*Acute and Chronic Sulfur Dioxide Fumigation
of Piñon Pine Seeds and Seedlings:
Data Compilation*

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ACUTE AND CHRONIC SULFUR DIOXIDE FUMIGATION OF PIÑON PINE SEEDS AND SEEDLINGS: DATA COMPILATION

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ABSTRACT

Piñon pine germinating seeds, emergent seedlings, and one-year-old seedlings were exposed to sulfur dioxide under both acute and chronic exposure conditions. These fumigations were conducted in order to determine the potential for damage to piñon pine in southwestern national parks and monuments where there is potential for exposure to elevated sulfur dioxide concentrations from smelters and power plants. Injury was apparent only in acute fumigations of one-year-old seedlings at ambient sulfur dioxide concentrations of greater than 3 ppm. Chronic fumigations were conducted only at ambient concentrations of 0.2 ppm. Piñon pine resistance was evidenced by lack of effect of fumigation on biomass and growth parameters. Growth rate data for both experimental and control seedlings were fit to a linear growth model with a correlation ($r^2 = 0.95$).

The results of this study agree with other data in the literature and indicate that damage from elevated sulfur dioxide concentrations in southwestern national parks and monuments is much more likely for other, more sensitive, species than for piñon pine.

I. INTRODUCTION

The National Park Service (NPS) is concerned about potential sulfur dioxide impacts on national parks and monuments in the Southwest resulting from emissions from various sources, primarily power plants and smelters. The Los Alamos National Laboratory (LANL) entered into an Interagency Agreement with the NPS to use an experimental fumigation facility in existence at LANL to investigate the effects of controlled exposures of selected plant species to sulfur dioxide. Piñon pine (*Pinus edulis*) was selected because it is a major ecological component of southwestern parks and monuments. Two previous studies (Caldwell et al., 1976; Hill et al., 1974) have addressed the effects of sulfur dioxide on piñon pine and both found piñon pine to be resistant; however only acute fumigations were conducted.

Previous investigations on effects of sulfur dioxide on desert ecosystems include fumigation of range grasses (Davis et al., 1966), Indian ricegrass (Ferenbaugh, 1978), desert grasses (Johnson, 1974), and Mojave Desert plants (Thompson et al., 1980; Thompson et al., 1984) and uptake by desert soils (Ferenbaugh et al., 1979). In other related studies conducted at Los Alamos National Laboratory, Gladney et al. (1993a, b, c, d, e) collected piñon pine foliage and soil samples in the vicinity of piñon pine from five national parks and monuments surrounding the Four Corners area and analyzed them for sulfur content to provide baseline data.

The purpose of this study was to expose germinating seeds, emergent seedlings (germinants), and one-year-old piñon pine seedlings to sulfur dioxide under both acute and

chronic exposure conditions to investigate effects of sulfur dioxide on growth parameters and to assess the various growth stages for damage.

II. MATERIALS AND METHODS

Fumigation Chambers - The LANL fumigation chambers used in these experiments are a modification of the continuous stirred tank reactor type chamber described by Heck et al. (1978). The chamber design is cylindrical (4 ft in diameter by 4 ft high) with a variable-speed impeller to enhance mixing and distribution of contents. Inlet air is filtered through activated charcoal beds, and test gases are introduced in dilute form at the inlet duct. The chambers are exhausted by a negative pressure, single-pass airflow system. The environmental control system consists of an atomizer to control humidity, a conditioning plenum for temperature control, airflow controllers, and micrometering valves to control fumigant concentration. Light is provided by metal halide lamps that provide approximately 3500 ftc of light at 15 in. below the chamber ceiling. Photoperiod is regulated by a time clock. All parameters are continuously monitored by sensors located within the chambers.

Experimental Plant Material - Piñon pine seeds and one-year-old seedlings were purchased from Colo-Hydro Inc., Longmont, Colorado.

Fumigation of Germinating Seeds - Piñon pine seeds were sown in 14x9x2 in. plastic trays on a 6:3:1 mixture of peat moss, vermiculite, and perlite. The trays were filled to a depth of 1.5 in., sixty seeds were spaced evenly in each tray, and the seeds covered with 0.125 in. of perlite. The trays were watered to saturation before being placed in the chambers, and then were watered lightly every other day throughout the study.

Chamber conditions were ~25°C, humidity 20 to 30%, and lighted by fluorescent light. The experimental seeds were fumigated with 0.2 ppm of sulfur dioxide for 7 h per day, 5 days per week. The airflow through the chambers was 8 scfm (standard cubic feet per minute), resulting in 9.5 air changes per hour in the chambers. Trays were rotated daily in the chambers to ensure uniform exposure conditions.

A total of 1920 seeds was used in the study: 960 as experimental subjects and 960 as controls. The 960 seeds in each set were divided into 16 trays of 60 seeds each. Two replicate fumigation experiments were conducted, using half of the experimental and control seeds in each experiment. Each experiment terminated five weeks after seeding. At the end of the five week period, the number of germinated seeds was counted, hypocotyl lengths were measured, and total dry weights were determined.

Chronic Exposure of Emergent Seedlings - Piñon pine seeds were sown in 1.5 in. diameter by 8 in. high plastic cylinders in a 6:3:1 mixture of peat moss, vermiculite, and perlite. Two seeds were planted per cylinder. The cylinders were watered, covered with plastic sheeting, and maintained in a greenhouse until seed germination occurred. After germination, seedlings were thinned to one per container. Seedlings were watered twice per week and fertilized once per week with Burpee® 20-3-8 Evergreen mixture.

The chambers received 12 h light and 12 h dark per day (LD 12:12). Light intensity at floor level was 2000 ftc. Daytime temperature was controlled at 30°C and nighttime temperature at 20-25°C. The chambers were maintained at ambient humidity of 20-30%. Experimental seedlings were fumigated with 0.2 ppm of sulfur dioxide for 7 h per day, 5 days per week. The airflow through the chambers was 8 scfm, or 9.5 air changes per hour.

The duration of this study was 16 weeks. Initially there were 80 seedlings each in the control and fumigated chambers. Twenty seedlings were removed from each chamber at 4-

week intervals, so that fumigated and control plants were obtained at 4 weeks, 8 weeks, 12 weeks, and 16 weeks. Whenever experimental seedlings were removed, they were replaced with other seedlings of similar size so that the canopy coverage characteristics within the chambers remained the same. The height of each seedling was measured prior to initiation of the study. Parameters that were measured at each harvest were post-treatment plant height, number of branches, and dry weight of needles, stems, and roots.

Acute Exposure of One-Year Seedlings - One-year-old seedlings were planted in a 6:3:1 mixture of peat moss, vermiculite, and perlite in small plastic buckets, 7 in. in diameter and 10 in. high. Three seedlings were planted per bucket, and the potting mixture level was brought up to the rim of the buckets to prevent damping off by elimination of the dead air space between the soil surface and the bucket rim. Seedlings were acclimatized in a greenhouse for two months after potting to overcome transplant shock before fumigation experiments were initiated. The seedlings were watered twice per week and fertilized once per week with Burpee® 20-3-8 Evergreen mixture.

Ambient chamber conditions during acute fumigations were temperature about 20°C and humidity 20-30%. Light intensity at seedling level was about 2000 ftc. Airflow through the chambers was 10 scfm, or 11.9 air changes per hour, and acute exposures lasted for three hours. Sulfur dioxide was provided as a square wave function during the 3-h fumigation. Exposure concentrations ranged from 2.75 to 4.75 ppm in 0.5 ppm increments.

Seedlings were fumigated in sets of 6 per treatment. Each treatment was replicated 10 times. Four treatments were run each day, two in the morning and two in the afternoon. Scheduling of chambers (Table 1) according to treatment, day, and time of day was random. Controls are represented by zeros in Table 1. Plants were evaluated for visible injury two-to-five days after fumigation, whenever symptom expression was most obvious. Percent of total leaf area affected was estimated for each seedling.

Following evaluation of visual injury, seedling foliage was analyzed for sulfur content. For sulfur analysis, the 60 seedlings fumigated at each sulfur dioxide concentration were divided into two sets: those fumigated during morning exposures and those fumigated during afternoon exposures. Foliage from each set was composited into two samples, representing "old" and "new" needles. "New" needles were comprised of needles from first-year branches, and "old" needles were comprised of primary needles on the stem. This distinction was made because essentially all observed injury occurred on first-year branches, and the branch foliage was accordingly analyzed separately to determine if any correlation existed between injury and sulfur content. As a result of the AM-PM separation and the subsequent old-new separation, four samples for sulfur analysis were obtained at each fumigation level: AM-old, AM-new, PM-old, and PM-new. These samples were prepared and analyzed as described in the Sulfur Analysis section.

Chronic Exposure of One-Year Seedlings - One-year-old seedlings were received from the vendor in plastic cylindrical containers, 1.5 in. in diameter by 8 in. high. The seedlings used in this study were not transplanted from the cylindrical containers, but were acclimatized in the greenhouse for two months prior to fumigation. They were watered twice weekly and fertilized once per week with Burpee® 20-3-8 Evergreen mixture.

Chamber conditions for year-old seedlings were the same as previously described for emergent seedlings. Photoperiod was LD 12:12, with a light intensity of 2000 ftc at seedling level. Daytime temperature was 25-30°C, and nighttime temperature was 20-25°C. Ambient humidity was 20-30%. Seedlings were fumigated 7 h per day, 5 days per week, at a sulfur dioxide concentration of 0.2 ppm. Airflow was 8 scfm, or 9.5 air changes per hour.

The experimental protocol for this 16-week study was the same as previously described for emergent seedlings. Eighty seedlings initially were placed in each chamber. Twenty seedlings each were removed from the control and fumigated chambers at 4, 8, 12, and 16 weeks. Seedlings were replaced to maintain canopy coverage. Height and number of branches were determined for each seedling prior to fumigation. Parameters measured at each harvest were post-treatment height and number of branches, and dry weight of needles, stems and roots.

