J. Amer. Soc. Hort. Sci. 106(1):77–79. 1981.

Response of Sweet Cherry and Apricot Pollen Tube Growth to High Levels of Sulfur Dioxide[1]

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Additional index words. Prunus avium, Prunus armeniaca, air pollution, dose, spline function analysis

Abstract. **Pollen tube growth of 'Tilton' apricot (*Prunus armeniaca* L.) was reduced by exposure to SO_2. An empirical model, based on modified spline functions, described the decrease in pollen tube growth due to increasing dose (hours exposure × concentration of SO_2) expressed on logarithmic scale. The response curve, based on this analysis, was "S-shaped" with a decrease from 98.5% pollen tube growth (PTG) for unexposed pollen tubes, based on percent of the style that the longest pollen tubes had grown to 91.6% at ℓn dose 4.0. Thesewas then a very sharp decrease in PTG to about 45% at ℓn dose 5.7, then a gradual curvilinear response to <1% PTG at the maximum ℓn dose of 7.7. There data strongly indicate that there is a threshold response to SO_2 with respect to PTG. Response of 'Van' PTG in 'Napoleon' sweet cherry (*P. avium* L.) styles was similar to apricot, but not as definitive because of greater within year variation and differences between years. In one year (1979), a spline function model of PTG in cherry suggested a threshold value at about ℓn dose of 2.1, while in another year (1978), there was a nearly linear decrease in PTG with increasing ℓn dose.**

Response of plants to gaseous pollutants depends on the concentration of the gas, the exposure period, the variable pattern of fumigation, and factors such as plant age and species, air temperature, humidity, light, wind speed, water, and nutrient status. Time of exposure and gas concentration are the basic parameters used in evaluating air quality standards with regard to plant damage. Generally, SO_2 concentrations do not exceed 0.26–0.52 mg SO_2/m^3 although there are obviously times and places where levels have been considerably higher (3, 9, 11, 13). Yields of sweet cherries were reduced by SO_2 when the average fumigation concentrations were 0.83 and 0.272 mg SO_2/m^3 for a 7-month period, and the maximum concentrations (30 min average) were 9.4 and 17.0 mg SO_2/m^3 (9). The only time-concentration studies found in the literature concerning SO_2 and pollen of fruit trees showed that pear pollen germination was reduced by exposure to 0.785 mg SO_2/m^3 for 1 hr. Fruit set was reduced in these studies by treatments with 0.523 and 1.3 mg SO_2/m^3 during pollination (12). This study was undertaken to determine the effects of time of exposure and concentration of SO_2 on pollen tube growth, *in vivo,* of sweet cherry and apricot.

Materials and Methods

Branches of 'Tilton' apricot and 'Napoleon' sweet cherry were cut during March and April, 1978 and 1979, and forced to flower at 18°C and 20 to 30% relative humidity. Fumigation and pollen tube examination methods have been previously described (2). Pollen tube growth in the pistil was expressed as percent of style length, based on the longest pollen tube visible. Apricot flowers were selfed. Sweet cherry flowers were emasculated prior to opening, and 'Van' sweet cherry was used as the pollen source. In 1978, apricot flowers were fumigated at 0 and about 0.5, 3, 33, and 96 mg SO_2/m^3 (at reference conditions, ppm SO_2=mg SO_2/m^3 × 0.382) for 0 to 72 hr. There was a total of 46 different fumigation combinations. A single forced branch with 20 to 30 flowers, 10 of which were examined for pollen tube growth (PTG), was used as a single data point. Sweet cherry branches were treated in a similar manner except that fumigation concentrations were 0, and about 0.4–1, 2, 5, and 6.5 mg SO^2/m^3 for 0 to 72 hr for a total of 49 different combinations. In 1979, apricots were fumigated for 0, 2, 4, 8, and 24 hr at concentrations of 0, and about 2, 5, 7, 14, and 32 mg SO_2/m^3. Sweet cherries were fumigated for 0, 2, 4, 8, and 24 hours at concentrations of 0, and about 2, 6, and 14 mg SO_2/m^3. Data points were as described for 1978, except that 10 branch replicates were tested at each time, concentration, and species. Sulfur dioxide levels were generated by metering through a Matheson Model 610-A flow meter from a SO_2 cylinder. Air SO_2 levels were sampled and analyzed for the duration of each fumigation using an EPA method (1). Data were analyzed as weighted multiple linear regression (5) using modified spline functions (7). The spline functions used were:

1) $PTG = \alpha + \beta\ \ell n\ dose$, where $\ell n\ dose \leq C_1$.
2) $PTG = \alpha + \beta\ \ell n\ dose + \lambda\ (\ell n\ dose - C_1)^2$, where $C_1 < \ell n\ dose \leq C_2$.
3) $PTG = \alpha + \beta\ \ell n\ dose + \lambda\ \ell n\ dose - C_1)^2 + \zeta\ (\ell n\ dose - C_2)^2$, where $\ell\ dose > C_2$.

