruit set under greenhouse conditions probably accounted for most of the reduction in berry count. Bloom development under greenhouse conditions was very rapid, and during the immediate pre-bloom and bloom periods, warm sunny weather resulted in temperatures exceeding 33C during the daytime. High temperatures during and immediately following bloom have been reported to reduce fruit set and increase berry drop (Winkler et al., 1974).

Increasing paclobutrazol rates reduced leaf area (Table 2) with a subsequent reduction in total available assimilates (De Jong and Doyle, 1984). With all treatments, the developing fruit attracted sufficient assimilates for berry growth. There was no evidence for previously reported increases (Reynolds, 1988) or decreases (Shaltout et al., 1988) in mean berry size in response to paclobutrazol application. However, fruit maturation was affected (Table 3). The SSC was $> 23\%$ for vines with 0 (i.e., control) or 1 μg a.i./g soil, but only 20% for vines treated with 1000 $\mu\text{g}\cdot\text{g}^{-1}$ soil. Lowest TA and highest juice pH were obtained from control plants. TA response to log-scale increases in paclobutrazol dosage had a significant ($P = 0.01$) quadratic component, the highest TA being obtained from vines treated with 10 μg a.i./g soil. The SSC : TA ratio declined linearly with log-scale increases in paclobutrazol dosage.

Shaltout et al. (1988) also reported reductions in sugar content (as °Brix) and increases in juice acidity following paclobutrazol applications. The reduction in total leaf area

where vegetative growth was reduced by paclobutrazol treatment (Table 2) decreased the ability of the vine to supply sufficient photoassimilates for fruit maturation (Williams et al., 1989). However, Reynolds (1988) suggested that the paclobutrazol-induced suppression of lateral-shoot development reduced the photoassimilate demands of these superfluous sinks, resulting in an increase in fruit soluble solids (°Brix) and a corresponding decrease in TA. Intrieri et al. (1986) observed a paclobutrazol-induced elevation in wood carbohydrate level, leading Reynolds and Wardle (1990) to further suggest that translocation of carbohydrates from the old wood to the clusters advanced fruit maturity.

While paclobutrazol was effective in controlling vegetative growth, conflicting evidence on paclobutrazol-induced changes in assimilate partitioning in fruiting grapevines suggests that further investigation is required.

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