Sulfur analyses were performed on foliage from fumigated seedlings. Ten control and ten fumigated seedlings were selected for analysis at the end of each four week period and were prepared and analyzed as described in the Sulfur Analysis section.

Sulfur Analysis - Sulfur content of the piñon pine foliage was measured using a Leco Model SC-132 sulfur analyzer (Bower et al., 1986; Gladney et al., 1985). Vegetation samples were dried in a forced-air circulation oven at 60°C for 48 hours, ground through a 0.5 mm sieve in a Brinckmann Spex grinder, pelletized, and combusted in the Leco analyzer furnace. Water vapor was removed from the combustion gases by adsorption on magnesium perchlorate, and sulfur dioxide was then measured by infrared absorption. Measurements were standardized against National Bureau of Standards (NBS) Standard Reference Materials (SRM) 1572 citrus leaves (certified sulfur concentration of 4070 ± 50 µg/g). Each day's work was quality-assured by concurrent analysis of a variety of NBS SRMs and Alpha Resources biological materials. Quality assurance practices and procedures are detailed in Gautier et al., 1989.

Statistical Analysis of Data - One unforeseen problem arose as a result of the choice of seedlings for this project. Seedlings were randomly chosen in groups of 20 for both the experimentals and controls. Although statistically appropriate, this resulted in a number of instances whereby the experimentals and controls differed statistically in size at the onset of the experimentation; this was not realized at the time. Consequently, during the data analysis it was very difficult to compare growth of experimentals and controls. In hindsight, a more appropriate technique would have been to match seedlings at the onset.

In order to analyze the data *a posteriori*, control and experimental samples were compared and individuals were excluded until the samples were statistically alike in terms of means, standard deviations and ranges of initial stem length. Growth parameters (e.g. initial stem length, post stem length, stem weight, root weight, needle weight, initial branching and post branching) of experimentals were then compared to controls.

Means were compared using one way ANOVA techniques and regression lines were fit using linear and curvilinear least squares techniques.

III. RESULTS

Fumigation of Germinating Seeds - Most of the seeds (86.5% of controls, 84.7% of experimentals) germinated in the fumigation chambers and grew during the five week experiments. This high germination frequency provided confidence in the experimental design and results. The responses of the experimental seeds were similar to the controls (Table 2). There were no statistical differences between the root-shoot lengths of seeds fumigated at 0.2 ppm and controls ($F = 0.0320$; $df = 1,1642$; $p = 0.8581$; Tables A-1 and A-2 in Appendix A and summarized in Table A-3). Because biomass of individual seeds was too small for accurate measurement, dry mass per tray was measured (Table A-4 in Appendix A). There were no significant differences between root mass of experimental and control germinating seedlings ($F = 1.3758$; $df = 1,15$; $p = 0.2604$) or between stem-needle mass of experimental and control germinating seedlings ($F = 0.0002$; $df = 1,31$; $p = 0.9894$).

Chronic Exposure of Emergent Seedlings - A number of growth parameters were measured on the emergent seedlings at 1, 2, 3, and 4 month intervals (Tables A-5 through A-8 in Appendix A and summarized in Table 3). With minor exceptions there were no differences between experimentals and controls in post-experimental stem length, stem mass, needle mass, root mass or branching (Table 4). At 2 months, there was a statistical difference between mean stem mass of experimentals and controls and at 3 months needle mass and root mass differed between experimentals and controls. In general, there appear to be no consistent effects of sulfur dioxide fumigation at 0.2 ppm for 16 weeks on the emergent seedlings.

Acute Exposure of One-Year Seedlings - No injury was observed below a sulfur dioxide concentration of 3.25 ppm (Table 5). Above this concentration injury increased at an exponential rate (Figure 1). The following polynomial regression curve:

$$I = -6.7S + 2.9S^2 - 0.6,$$

where

I = Number of injured trees

S = Sulfur dioxide concentration in ppm

is statistically significant ($p < 0.04$, $r^2 = 0.88$) and shows rapidly increasing visible damage above 3.5 ppm.

Results of the foliar sulfur analyses (Table 6) show no apparent differences among the control and fumigated seedlings either in terms of fumigation level ($F = 1.2821$; $df = 5,23$; $p = 0.3145$), time of fumigation ($F = 3.0654$; $df = 1,23$; $p = 0.0939$), or age of needles ($F = 0.3714$; $df = 1,23$; $p = 0.5485$).

Figure 1. Relationship between injury to Piñon Pine and fumigation levels in ppm SO₂.

Chronic Exposure of One-Year Seedlings - Chronic exposure of one-year seedlings to 0.2 ppm sulfur dioxide also seems to have little effect on the length or mass parameters of the seedlings (Table 7). As none of the experimentals differed significantly from the controls (Table 8), there does not appear to be any effect of the sulfur dioxide fumigation, even at these longer exposure periods. Detailed data compilations of stem length, stem and needle dry weights, and number of branches for individual seedlings fumigated for various time periods ranging from one to four months are found in Appendix A (Tables A-9 through A-13).

The foliage sulfur analyses of fumigated seedlings and controls (Table A-14) shows an accumulation of sulfur in the fumigated seedlings during the course of the exposure (Table 9). The sulfur content of fumigated seedlings was significantly different from that of controls for each exposure period. The patterns of accumulation are predictable and interesting (Figure 2). The controls gradually decreased in sulfur content over the 4 month experiment, while the experimental seedlings increased in sulfur content. Although few detrimental effects were seen from the sulfur dioxide fumigation, there was clearly an accumulation of sulfur in the plant tissues.

Figure 2. Sulfur concentration in foliage of seedlings exposed for 1, 2, 3 or 4 months. Means are indicated by horizontal lines, 95% confidence intervals (diamond) and dotted horizontal line indicates grand mean. (C = control; E = experimentals exposed to 0.2 ppm SO₂ for 1-4 months)

Growth Rates of Fumigated and Control Seedlings - The pre- and post-experiment measurements of individual stem lengths give a measure of seedling growth and allow another comparison of the fumigated seedlings with controls. Both the chronic and acute experiments were combined and show a strong linear growth pattern during the experiment. The slopes were similar for both the controls and the experimentals (1.07 and 1.11 respectively) and the coefficients of determination (r^2 values) are both high (0.98 and

0.97). This similarity in growth rate is a further indication that there are no observable influences of sulfur dioxide fumigation during the course of the experiments. Because of the growth rate similarity, experimentals and controls were combined to produce the following general growth model (Figure 3):

$$P = 1.1I + 1.03,$$

where P = Post experiment stem length (mm)
 I = Initial stem length (mm)

$$(r^2 = 0.95, p = 0.0000).$$

Figure 3. Relationship between pre- and post-experimental stem lengths for both chronic and acute experiments.

IV. DISCUSSION

An examination of all the data from the Los Alamos study indicates that the only injury or deleterious effect on piñon pine that was observed occurred during acute, 3-h fumigations of one-year seedlings at ambient sulfur dioxide concentrations greater than 3 ppm. This injury consisted of visible browning of needles. The conclusion is that piñon pine is very tolerant to sulfur dioxide exposure. This is demonstrated by the lack of effect of fumigation on biomass and other growth parameters of fumigated plants. Furthermore, a growth model of post-fumigation stem length versus pre-fumigation stem length (Figure 3) shows no significant differences between the fit of the experimental seedlings and the control seedlings to this model.

This agrees with results of acute fumigation studies performed by Caldwell et al. (1976) and Hill et al. (1974). Hill et al. exposed piñon pine to various concentrations of sulfur dioxide for two-hour, acute fumigations and recorded zero percent foliar injury at 4

ppm, 0.06 percent foliar injury at 6 ppm, and 2 percent foliar injury at 10 ppm. Fumigation at each concentration was replicated several times. These results compare to a somewhat lower injury threshold of 3.25 ppm in the Los Alamos study, but the Los Alamos study used one-year seedlings. The study of Hill et al. apparently used more mature piñon pine trees, which should be less sensitive. The exact age of the piñon pines fumigated by Hill et al. was not specified. Caldwell et al. conducted four-hour fumigations of piñon pine at sulfur dioxide concentrations ranging up to 3.4 ppm over a relative humidity range of 31-54 percent. Results were not reported in terms of percent foliar injury. Instead, the 14 species evaluated in the study were ranked as to relative resistance using a complicated "sensitivity ranking procedure." Piñon pine was determined to be one of the two most resistant species, which agrees with the conclusion of the Los Alamos study. As in the Hill et al. study, Caldwell et al. did not specify the age of the piñon pine trees used in their study.

No report of chronic sulfur dioxide fumigation of piñon pine could be found in the literature. In the Los Alamos study, chronic fumigation (up to four weeks) was performed at only one ambient sulfur dioxide concentration (0.2 ppm), and no foliar injury was detectable as a result of this exposure. As shown in Table 9 and Figure 2, however, there was a significant increase in foliar sulfur concentration. This is to be expected, as sulfur dioxide is readily taken up through stomata and enters into the sulfur metabolism of the plant (Ziegler, 1975). Deleterious effects are not apparent unless the capacity of the plant to metabolize the excess sulfur into innocuous storage compounds is exceeded.

As most other *Pinus* species range in sensitivity from extremely sensitive to moderately tolerant to sulfur dioxide exposure, a possible explanation for the high sulfur dioxide tolerance of piñon pine is that it is more xerophytically adapted to desert conditions, possessing thicker epidermal and epicuticular wax layers and being physiologically adapted to shorter periods of stomatal opening. The results of the Los Alamos study indicate that piñon pine is not nearly as likely to be affected by exposure to ambient sulfur dioxide as are other, more sensitive, species. Nonetheless, the foliar damage resulting from high sulfur dioxide levels should ultimately lead to growth differences, although this might take several years to become apparent.