C_1 and C_2 are formally known as knots, but simply represent the continuous intersection of different curves fitted to the data. In the present instance, these points were found by iteration to maximize the R^2 subject to the conditions that PTG>0 and PTG was non-increasing with increasing ℓn dose (over the range of the experiment).

Results and Discussion

Apricot. Pollen tube growth of 'Tilton' apricot, *in vivo* was reduced by increasing dosage of exposure to SO_2 (hr exposure × mg SO_2/m^3) (Fig. 1). Analysis of the effects of year (1978 and 1979), time of exposure, and concentration of SO_2 showed no difference between years and no unique responses to time and concentration that are not expressed as dose. An empirical model was constructed using modified spline functions (7) relating the response of PTG, *in vivo*, to ℓn dose of SO_2, and showed that there were 3 regions of varying response. These regions are shown in Fig. 1, and

[1]Received for publication July 5, 1980. Technical Paper No. 5557. Oregon Agricultural Experiment Station. This research was supported by the Wasco County Fruit and Produce League.
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Table 1· Spline function values for empirical models relating to pollen tube growth of 'Tilton' apricot and 'Van' sweet cherry in response to SO_2 fumigation.

Cultivar	Year	Knot C_1	Knot C_2	Coefficients α	Coefficients β	Coefficients λ	Coefficients ζ	R^{2z}
'Tilton' apricot	1978,1979	4.0	5.7	98.52	−1.79	−13.48	24.98	0.964
'Van' sweet cherry	1978	2.1	3.7	63.60	−3.43	−2.47	4.77	0.339
'Van' sweet cherry	1979	2.1	3.7	42.62	−1.08	−4.03	7.85	0.984

[z]The R^2 values were based on the mean PTG values at each dosage combination and not the total numbers of observations as plotted in Figs. 1 and 2. Numbers of dosage combinations were: 1) 1978 apricot, 46; 2) 1979 apricot, 21; 3) 1978 cherry, 49; and 4) 1979 cherry, 9. Numbers of observations were: 1) 1978 apricot, 83; 2) 1979 apricot, 250; 3) 1978 cherry, 82; and 4) 1979 cherry, 116.

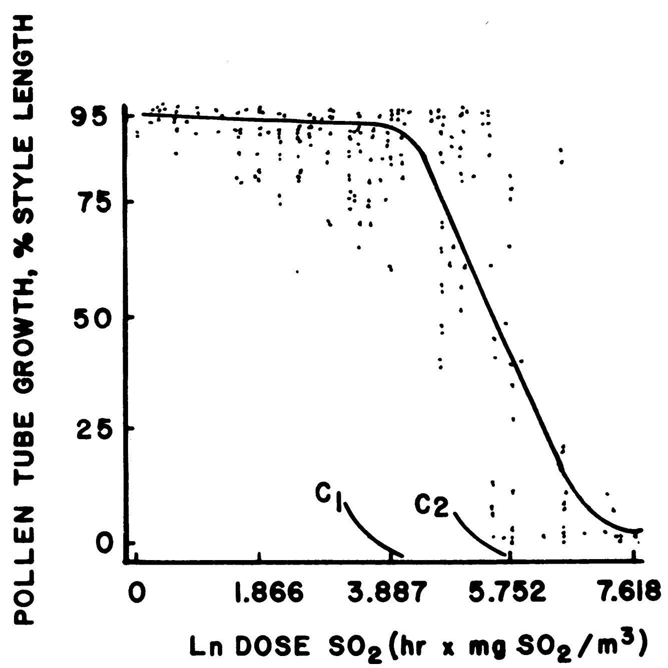

Fig. 1. Effect of ℓn dose (hr exposure x mg SO_2/m^3) of SO_2 on PTG, expressed as percent of style length, of 'Tilton' apricot, 1978 and 1979. The curve was derived with weighted PTG values using modified spline function analysis. Points C_1 and C_2 represent –n dose values where the curves intercept. Table 1 gives the coefficients for the model with the model equations in the text.

the parameters delineating these regions are shown in Table 1. Figure 1 shows that there is a very gradual reduction in PTG as ℓn dose increases to about 4.0, a sharp decrease in PTG from ℓn dose of 4.0 to 6.8 and then a necessary leveling off because PTG was approaching 0 at the higher ℓn doses. A weighted procedure (5) was used because of the clear lack of homogenity of the sampling variance. It is evident in Fig. 1 that response was more variable at intermediate dose levels. This is partly, but not wholly, because of the binomial nature of the data where results are expected to be most variable at the 50% level of response. Transformation (arcsine) was not a sufficient solution. The weights assigned were a smoothed function approximating the general variability and were inversely proportioned to the variability; that is, the less variable results were more heavily weighted.

Apricots appear to be able to tolerate fairly high doses of SO_2 without severe effects on PTG. There appears to be a threshold ℓn dose of approximately 4.0 below which there is a very modest reduction in PTG. Apricot yields should, therefore, not be affected by SO_2, at least not by a mechanism involving PTG. The SO_2 concentrations used to reach ℓn dose of 4.0 were generally greater

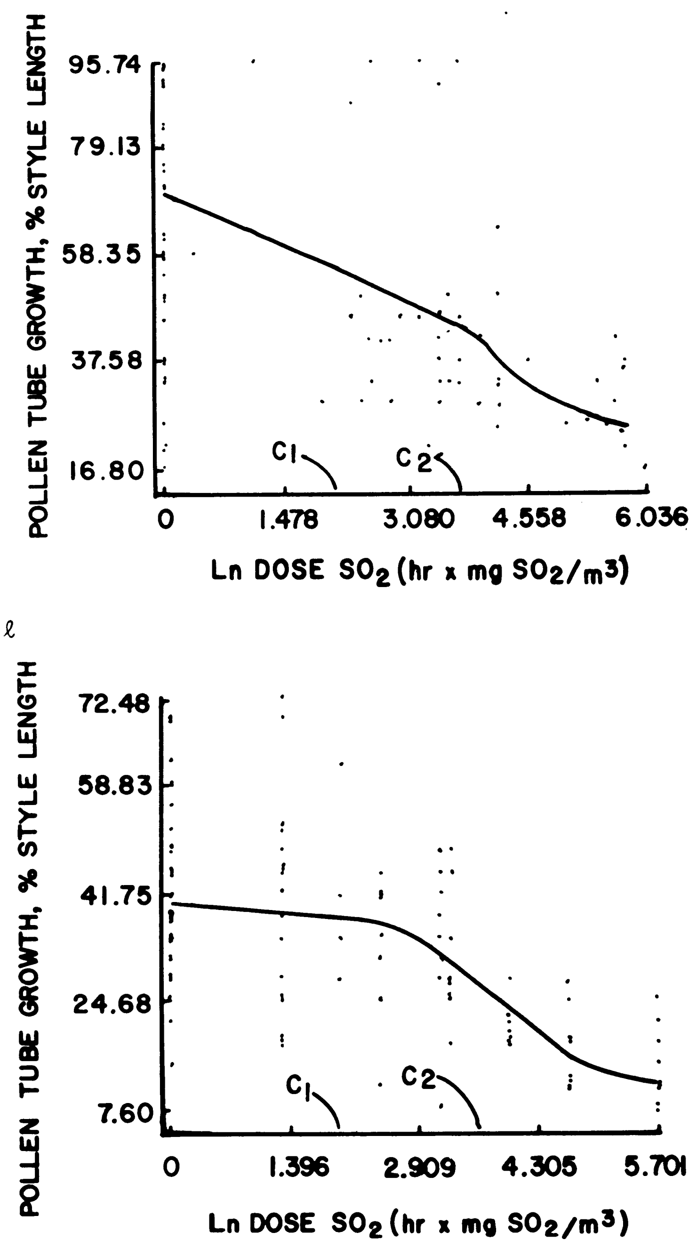

Fig. 2. Effect of ℓn dose (hr exposure x mg SO_2/m^3) of SO_2 on PTG, expressed as percent of style length, of 'Van' pollen in 'Napoleon' sweet cherry styles in 1978 (top) and 1979 (bottom). Curves were derived with weighted PTG values using modified spline function analysis. Points C_1 and C_2 represent ℓn dose values where the curves intercept. Table 1 gives the coefficients for the models with the model equation in the text.

than those commonly encountered in the atmosphere (3, 9, 11, 13). SO_2 probably has no effect in orchard situations in spite of the facts that: 1) not all combinations of time, concentration, and environmental conditions were examined; 2) response to SO_2 could be affected at temperature and humidities (9, 11) different from those used in these studies; and 3) plants tend to have higher threshold values for injury to occur from SO_2 when treated under controlled exposure conditions as compared to ambient conditions (3). There may also be other responses of apricots to SO_2 that were not observed such as leaf damage or fruit abscission.