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Table 1. Acute exposure schedule. Concentration of SO₂ (ppm) assigned to different chambers in different fumigations.

Day	AM-1		PM-2	
	Chamber 1	Chamber 2	Chamber 1	Chamber 2
1	3.25	4.75	2.75	0.00
2	4.75	0.00	4.25	3.25
3	2.75	4.25	0.00	3.75
4	4.25	2.75	4.25	0.00
5	2.75	3.75	3.75	4.75
6	0.00	3.75	2.75	3.75
7	4.25	4.75	0.00	2.75
8	3.75	0.00	4.75	3.25
9	3.25	3.75	3.25	4.75
10	3.25	4.25	4.75	2.75
11	2.75	0.00	3.75	4.75
12	4.75	2.75	2.75	3.25
13	4.75	4.25	3.25	4.25
14	3.75	4.25	0.00	3.25
15	0.00	4.25	3.75	3.25

Table 2. Summary of seed germination data.

	EXPERIMENTAL	CONTROL
No. Seeds Sown	960	960
No. Seeds Germinated	813	830
% Germinated	84.7	86.5
Root-Shoot Length (mm)		
Mean Length	26.7	26.6
SD	4.95	5.01
Min. Length	11	10
Max. Length	53	46
Total Dry Weight (g)	66.3	66.2

Table 3. Emergent Seedling Study: Summary of data of one to four month exposures.

Control Group; Filtered Air

Exposure Length	Date 1986-1987	Tree No.	DRY WEIGHTS (mg)				No. of Branches	AVERAGE STEM LENGTHS (mm)		
			Stems	Needles	Roots			Initial	Post Exp.	% Increase
1-MO.	9/9-10/10	121-140	375.1	1192.3	1146.8		1	28	29.1	3.8
2-MO.	9/9-11/12	141-160	454.4	2169	1653.8		15	30	32.9	9.7
3-MO.	9/9-12/11	161-180	467.9	2953.2	2778.8		25	27.7	30.8	11.2
4-MO.	9/9-1/12	181-200	473.2	2635.3	3134.5		21	24.8	27.5	10.9
3A-MO*	10/10-1/12	221-240	498.5	2004.4	2636.4		10	26.1	29.3	12.5
2A-MO*	11/12-1/12	261-280	624.9	2376	3654.6		19	31.7	34	7.4
1A-MO*	12/11-1/12	281-300	514.4	2015.4	2975.4		4	29.5	32.1	8.8

Experimental Group; 0.2 ppm Sulfur Dioxide

Exposure Length	Date 1986-1987	Tree No.	DRY WEIGHTS (mg)				No. of Branches	AVERAGE STEM LENGTHS (mm)		
			Stems	Needles	Roots			Initial	Post Exp.	% Increase
1-MO.	9/9-10/10	41-60	350.3	998.3	1080.6		5	26	27	3.7
2-MO.	9/9-11/12	61-80	361.8	1468.3	1314		8	25.8	28	8.7
3-MO.	9/9-12/11	81-100	425.9	2044.5	2127.7		9	26.5	28.9	9.1
4-MO.	9/9-1/12	101-120	556.7	2869.6	3392.4		18	28.3	31.9	12.7
3A-MO*	10/10-1/12	201-220	523.6	2061.8	2673		7	25.7	28.6	11.1
2A-MO*	11/12-1/12	241-260	545.7	2289.5	3127.3		12	28.8	31.4	9.2
1A-MO*	12/11-1/12	301-320	626.7	2377.9	3304.7		4	29.7	33.1	11.3

Notes. No branches were observed for seedlings prior to treatment. The number of branches shown reflects post-treatment observation.

* "A" designation denotes plants introduced into chambers as replacements to maintain canopy coverage when plants were removed during the course of fumigation

Table 4. Comparison of various plant growth parameters between controls and experimentals for various fumigation periods in the Emergent Seedling Study.

Fumigation Period	Initial Stem Length	Post Stem Length	Stem Mass	Needle Mass	Root Mass	Initial Branch Number	Post Branch Number
1 Month	ns	ns	ns	ns	ns	ns	ns
2 Months	ns	ns	p<0.04	ns	ns	ns	ns
3 Months	ns	ns	ns	p<0.008	p<0.03	ns	ns
4 Months	ns	ns	ns	ns	ns	ns	ns
All	ns	ns	ns	ns	ns	ns	ns

Table 5. Acute exposure: Determination of foliar threshold on 1 year seedlings.

TIME OF DAY	Conc. (ppm)	Sample Size	Amount of Injury					Total Injured	Appearance of Injury					
			0-10%	15-30%	35-55%	60-80%	85-100%		1	2	3	4	5	
AM	0	30	0	0	0	0	0	0	0	0	0	0	0	0
PM	0	30	0	0	0	0	0	0	0	0	0	0	0	0
AM	2.75	30	0	0	0	0	0	0	0	0	0	0	0	0
PM	2.75	30	0	0	0	0	0	0	0	0	0	0	0	0
AM	3.25	18	0	0	0	0	0	0	0	0	0	0	0	0
PM	3.25	42	0	2	3	1	0	6	0	0	0	3	3	3
AM	3.75	30	4	3	3	0	0	10	0	1	1	0	8	8
PM	3.75	30	5	3	2	0	0	10	0	0	0	5	3	2
AM	4.25	42	10	6	10	1	0	27	0	7	14	3	3	3
PM	4.25	18	2	0	2	0	0	4	0	0	0	2	2	2
AM	4.75	30	2	5	4	2	1	14	0	0	11	1	2	2
PM	4.75	30	7	5	2	0	0	14	0	0	7	6	1	1

AM 0830 - 1130
PM 1330 - 1630

Table 6. Acute Fumigation Sulfur Data.

Fumigation SO ₂ Conc. (ppm)	Time	Needles	Foliar Sulfur Conc. (ppm)
Control	AM	old	1990 ± 100
		new	1870 ± 90
	PM	old	1880 ± 90
		new	1850 ± 90
2.75	AM	old	1930 ± 90
		new	1970 ± 100
	PM	old	1900 ± 90
		new	870 ± 90
3.25	AM	old	1800 ± 90
		new	1780 ± 90
	PM	old	1920 ± 90
		new	1920 ± 90
3.75	AM	old	1990 ± 100
		new	2010 ± 100
	PM	old	1920 ± 90
		new	890 ± 90
4.25	AM	old	2050 ± 100
		new	040 ± 100
	PM	old	880 ± 90
		new	1830 ± 90
4.75	AM	old	1880 ± 90
		new	1890 ± 90
	PM	old	1880 ± 90
		new	1890 ± 90

Table 7. Chronic Fumigation: Growth response of one-year-old piñon pine seedlings.

Control Group; Filtered Air

Exposure Length	Date 1987	Tree No.	DRY WEIGHTS (mg)			AVG. # OF BRANCHES		AVG. STEM LENGTH (mm)		
			Stems	Needles	Roots	Initial	Post-Exp	Initial	Post-Exp	% Increase
1-MO.	4/6-5/6	321-340	3972.9	13560.1	13001.3	2	5.1	105.5	111.5	5.7
2-MO.	4/6-6/6	341-360	4027.5	14410.1	12263	2.6	5	102.9	106	3
3-MO.	4/6-7/6	501-520	3980.1	13289.7	12944.9	2.4	4.6	100.7	105.1	4.4
4-MO.	4/6-8/7	361-380	5221.8	16580.4	14212.3	2	5.8	97.1	111.7	15
3A-MO*	5/6-8/7	381-400	4615.1	15115.9	13563.4	2.2	5.7	97.4	105.3	8.1
2A-MO*	6/6-8/7	521-540	5369	15452	21176.2	2.4	6.2	93.4	112.6	20.5
1A-MO*	7/6-8/7	601-620	6106.9	15433.6	13403.2	5.3	6.9	112.5	120.6	7.2

Experimental Group; 0.2 ppm sulfur dioxide

Exposure Length	Date 1987	Tree No.	DRY WEIGHTS (mg)			AVG. # OF BRANCHES		AVG. STEM LENGTH (mm)		
			Stems	Needles	Roots	Initial	Post-Exp	Initial	Post-Exp	% Increase
1-MO.	4/6-5/6	401-420	3553.8	13033.9	10762.4	2.6	4.1	95.6	100.5	5.1
2-MO.	4/6-6/6	421-440	3254.9	14790	10199.2	1.8	4.8	91.1	94.5	3.7
3-MO.	4/6-7/6	441-460	3394.9	15330	13306.5	1.3	4.3	87.7	94.5	7.8
4-MO.	4/6-8/7	461-480	4765.9	15663.3	13623.9	1.9	5.5	89.1	103.2	15.9
3A-MO*	5/6-8/7	481-500	5260.8	14630.5	13396	2	5.6	88.6	107.2	21
2A-MO*	6/6-8/7	541-560	5669.6	15650.8	13118.9	2.7	5.4	92.9	114.6	23.4
1A-MO*	7/6-8/7	621-640	5739	17261.5	15255.8	4.6	6.6	103.6	113.5	9.5

* "A" designation denotes plants introduced into chambers as replacements to maintain canopy coverage when plants were removed during the course of fumigation

Table 8. Comparison of various plant growth parameters between controls and experimentals for various fumigation periods in the Chronic Fumigation Study.

Exposure Length	Initial Stem Length	Post Stem Length	Stem Mass	Needle Mass	Root Mass	Initial Branch Number	Post Branch Number
1 Month	ns	ns	ns	ns	ns	ns	ns
2 Months	ns	ns	ns	ns	ns	ns	ns
3 Months	ns	ns	ns	ns	ns	ns	ns
4 Months	ns	ns	ns	ns	ns	ns	ns

Table 9. Summary of chronic fumigation sulfur data. Mean values (± 1 SD) for controls and for SO₂ fumigations for 1, 2, 3 and 4 months. Probability values show significance levels for comparison of each pair of means.

Exposure Length	AVERAGE FOLIAR SULFUR CONCENTRATION (ppm)		
	Control	0.2 ppm SO ₂	p =
1 month	1881 $\pm$ 247.8	2226 $\pm$ 279.8	0.0092
2 month	1606 $\pm$ 149.5	2116 $\pm$ 300.7	0.0001
3 month	1526 $\pm$ 300.4	2675 $\pm$ 360.5	0.0000
4 month	1716 $\pm$ 294.5	2755 $\pm$ 249.6	0.0000

APPENDIX A:
Fumigation Data

TABLE A-1: Seed Germination Study, Root-Shoot Lengths, Control Seeds

CONTROL GROUP, PART 1									CONTROL GROUP, PART 2								
LENGTH (mm)									LENGTH (mm)								
Seed #	1	2	3	4	5	6	7	8	Seed #	1	2	3	4	5	6	7	8
1	37	37	28	24	26	37	38	18	1	35	22	24	35	29	28	31	21
2	32	40	22	23	38	38	32	30	2	25	27	25	31	26	21	23	24
3	23	39	10	20	23	42	24	20	3	22	24	25	26	26	29	30	28
4	25	25	31	21	30	29	21	29	4	30	26	26	34	30	20	25	28
5	33	28	28	23	28	19	30	25	5	18	26	20	30	28	25	20	23
6	36	34	23	29	37	22	34	27	6	17	29	24	27	29	25	24	30
7	22	36	40	22	38	29	27	24	7	23	30	25	39	25	23	28	22
8	27	24	30	19	28	30	28	29	8	29	21	23	38	24	19	22	25
9	30	20	30	19	26	34	31	20	9	30	23	23	30	25	30	28	26
10	23	30	44	20	34	44	27	36	10	32	22	29	31	24	27	29	29
11	28	25	27	29	42	32	35	23	11	30	18	30	23	27	26	25	21
12	37	26	30	34	32	41	28	35	12	20	20	26	27	29	28	24	28
13	25	20	33	31	46	34	32	28	13	27	31	28	28	25	21	26	26
14	35	26	35	22	23	30	16	43	14	23	23	21	25	26	24	26	35
15	23	20	21	28	21	27	30	23	15	21	26	23	30	28	23	23	27
16	30	41	24	31	23	27	40	25	16	32	30	30	23	21	21	25	19
17	35	28	29	36	34	33	26	31	17	23	26	26	21	22	25	24	24
18	30	26	32	28	22	27	35	25	18	25	21	20	25	30	20	21	25
19	24	36	24	36	30	35	36	28	19	18	25	23	23	32	20	23	30
20	26	23	25	24	30	27	34	25	20	22	18	30	30	27	20	25	33
21	40	22	33	23	33	27	25	23	21	16	17	20	32	29	18	34	22
22	33	28	26	30	26	38	18	24	22	24	25	21	29	26	35	29	22
23	21	28	31	25	30	25	30	20	23	22	27	29	27	32	23	23	24
24	24	20	31	20	32	32	27	30	24	21	20	30	25	25	23	24	24
25	16	30	30	23	37	25	38	25	25	28	17	21	23	23	21	26	23
26	30	20	24	25	28	32	32	20	26	20	22	24	32	31	34	25	17
27	21	23	33	29	28	29	28	33	27	25	22	20	33	32	25	28	30
28	33	35	20	32	37	23	28	17	28	23	18	27	37	26	14	28	20
29	42	30	36	24	28	30	30	30	29	23	20	17	36	22	20	20	16
30	29	31	24	21	33	39	21	22	30	22	22	23	30	20	20	23	20
31	38	27	27	33	27	38	25	41	31	26	23	21	27	20	22	31	26
32	38	26	29	27	24	33	15	22	32	25	25	18	23	25	20	28	25
33	32	37	23	18	32	22	28	23	33	24	23	19	28	28	22	22	20
34	28	26	20	16	35	30	30	36	34	26	28	28	25	21	28	25	24
35	27	40	21	37	20	25	29	30	35	23	24	28	25	27	28	21	20
36	29	30	28	20	30	30	38	28	36	18	22	24	30	33	35	22	28
37	27	21	34	37	20	18	24	29	37	23	21	30	25	19	27	34	29
38	38	40	23	27	24	30	32	22	38	25	18	26	30	28	25	25	20
39	21	30	30	23	22	33	28	32	39	16	30	19	20	23	20	21	25
40	27	41	30	20	26	22	35	28	40	27	20	28	26	20	20	26	26
41	18	28	23	33	31	17	31	29	41	28	21	22	22	20	18	22	24
42	30	35	37	26	20	22	28	36	42	27	16	26	25	30	30	27	29
43	27	27	34	35	27	23	19	35	43	22	27		31	31	24	22	20
44	30	28	33	21	32	22	36	21	44	25	23		22	27	26	26	15
45	30	35	29	29	20	31	32	25	45	22	24		30	21	24	23	22
46	27	29	25	34	33	27	15	36	46	20	22		26	25	25	25	25
47	46	19	33	26	30	28	32	23	47	32	23		21	22	28	25	23
48	26	23	22	27	40	27	27	30	48	22	18		38	25	22	16	26
49	25	23	25	23	35	35	31	21	49	20	19		33	29	28	20	28
50	24	26	32	18	16	21	22	29	50	21				24	22	16	23
51	39	25	30	22	33	27	20	27	51	20				26	22	22	22
52	26	28	27	25	23	28	27	32	52	24				25		19	
53		25	29	29	19	22	30	20	53								
54		29	30	34			22	31	54								
55							23	31	55								
56							32		56								
57							33		57								
58									58								
59									59								
60									60								

TABLE A-2: Seed Germination Study, Root-Shoot Lengths, Fumigated Seeds

EXPERIMENTAL GROUP, PART 1									EXPERIMENTAL GROUP, PART 2								
LENGTH (mm)									LENGTH (mm)								
TRAY									TRAY								
Seed #	1	2	3	4	5	6	7	8	Seed #	1	2	3	4	5	6	7	8
1	36	30	28	22	35	22	26	27	1	30	23	18	25	30	19	26	21
2	37	36	28	29	24	30	32	35	2	28	20	25	22	22	22	20	23
3	32	30	36	29	22	32	23	30	3	21	20	23	22	21	18	20	21
4	37	31	35	34	31	30	24	30	4	22	18	30	22	17	20	18	22
5	36	30	30	31	22	45	35	25	5	21	24	24	24	20	25	24	20
6	42	35	28	26	21	30	34	32	6	23	30	21	18	23	24	17	24
7	31	24	39	25	19	26	24	35	7	22	25	25	24	31	20	24	21
8	27	27	33	30	34	27	37	28	8	30	18	25	26	24	23	23	23
9	40	23	23	31	27	28	32	27	9	17	23	20	23	25	23	21	20
10	40	24	28	33	22	38	35	20	10	20	21	23	23	20	23	23	18
11	23	21	25	17	35	15	34	26	11	28	20	25	26	26	16	26	30
12	31	15	29	28	30	36	22	36	12	27	33	22	22	21	23	19	24
13	25	18	31	28	34	27	43	30	13	27	26	15	22	15	21	22	28
14	25	35	32	25	21	21	32	46	14	26	23	21	20	28	21	19	25
15	37	29	33	22	30	35	30	26	15	23	19	16	23	21	20	25	25
16	25	20	18	32	29	33	35	30	16	24	20	35	20	26	17	17	19
17	36	28	29	30	29	32	28	18	17	24	20	21	20	21	21	21	25
18	39	23	29	29	25	28	25	29	18	28	21	20	25	24	20	17	23
19	31	33	27	30	38	27	35	17	19	30	18	24	21	22	23	23	24
20	47	25	19	28	32	29	33	29	20	27	16	22	25	18	19	26	22
21	27	27	33	26	31	44	25	30	21	25	24	24	17	22	14	26	28
22	46	39	28	34	35	42	21	31	22	32	25	23	20	23	16	20	24
23	43	27	25	33	25	41	40	24	23	21	23	14	23	23	20	23	20
24	32	24	30	33	21	38	30	44	24	24	21	22	20	20	25	24	27
25	32	40	40	32	28	28	31	32	25	22	22	24	23	32	20	24	18
26	20	32	20	18	35	30	35	20	26	20	27	27	26	20	22	19	16
27	28	28	38	35	45	21	33	26	27	22	21	25	17	23	20	24	19
28	40	33	15	34	39	32	32	37	28	28	18	22	19	19	27	11	22
29	39	34	30	35	32	26	31	23	29	17	21	21	18	24	19	20	27
30	37	21	34	24	22	36	25	28	30	21	20	23	20	33	21	15	26
31	38	25	22	35	27	32	42	30	31	30	24	15	22	31	21	18	16
32	40	48	28	21	41	28	26	25	32	23	20	27	20	24	28	22	21
33	25	36	28	33	30	29	29	31	33	20	20	15	20	25	20	26	27
34	39	37	30	44	28	32	28	37	34	25	25	24	20	19	25	20	16
35	21	33	26	36	42	28	34	28	35	30	23	20	23	23	24	27	22
36	23	34	35	27	35	24	31	28	36	24	25	22	23	25	23	22	21
37	44	44	34	26		26	35	45	37	22	16	19	18	23	21	21	20
38	32	26	29	34		28	27	32	38	26	33	20	21	26	17	18	27
39	31	24	36	34		42	30	30	39	26	19	16	17	23	22	23	20
40	28	37	28	36		29	31	35	40	22	28	17	21	27	16	32	31
41	32	35	34	32		37	46	40	41	27	21	24	24	19	24	22	27
42	23	23	34	25		34	23	33	42	20	25	31	25	17	21	25	32
43	29	39	24	37		23	39	33	43	25	30	25	29	32	12	20	25
44	29	37	25	32		34	28	28	44	25	22	20	21	18	19	15	21
45	37	31	27	29		28	32	33	45	24	23	35	20	25	18	18	21
46	28	34	25	40		22		40	46	25	24	25	25	23	20	18	18
47	35	42	28	30				24	47	26	22	23	28	23		15	25
48	36	33	35	30				43	48	22	18	21	23	23			23
49	40	32	31	33				31	49	19	21	24	21	22			22
50	45	35	33	37				37	50	19	22	22	30	18			20
51	25	29	42	30				29	51	29	20	19	25	23			20
52	26		22	37				38	52	23			20	22			19
53	53		30	42					53	32			22	21			28
54	37		32	37					54	23			21	21			21
55	34		35						55	22			16	26			23
56			42						56				21				
57			32						57								
58			30						58								
59									59								
60									60								

TABLE A-3: Seed Germination Study, Root-Shoot Lengths, Data Summary

STATISTICAL ANALYSIS: CONTROL GROUP, PART 1.