Sweet cherry. Average growth of 'Van' pollen tubes in 'Napoleon' sweet cherry styles did decrease as ℓn dose of SO_2 increased (Fig. 2), but the actual form of the response was not well-defined because of the great variation within and between years. Experimental conditions were similar in both years, but there was a difference of about 20% (αvalues in Table 1 for 1978 and 1979) in the average PTG at 0 dose and a difference in variability. Some of the variation in PTG could be because 'Van' and 'Napoleon' are compatible at only one allele (10). Therefore, on the average, about half of the 'Van' pollen is compatible (has a different *S* allele than the cells within the 'Napoleon' style) and could be expected to grow the total length of the style, whereas half of the tubes would cease growth prior to reaching the base of the style. It was assumed that more than enough pollen was placed on each pistil, such that the incompatibility alleles would not have been a factor when the measurement was of the longest pollen tube. At least 20 pollen tubes have been observed in cherry styles (6) and that many or more could be observed in our system although counts were not made in every pistil. Assuming no interference, we found the probability of no compatible pollen tubes growing to be far less than 0.001. Thus, this does not seem to be a plausible explanation of much, if any, of the variability. Environmental conditions not conducive to growth or lack of uniformity of flower condition probably contribute to the variability. Probably not all flowers were emasculated at the proper stage of maturity (8).

From past experience, PTG in cherry is more variable than apricot PTG, and we know of no particular reason for the great difference between years and/or the extreme variability in 1978. The results shown for 1979 (Fig. 2) suggest a threshold at about ℓn dose of 2.1, considerably lower than for apricot (4.0). It was not possible to find knot points (C_1, C_2) for 1978 because of the great variability. Thus, the knot points from 1979 were used for 1978. There is virtually no evidence of a threshold. If anything, there is nearly linear decrease in PTG with increased ℓn dose.

As with the apricot, cherry PTG in response to CO_2fumigation is probably related to other environmental conditions not studied, such as temperature and humidity. Even though cherry PTG appears to be more susceptible to SO_2 than does apricot PTG, the SO_2 levels causing a response were generally greater than those commonly encountered in ambient situations (3, 9, 11, 13). However, sweet cherry yields have been reduced where the SO_2 concentrations have been as high as 9.4 and 17.0 mg SO_2/m^3 (30 minute averages) (9). The 17.0 mg/m^3 SO_2 concentration for 30 minutes corresponds to a ℓn dose of about 2.14 in our system, roughly the same as the estimated threshold level of 2.1. It is possible that reduced PTG caused some of the reduced yields found in that study if the high levels occurred during anthesis.

Literature Cited

1. Code of Federal Regulations. 1973. Title 40. Protection of the environment. p.189–192. Appendix A. Reference method for the determination of sulfur dioxide in the atmosphere (pararosaniline method). The Office of the Federal Register. National Archives and Records Service.
2. Facteau, T. J. and K. E. Rowe. 1977. Effects of hydrogen fluoride and hydrogen chloride on pollen tube growth and sodium fluoride on pollen germination in 'Tilton' apricot. J. Amer. Soc. Hort. Sci. 102:95–96.
3. Jones, H. C., D. Weber, and D. Basille. 1974. Acceptable limits for air pollution dosages and vegetation effects: sulfur dioxide. Paper 74-225. 67th Annual Meeting, Air Pollution Control Association, Denver, Colo.
4. Katz, M. 1949. Sulfur dioxide in the atmosphere and its relation to plant life. Ind. Eng. Chem. 41:2450–2465.
5. Neter, J. and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin, Homewood, Ill. p. 326–328.
6. Roy, B. 1938. Studies on pollen tube growth in Prunus. J. Pom. & Hort. Sci. 16:320–328.
7. Smith, P. L. 1979. Splines as a useful and convenient statistical tool. Amer. Statistician 33:57–62.
8. Tufts, W. P. and G. L. Philp. 1925. Pollination of the sweet cherry. Univ. Calif. Bul. 385.
9. U. S. Environmental Protection Agency. 1973. Effects of sulfur oxides in the atmosphere on vegetation; Revised chapter 5 for Air Quality Criteria for Sulfur Oxides. Rpt. EPA–R3–73—030. p. 43.
10. Way, R. D. 1968. Pollen incompatibility groups of sweet cherry clones. Proc. Amer. Soc. Hort. Sci. 92:119–123.
11. Webster, C. C. 1967. The effects of air pollution on plants and soil. Agr. Res. Council, London. p. 53.
12. Yoshihiro, M. 1971. Pollution factors and control of their effects. Experiments with pears. Kagabu No Jibben 22:1145–1148. [Chem. Abst. (1972) 77:15326Z.]
13. Zahn, R. 1970. The effects on plants of a combination of subacute and toxic sulfur dioxide. Staub-Reinhalt Luft 30:20–23.