	TRAY 1	TRAY 2	TRAY 3	TRAY 4	TRAY 5	TRAY 6	TRAY 7	TRAY 8	TOTALS
NO. SEEDS SOWN	60	60	60	60	60	60	60	60	480
NO. GERMINATED	52	54	54	54	53	53	57	55	432
% GERMINATED	86.7	90.0	90.0	90.0	88.3	88.3	95.0	91.7	90.0
MEAN	29.3	28.7	28.3	26.1	29.1	29.2	28.5	27.4	28.3
STD	6.29	6.14	5.61	5.56	6.39	6.18	5.84	5.71	5.97
MIN. LENGTH	16	19	10	16	16	17	15	17	10
MAX. LENGTH	46	41	44	37	46	44	40	43	46

STATISTICAL ANALYSIS: CONTROL GROUP, PART 2.

									TOTALS
NO. SEEDS SOWN	60	60	60	60	60	60	60	60	480
NO. GERMINATED	52	49	42	49	52	51	52	51	398
% GERMINATED	86.7	81.7	70.0	81.7	86.7	85.0	86.7	85.0	82.9
MEAN	23.9	23.0	24.3	28.3	25.9	24.0	24.6	24.4	24.8
STD	4.26	3.76	3.67	4.79	3.60	4.36	3.77	4.08	4.04
MIN. LENGTH	16	16	17	20	19	14	16	15	14
MAX. LENGTH	35	31	30	39	33	35	34	35	39

STATISTICAL ANALYSIS: EXPERIMENTAL GROUP, PART 1.

	TRAY 1	TRAY 2	TRAY 3	TRAY 4	TRAY 5	TRAY 6	TRAY 7	TRAY 8	TOTALS
NO. SEEDS SOWN	60	60	60	60	60	60	60	60	480
NO. GERMINATED	55	51	58	54	36	46	45	52	397
% GERMINATED	91.7	85.0	96.7	90.0	60.0	76.7	75.0	86.7	82.7
MEAN	33.7	30.5	29.8	30.7	29.9	30.3	31.2	30.8	30.9
STD	7.24	6.79	5.56	5.45	6.53	6.13	5.62	6.43	6.22
MIN. LENGTH	20	15	15	17	19	15	21	17	15
MAX. LENGTH	53	48	42	44	45	45	46	46	53

STATISTICAL ANALYSIS: EXPERIMENTAL GROUP, PART 2.

									TOTALS
NO. SEEDS SOWN	60	60	60	60	60	60	60	60	480
NO. GERMINATED	55	51	51	56	55	46	47	55	416
% GERMINATED	91.7	85.0	85.0	93.3	91.7	76.7	78.3	91.7	86.7
MEAN	24.3	22.4	22.4	22.0	23.1	20.7	21.3	22.7	22.4
STD	3.65	3.76	4.40	2.96	3.95	3.17	3.86	3.69	3.68
MIN. LENGTH	17	16	14	16	15	12	11	16	11
MAX. LENGTH	32	33	35	30	33	28	32	32	35

TABLE A-4: Seed Germination Study, Dry Weight Data

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*DRY WEIGHTS: (STEMS/NEEDLES), ROOTS

TRAY NO.	STEMS/NEEDLES(GRAMS)				ROOTS(GRAMS)	
	EXPERIMENTAL GROUP		CONTROL GROUP		PART 2	PART 2
	PART 1	PART 2	PART 1	PART 2	EXPERIMENTAL	CONTROL
1	4.695	5.218	3.874	4.782	1.554	1.526
2	4.039	3.701	4.242	3.866	1.761	1.562
3	4.235	4.204	4.049	3.368	1.668	1.211
4	4.178	4.216	3.917	4.043	2.117	1.557
5	3.209	4.674	4.006	4.275	2.115	1.788
6	3.652	3.675	4.392	3.952	1.812	1.779
7	3.582	4.023	4.835	3.932	1.609	1.778
8	4.275	4.699	4.572	4.136	1.378	1.728
TOTAL WEIGHTS	31.865	34.41	33.887	32.354	14.014	12.929
EXPERIMENTAL	66.275		CONTROL	66.241		

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*DRY WEIGHTS FOR ROOTS, PART 1, EXPERIMENTAL & CONTROL GROUPS WERE NOT OBTAINED

TABLE A-5: Emergent Seedling Study, 1-Month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
121	28	30	22.8	75.1		0
122	23	24	17.1	36.5		0
123	31	32	20.9	80.5		0
124	21	22	13.5	51.9		0
125	32	32	23.4	71.9		0
126	32	33	22.1	42.7		0
127	27	27	20.4	32.3		0
128	45	48	28.1	110.0		1
129	26	27	19.0	59.5		0
130	27	27	18.3	72.3		0
131	28	28	17.5	25.4		0
132	25	26	15.7	67.8		0
133	27	31	16.6	85.9		0
134	29	32	19.2	68.9		0
135	26	26	14.5	18.4		0
136	25	27	21.5	37.5		0
137	30	30	19.5	67.4		0
138	28	28	16.0	105.0		0
139	23	24	13.1	22.1		0
140	27	27	15.9	61.2		0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
28.00		29.05		375.1 1192.3 1146.8		1

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
281	26	37	23.3	101.3	144.7	0
282	27	27	17.7	63.0	107.1	0
283	31	35	29.3	119.5	210.1	0
284	30	32	30.3	90.7	100.1	0
285	29	30	23.5	109.2	230.2	0
286	27	27	19.8	86.7	124.8	0
287	27	27	24.5	89.3	134.8	0
288	37	37	22.1	66.3	51.5	0
289	29	31	22.3	81.1	136.2	0
290	30	32	30.0	124.9	182.4	2
291	29	32	27.9	100.5	139.6	0
292	29	29	23.8	104.3	203.2	0
293	30	31	23.5	99.7	175.6	1
294	28	28	25.8	84.7	105.0	0
295	30	31	20.9	76.0	133.9	0
296	33	39	39.5	138.4	188.0	0
297	36	38	31.4	127.5	210.9	0
298	28	36	33.0	139.9	122.8	1
299	24	25	20.6	99.5	107.8	0
300	29	37	25.2	112.9	165.9	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
29.45		32.05		514.4 2015.4 2975.4		4

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
41	29	29	19.9	65.1		0
42	24	28	18.4	21.0		0
43	24	24	17.0	95.5		0
44	24	25	15.9	52.3		0
45	17	20	10.6	31.0		0
46	36	36	24.8	59.0		0
47	24	26	16.1	109.9		0
48	27	30	22.0	62.5		0
49	21	21	12.7	31.4		0
50	20	23	14.1	29.9		1
51	33	33	25.0	60.0		0
52	29	32	22.4	44.7		0
53	26	26	15.7	81.1		0
54	28	28	17.1	22.2		0
55	22	22	12.5	33.3		0
56	28	28	18.1	48.1		0
57	33	33	22.4	58.8		2
58	32	32	20.2	35.9		2
59	18	18	11.1	41.6		0
60	25	25	14.3	15.0		0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
26.00		26.95		350.3 998.3 1080.6		5

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
301	31	32	22.7	87.1	145.6	0
302	32	33	27.9	114.8	155.5	0
303	35	35	39.9	180.0	176.8	1
304	24	29	29.3	117.5	179.2	0
305	33	35	34.5	147.6	180.0	1
306	26	29	22.7	83.2	111.8	0
307	32	40	44.3	117.4	238.7	0
308	41	41	46.6	100.2	141.6	0
309	24	27	28.0	98.8	144.7	0
310	31	36	32.0	171.8	179.8	0
311	31	33	28.2	99.1	145.2	0
312	34	35	35.8	110.1	210.2	0
313	23	26	27.1	93.8	112.5	0
314	27	30	25.0	101.0	169.3	0
315	32	36	38.0	158.0	233.9	0
316	22	28	19.2	48.8	66.0	0
317	30	32	34.8	150.4	241.5	0
318	24	29	26.3	143.2	164.4	2
319	23	28	21.0	121.3	150.2	0
320	39	47	43.4	133.8	157.8	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
29.7		33.05		626.7 2377.9 3304.7		4

TABLE A-6: Emergent Seedling Study, 2-Month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
141	25	28	21.9	123.1		0
142	31	36	15.7	130.5		1
143	33	36	21.1	151.0		0
144	29	32	18.3	67.1		0
145	34	39	22.1	50.8		2
146	29	32	22.7	106.6		2
147	28	31	22.8	85.5		1
148	22	23	16.4	136.8		0
149	28	28	35.4	84.0		0
150	28	28	22.9	123.4		0
151	31	33	26.4	79.7		0
152	40	42	12.8	112.8		0
153	32	35	13.2	122.2		0
154	20	22	22.1	55.8		1
155	37	38	24.8	72.2		0
156	36	39	21.8	137.5		0
157	23	28	28.1	120.5		1
158	40	45	40.3	127.9		3
159	24	28	20.4	153.1		3
160	29	34	25.2	128.5		1
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES	
29.95		32.85	454.4	2169.0	1653.8	15

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
261	30	32	31.8	127.0	133.2	2
262	30	32	35.7	107.1	180.5	0
263	31	37	30.6	100.5	206.0	0
264	34	38	49.0	188.5	299.8	1
265	27	27	22.7	93.4	158.3	0
266	40	43	35.3	115.2	221.1	0
267	33	36	30.8	96.1	136.4	1
268	31	34	28.2	100.0	147.9	1
269	32	34	27.0	160.6	212.3	1
270	33	33	28.7	138.6	213.7	1
271	33	35	28.9	103.2	144.5	1
272	30	30	30.5	119.4	172.9	1
273	31	31	22.1	68.6	65.7	2
274	33	33	22.1	119.9	106.9	4
275	33	34	35.0	118.6	241.0	1
276	36	41	43.5	145.5	251.7	1
277	28	30	21.6	94.0	160.7	1
278	32	36	40.2	156.5	243.6	0
279	26	29	25.2	112.9	189.2	1
280	30	35	36.0	110.4	169.2	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES	
31.65		34.00	624.9	2376.0	3654.6	19

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
61	24	29	20.5	45.7		0
62	22	28	14.5	126.9		0
63	28	32	15.0	86.5		0
64	29	31	22.8	69.6		1
65	23	27	21.1	97.4		0
66	19	22	22.9	69.5		0
67	28	31	18.8	87.4		0
68	27	32	26.3	57.8		0
69	22	22	13.4	37.8		3
70	22	22	20.2	65.1		0
71	21	21	25.3	106.8		0
72	27	27	14.9	72.7		0
73	32	33	13.7	85.6		0
74	32	32	17.6	54.6		0
75	30	31	19.7	75.0		3
76	28	32	19.9	27.5		0
77	29	30	14.2	61.4		0
78	22	22	19.4	68.6		0
79	26	28	6.9	94.9		1
80	24	28	14.7	77.5		0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES	
25.75		28.00	361.8	1468.3	1314.0	8

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
241	30	30	28.2	94.5	139.8	0
242	30	30	26	91.4	155.3	0
243	28	30	24.7	63.8	94.9	0
244	30	30	26.1	109.5	147.1	0
245	23	23	20.6	59.9	119.9	0
246	25	27	21.4	86.4	147.0	2
247	31	33	28.1	161.1	186.3	3
248	30	35	31.8	165.3	188.2	1
249	26	30	25.4	105.0	151.5	0
250	31	37	33.3	160.9	241.8	0
251	24	26	23.8	102.6	204.6	1
252	24	30	29.7	107.2	107.1	0
253	31	33	28.0	137.2	157.6	0
254	30	34	27.5	128.3	152.1	2
255	40	40	30.0	75.4	57.0	0
256	22	27	23.9	73.3	105.5	0
257	20	25	21.8	110.0	132.5	1
258	30	33	24.8	135.6	194.6	1
259	37	37	34.3	160.5	236.7	1
260	33	38	36.1	161.6	207.8	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES	
28.75		31.4	545.5	2289.5	3127.3	12

TABLE A-7: Emergent Seedling Study, 3-Month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
161	28	30	20.9	186.7	130.1	6
162	28	30	21.5	192.3	176.1	1
163	25	30	18.9	113.3	115.8	2
164	32	35	29.7	135.9	171.0	1
165	30	36	29.3	149.1	147.0	0
166	25	30	19.1	153.2	116.8	2
167	33	35	30.9	190.7	168.3	3
168	32	37	35.8	202.1	170.4	1
169	24	27	20.0	99.5	186.7	0
170	32	34	34.3	189.4	94.3	3
171	27	29	20.7	144.2	143.4	1
172	26	33	25.1	253.5	208.3	3
173	25	27	19.7	79.6	113.0	0
174	30	31	20.8	134.9	130.4	1
175	26	30	24.5	97.6	91.7	0
176	22	22	14.0	91.0	115.5	0
177	27	34	22.3	94.5	85.4	0
178	23	23	13.2	118.4	106.0	1
179	30	32	23.7	139.2	116.5	0
180	28	30	23.5	188.1	192.1	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
27.65		30.75		467.9		25

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
221	29	34	29.9	139.3	200.9	1
222	30	30	30.6	128.6	192.0	1
223	24	30	26.9	95.0	151.2	1
224	22	29	22.2	131.2	148.3	0
225	26	27	22.2	144.2	155.6	0
226	24	30	30.8	110.2	99.0	1
227	22	25	12.9	35.5	29.5	0
228	28	32	32.7	84.2	146.7	1
229	25	28	22.5	69.8	125.6	1
230	26	31	25.5	75.2	108.8	0
231	24	27	22.6	88.0	92.1	0
232	20	22	13.0	68.3	64.8	0
233	24	28	24.4	76.0	119.7	0
234	26	30	27.2	135.3	204.1	1
235	25	28	30.8	142.0	161.3	1
236	23	27	21.8	119.3	135.5	1
237	25	28	16.3	46.5	82.1	0
238	32	32	25.7	79.2	144.4	0
239	28	28	26.1	122.2	132.2	0
240	38	40	34.4	114.4	142.6	1
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
26.05		29.3		498.5		10

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
81	29	33	28.0	122.7	137.3	0
82	24	26	19.9	101.0	123.4	0
83	22	27	16.6	95.6	92.5	1
84	25	31	20.2	111.6	110.5	0
85	34	41	33.2	180.8	154.1	0
86	31	35	31.9	120.3	146.3	1
87	20	20	10.0	38.9	45.6	0
88	27	27	27.8	11.6	24.1	0
89	27	30	23.8	118.6	104.3	1
90	27	30	15.8	94.9	109.7	0
91	35	36	33.5	107.6	122.5	0
92	23	25	13.9	134.5	131.8	0
93	27	28	27.8	159.2	138.3	1
94	28	30	19.3	126.5	139.4	2
95	29	30	23.1	79.9	67.9	2
96	26	28	21.7	74.5	119.2	0
97	29	31	24.4	145.5	151.5	0
98	20	20	14.2	82.1	109.9	1
99	29	29	11.2	70.0	31.2	0
100	17	20	9.6	68.7	68.2	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
26.45		28.85		425.9		9

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
201	25	26	13.4	25.7	30.5	0
202	30	32	29.2	90.5	130.5	0
203	23	23	20.5	84.5	100.6	1
204	27	28	32.3	146.8	171.3	2
205	28	28	26.1	60.2	111.5	0
206	24	27	26.8	189.1	146.4	1
207	25	27	25.4	85.8	151.8	0
208	22	25	21.4	119.9	150.8	1
209	23	26	31.5	86.2	144.6	0
210	27	31	32.8	128.0	165.3	1
211	25	29	23.4	121.1	155.9	0
212	27	32	29.4	134.2	179.5	0
213	26	30	23.5	69.9	83.7	0
214	23	25	22.5	107.0	135.6	0
215	28	33	29.4	81.9	100.3	0
216	24	25	25.5	103.3	168.9	1
217	30	36	33.3	139.8	201.1	0
218	25	30	27.8	106.3	127.8	0
219	22	28	24.5	73.8	159.2	0
220	30	30	24.9	107.8	57.7	0
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES		
25.7		28.55		523.6		7

TABLE A-8: Emergent Seedling Study, 4-Month Exposure Data

CONTROL						
TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
181	18	24	17.3	138.6	112.9	3
182	29	31	32.4	158.4	217.6	0
183	22	24	12.9	115.9	150.8	1
184	22	24	20.5	123.8	163.2	1
185	27	27	27.7	185.0	170.4	4
186	20	23	21.2	31.7	16.9	0
187	30	38	34.7	255.0	236.7	2
188	17	23	21.1	114.5	127.4	0
189	25	27	25.0	118.8	115.0	1
190	28	30	33.7	98.2	201.1	0
191	24	24	20.4	119.0	154.7	1
192	22	22	20.5	85.4	220.3	2
193	25	26	24.3	95.0	155.7	0
194	29	32	22.0	138.6	119.3	0
195	22	24	22.2	102.8	174.1	3
196	25	33	23.2	154.4	124.7	1
197	30	30	29.5	178.5	146.9	1
198	28	28	25.6	207.2	181.0	1
199	27	34	23.7	97.8	240.2	0
200	25	25	15.3	117.3	105.6	0
AVG. STEM L. (mm)			TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES
24.75 27.45			473.2 2635.9 3134.5			21

EXPERIMENTAL						
TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	
101	25	33	27.5	233.7	256.5	1
102	28	30	32.1	145.0	225.6	0
103	24	29	25.7	146.5	210.0	1
104	35	39	36.0	210.6	184.7	2
105	21	23	0.0	84.8	36.5	0
106	23	27	21.7	132.8	162.4	1
107	39	44	51.7	170.1	269.9	2
108	33	33	23.9	133.1	154.3	0
109	24	27	30.0	199.0	190.5	2
110	28	34	31.7	258.9	241.0	2
111	30	35	26.8	126.3	142.9	1
112	25	27	23.1	70.5	114.3	0
113	30	35	28.9	134.6	206.1	0
114	27	30	22.2	119.7	154.1	0
115	27	29	27.5	127.1	151.8	0
116	27	30	22.3	123.5	172.2	0
117	24	27	19.3	77.5	109.1	0
118	43	43	43.8	114.3	113.0	4
119	28	34	38.0	106.4	148.9	0
120	25	29	24.5	155.2	148.6	2
AVG. STEM L. (mm)			TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES
28.3 31.9			556.7 2869.6 3392.4			18

TABLE A-9: Chronic Fumigation Study, Unexposed Controls, Pre-Fumigation Harvest

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	STEMS	NEEDLES	ROOTS		
581	100	203.3	466.1	414.5		4
582	111	279.3	701.0	297.6		6
583	112	180.9	433.2	212.1		1
584	90	218.4	572.3	549.0		4
585	70	117.0	396.5	705.3		0
586	80	144.1	324.7	708.3		2
587	90	259.5	983.4	432.0		5
588	113	167.4	531.7	1013.5		2
589	75	134.2	533.3	425.5		3
590	95	196.6	566.0	349.1		2
591	85	186.1	686.4	349.6		2
592	80	159.0	549.9	195.6		0
593	90	169.5	440.2	380.3		1
594	100	177.1	568.7	445.6		3
595	75	150.1	450.5	698.9		3
596	83	212.3	520.0	557.1		1
597	80	113.2	376.3	366.4		0
598	65	160.4	464.0	467.2		2
599	80	150.7	562.1	308.4		7
600	102	141.1	468.8	573.3		3

AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (grams)			TOTAL # BRANCHES	
88.8 0		3520.2	10595.1	9449.3	51	

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES
	INITIAL	STEMS	NEEDLES	ROOTS		
561	105	319.6	730.5	1067.9		5
562	73	114.9	434.2	463.1		0
563	90	213.5	724.5	386.5		3
564	100	171.8	554.3	489.6		3
565	87	115.3	368.0	667.3		0
566	90	168.5	762.9	738.6		5
567	102	128.7	487.9	236.2		4
568	65	95.8	254.1	420.4		0
569	85	122.1	425.8	497.2		0
570	80	109.8	413.0	789.0		4
571	78	142.4	525.2	674.9		1
572	90	151.2	488.0	447.1		3
573	90	181.5	499.2	460.0		4
574	105	124.5	369.7	680.9		3
575	90	242.1	428.7	429.1		2
576	115	276.0	639.0	920.5		2
577	78	144.4	547.6	450.5		2
578	112	233.3	576.4	577.6		3
579	90	187.7	536.9	594.2		4
580	75	144.2	542.0	563.2		3

AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES	
90 0		11553.8	10307.9	11553.8	51	

TABLE A-10: Chronic Fumigation Study, 1-month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)	NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES
321	130	130	194.0	880.5
322	100	104	166.9	709.6
323	120	130	232.1	605.0
324	115	120	175.9	491.6
325	104	104	153.1	405.9
326	105	110	180.5	625.9
327	76	82	136.7	589.7
328	100	105	195.2	859.0
329	131	132	282.5	712.7
330	103	112	229.2	856.2
331	97	104	187.4	703.0
332	102	105	241.5	673.2
333	101	106	203.1	738.5
334	102	110	201.7	778.8
335	95	103	187.4	654.4
336	90	104	178.7	755.3
337	101	113	169.0	472.0
338	122	124	186.1	631.6
339	116	122	250.5	730.1
340	100	110	221.4	687.1
AVG. STEM L. (mm)				
105.5 111.5 3972.9 13560.1 13001.3 40 101				

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)	NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES
601	120	130	391.2	690.9
602	120	132	299.3	793.0
603	100	116	221.1	358.3
604	115	128	407.3	1213.2
605	120	123	336.4	794.7
606	105	120	385.1	822.5
607	110	105	228.4	761.5
608	82	84	229.9	860.3
609	124	124	274.7	698.1
610	110	118	293.8	999.6
611	115	117	301.7	833.5
612	130	140	405.1	789.9
613	100	103	234.8	600.0
614	100	118	339.1	865.5
615	130	141	274.9	747.6
616	120	130	361.8	854.4
617	120	128	294.5	778.8
618	97	105	217.4	501.1
619	120	129	266.5	643.1
620	112	120	343.9	827.6
AVG. STEM L. (mm)				
112.5 120.55 6106.9 15433.6 13403.2 105 136				

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)	NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES
401	100	100	299.5	932.9
402	100	108	149.1	699.5
403	103	105	138.6	580.3
404	95	95	172.0	798.2
405	102	105	187.6	796.6
406	90	92	146.4	627.0
407	92	100	163.7	704.7
408	89	91	157.0	483.9
409	120	123	191.0	519.1
410	99	101	231.9	743.1
411	70	80	123.8	514.9
412	90	95	142.4	490.1
413	96	100	177.5	908.4
414	105	115	157.6	560.3
415	101	111	199.1	558.5
416	92	103	179.0	686.7
417	106	111	284.0	663.6
418	80	90	160.2	476.1
419	100	100	187.3	630.8
420	82	85	106.1	659.2
AVG. STEM L. (mm)				
95.6 100.5 3553.8 13033.9 10762.4 52 81				

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)	NO. OF BRANCHES
	INITIAL	POST-EXP.	STEMS	NEEDLES
621	103	105	251.4	631.3
622	80	91	155.3	396.6
623	90	103	252.0	748.8
624	100	115	320.4	1176.6
625	102	110	359.0	1137.7
626	75	83	169.5	548.0
627	95	103	290.5	1106.2
628	95	104	229.8	662.1
629	105	128	285.5	677.5
630	115	115	225.8	664.7
631	100	112	278.9	820.2
632	130	140	396.9	1168.4
633	115	130	256.0	652.9
634	90	97	269.6	967.9
635	115	119	387.6	1015.5
636	120	143	356.9	1185.4
637	120	125	352.7	1104.6
638	100	109	316.9	857.9
639	112	122	283.0	875.5
640	110	115	301.3	863.7
AVG. STEM L. (mm)				
103.6 113.45 5739.0 17261.5 15255.8 92 131				

TABLE A-11: Chronic Fumigation Study, 2-month Exposure Data

CONTROL

		STEM LENGTH (mm)		DRY WEIGHTS (mg)		NO. OF BRANCHES	
TREE NO.	INITIAL POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL POST-EXP.		
341	112	115	218.6	845.5	697.5	0	4
342	110	113	213.4	560.3	606.6	1	3
343	78	82	190.9	719.8	599.8	3	4
344	98	108	234.7	735.0	617.7	3	6
345	119	124	246.5	603.1	400.4	3	3
346	110	110	198.9	531.4	670.5	0	3
347	107	107	200.8	455.4	304.4	3	5
348	86	90	153.4	499.8	350.7	4	10
349	125	125	243.3	1001.4	847.4	5	6
350	82	90	184.3	820.1	801.9	4	4
351	118	121	256.4	1066.0	689.8	4	8
352	98	98	163.7	613.2	554.6	1	1
353	117	120	307.5	957.8	712.7	3	6
354	83	90	153.8	688.8	813.1	2	6
355	95	95	135.1	784.7	586.3	2	7
356	88	90	143.0	777.8	803.2	2	6
357	117	117	222.6	610.6	612.2	3	5
358	87	93	143.7	890.3	458.7	5	6
359	117	117	249.0	524.7	492.8	0	0
360	110	114	167.9	724.4	642.7	4	6
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES			
102.85		4027.5		12263.0		52.0	
105.95		14410.1		12263.0		99.0	

		STEM LENGTH (mm)		DRY WEIGHTS (mg)		NO. OF BRANCHES	
TREE NO.	INITIAL POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL POST-EXP.		
521	90	96	344.2	1212.5	956.5	4	8
522	85	95	200.4	732.8	733.7	1	2
523	90	112	284.7	808.7	896.2	4	5
524	98	115	271.1	769.5	726.6	5	6
525	90	127	334.6	1033.6	734.9	2	6
526	85	108	212.6	708.0	574.3	1	4
527	115	128	185.5	403.2	376.0	0	4
528	95	116	295.7	580.6	629.5	2	5
529	80	75	139.6	440.6	347.0	0	1
530	100	117	213.7	710.3	734.4	1	4
531	90	113	303.3	785.2	1130.0	4	5
532	95	128	298.8	717.6	772.8	2	4
533	116	136	373.5	1084.9	694.0	5	17
534	102	125	283.6	777.9	539.2	2	9
535	76	106	286.4	854.6	892.9	0	12
536	75	95	263.7	940.0	855.9	4	13
537	110	124	313.2	753.8	731.8	2	5
538	108	115	354.1	973.8	1151.7	3	5
539	78	102	182.6	637.2	343.3	3	4
540	90	118	227.7	527.2	400.3	2	4
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES			
93.4		5369.0		15452.0		47	
112.55		14221.0		123			

EXPERIMENTAL

		STEM LENGTH (mm)		DRY WEIGHTS (mg)		NO. OF BRANCHES	
TREE NO.	INITIAL POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL POST-EXP.		
421	115	115	278.2	925.2	731.3	2	7
422	91	95	158.5	730.6	405.1	4	4
423	120	120	228.4	1090.9	640.9	1	5
424	80	80	94.9	574.6	263.6	0	2
425	105	107	217.6	569.4	544.3	4	5
426	70	70	140.7	434.4	418.1	2	4
427	95	95	176.7	680.7	459.0	3	6
428	95	102	233.0	995.8	655.2	1	7
429	71	85	84.8	555.5	332.6	1	4
430	82	92	159.4	717.6	541.5	0	1
431	80	85	230.1	1009.5	651.4	3	7
432	70	70	88.6	751.1	444.3	2	6
433	90	90	173.6	660.2	640.8	2	7
434	122	126	37.5	672.8	455.6	2	5
435	77	80	116.0	708.4	494.1	1	3
436	95	95	133.3	491.2	368.4	0	2
437	106	120	232.7	848.9	513.8	1	5
438	89	89	157.8	1179.2	610.5	2	6
439	81	81	165.4	702.5	507.9	1	6
440	88	92	147.7	491.5	520.8	3	4
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES			
91.1		3254.9		14790.0		35	
94.45		10199.2		96			

		STEM LENGTH (mm)		DRY WEIGHTS (mg)		NO. OF BRANCHES	
TREE NO.	INITIAL POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL POST-EXP.		
541	91	125	323.4	761.1	682.9	0	2
542	96	129	280.1	950.3	737.9	4	9
543	112	144	385.4	986.3	946.2	3	8
544	90	112	225.6	614.8	484.3	3	5
545	81	110	256.1	798.9	731.1	3	11
546	80	105	236.2	750.8	628.0	2	4
547	95	127	293.9	689.5	434.3	1	3
548	85	110	211.3	644.9	454.3	6	7
549	85	98	278.6	800.1	613.6	3	3
550	89	107	303.6	758.2	520.6	3	5
551	78	95	219.3	715.6	418.8	4	4
552	111	128	394.5	849.3	677.1	2	2
553	89	107	272.2	775.1	564.0	3	4
554	95	115	295.1	641.5	850.4	3	8
555	95	118	315.3	865.7	1003.6	4	10
556	75	98	260.0	1057.4	841.7	5	7
557	108	133	311.9	977.5	725.5	2	4
558	94	95	213.4	508.9	344.8	0	4
559	100	125	304.7	780.9	734.1	1	2
560	108	110	289.0	724.0	725.7	2	5
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)		TOTAL # BRANCHES			
92.85		5669.6		15650.8		54	
114.55		13118.9		107			

TABLE A-12: Chronic Fumigation Study, 3-month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
381	95	123	234.1	771.5	464.0	2	5
382	75	82	182.7	887.9	589.7	3	8
383	100	112	230.8	1094.1	790.7	3	7
384	100	110	247.0	844.5	878.4	0	8
385	81	86	228.1	640.6	409.0	3	5
386	80	105	241.7	975.0	679.3	3	9
387	92	96	231.5	643.2	516.3	3	4
388	95	109	228.6	718.6	726.1	2	5
389	72	81	138.8	561.8	681.4	1	3
390	106	109	329.9	1016.1	908.4	2	3
391	115	117	275.9	816.5	740.2	1	7
392	120	125	274.0	586.5	747.0	0	8
393	102	114	292.2	972.2	933.4	4	8
394	100	100	184.2	730.1	677.7	2	2
395	70	69	143.3	555.3	657.8	0	4
396	112	120	220.1	738.6	724.7	3	5
397	105	107	246.2	758.2	645.3	4	5
398	126	129	254.7	496.0	729.3	3	8
399	121	125	240.2	487.2	449.5	2	6
400	81	87	191.1	822.0	615.2	2	3
<hr/>							
AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
97.4 105.3		4615.1 15115.9 13563.4			43 113		

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
501	87	97	217.6	819.9	765.6	1	5
502	85	105	225.6	917.7	761.3	0	3
503	96	100	126.5	606.3	583.3	3	4
504	125	130	274.0	891.1	653.0	4	6
505	100	108	197.9	606.1	459.2	1	6
506	90	92	136.0	521.6	463.9	6	6
507	120	125	252.8	689.7	819.3	1	2
508	100	105	219.5	514.3	473.7	5	6
509	120	120	208.2	687.2	654.4	5	7
510	90	90	190.1	506.3	770.9	2	6
511	105	105	212.9	596.7	818.9	0	3
512	105	105	212.7	750.1	840.1	3	3
513	145	150	274.9	824.5	578.4	1	3
514	90	95	188.3	631.5	566.0	1	4
515	118	125	230.4	746.2	848.5	2	5
516	105	105	201.6	658.7	501.1	3	5
517	72	72	116.2	443.8	436.6	3	3
518	98	98	204.9	628.4	850.2	2	4
519	78	80	154.0	824.3	764.5	4	6
520	85	95	136.0	425.3	336.0	1	4
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AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
100.7 105.1		3980.1 13289.7 12944.9			48 91		

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
441	75	80	209.1	741.6	765.9	4	6
442	119	119	279.7	961.1	999.8	2	2
443	99	120	179.4	692.7	423.9	1	3
444	102	120	183.7	758.0	526.1	1	2
445	90	95	146.6	743.9	547.4	0	3
446	88	90	159.6	849.1	890.9	3	6
447	75	82	126.4	785.8	730.4	2	5
448	90	90	119.0	374.0	237.5	2	2
449	103	110	232.4	919.1	728.5	2	4
450	80	95	195.0	693.7	627.8	3	5
451	80	95	170.2	657.8	759.2	1	4
452	72	72	123.2	737.1	696.6	2	4
453	91	95	164.2	846.4	655.6	2	5
454	80	80	144.0	923.9	700.6	4	7
455	85	85	164.8	809.0	797.8	1	5
456	83	90	176.2	938.3	676.0	2	6
457	87	95	165.7	838.0	743.2	1	4
458	77	90	103.2	571.2	471.3	1	1
459	87	92	179.5	824.5	651.3	1	8
460	90	95	173.0	664.8	676.7	3	3
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AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
87.65 94.5		3394.9 15330.0 13306.5			38 85		

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
481	100	114	257.7	640.1	669.8	1	7
482	122	133	386.6	978.9	609.6	1	5
483	97	109	245.7	815.8	543.7	4	7
484	105	117	278.7	750.2	853.1	2	7
485	95	121	283.8	883.7	786.0	5	6
486	100	115	275.5	600.8	652.2	1	6
487	80	111	328.6	793.4	918.8	0	6
488	72	98	202.1	680.5	505.7	0	8
489	85	101	180.8	614.8	495.3	3	5
490	80	98	206.5	581.7	506.4	2	5
491	70	93	220.5	566.2	366.2	0	4
492	90	114	258.8	566.8	539.9	1	4
493	92	105	360.7	1132.0	1075.0	3	7
494	71	95	204.3	729.3	528.7	2	4
495	75	95	283.5	690.4	894.1	3	5
496	78	98	235.6	654.1	563.7	2	3
497	80	92	205.4	505.1	619.6	4	7
498	95	111	257.5	761.8	725.1	2	4
499	85	107	244.9	884.2	781.0	0	5
500	100	117	343.6	800.7	762.1	4	6
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AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
88.6 107.2		5260.8 14630.5 13396.0			40 111		

TABLE A-13: Chronic Fumigation Study, 4-month Exposure Data

CONTROL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
361	70	87	185.4	871.4	661.6	2	13
362	90	105	212.0	610.9	609.6	0	4
363	116	125	303.9	841.7	658.5	4	10
364	120	141	193.2	681.8	591.7	0	3
365	86	100	191.3	619.4	673.2	2	6
366	100	115	204.3	702.5	606.1	1	2
367	114	133	238.6	655.1	610.0	0	3
368	108	138	259.2	817.7	550.3	5	6
369	100	104	307.8	1000.4	782.3	3	5
370	90	115	299.2	779.7	774.3	1	5
371	92	112	283.7	910.1	751.6	3	7
372	95	110	276.2	961.4	596.9	2	7
373	95	120	302.6	910.3	681.8	4	4
374	90	96	257.2	785.2	662.3	1	9
375	102	110	306.5	1188.8	767.0	3	4
376	91	97	286.5	757.7	977.2	3	5
377	95	100	285.5	929.2	747.1	2	6
378	85	98	290.0	926.1	965.5	3	6
379	82	93	269.7	792.5	714.8	1	5
380	120	134	269.0	838.5	830.5	0	5

AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
97.05 111.65		5221.8 16580.4 14212.3			40 115		

EXPERIMENTAL

TREE NO.	STEM LENGTH (mm)		DRY WEIGHTS (mg)			NO. OF BRANCHES	
	INITIAL	POST-EXP.	STEMS	NEEDLES	ROOTS	INITIAL	POST-EXP.
461	85	119	349.9	1066.3	682.8	1	8
462	93	114	237.3	714.5	746.2	1	2
463	90	95	251.9	744.9	847.0	1	4
464	105	112	281.7	815.3	860.4	1	6
465	75	86	139.7	427.9	334.5	1	5
466	97	105	269.3	976.7	710.6	3	7
467	80	98	201.7	568.7	516.8	2	4
468	110	115	256.2	798.5	724.1	1	7
469	83	109	275.1	900.2	799.1	2	4
470	97	117	313.4	802.2	714.4	1	3
471	80	92	194.4	887.3	582.2	2	4
472	93	100	175.5	777.2	671.3	3	8
473	83	100	196.5	849.2	500.4	3	7
474	70	93	251.7	860.3	814.2	1	5
475	93	105	339.3	1006.9	1001.0	0	6
476	84	90	166.2	760.8	615.8	3	6
477	94	105	263.1	623.8	756.7	4	5
478	70	83	206.0	720.0	686.1	4	7
479	93	117	272.5	999.1	738.6	4	6
480	106	109	124.5	363.5	321.7	0	6

AVG. STEM L. (mm)		TOTAL DRY WEIGHTS (mg)			TOTAL # BRANCHES		
89.05 103.2		4765.9 15663.3 13623.9			38 110		

TABLE A-14: Chronic Fumigation Study, Sulfur Data

CONTROL			0.2 PPM SO ₂		
RESULT	UNCERTAINTY	UNITS	RESULT	UNCERTAINTY	UNITS
1 MONTH EXPOSURE			1 MONTH EXPOSURE		
1940.0000	100.0000	UG/G	2010.0000	100.0000	UG/G
1690.0000	80.0000	UG/G	2150.0000	100.0000	UG/G
2400.0000	120.0000	UG/G	2010.0000	100.0000	UG/G
1610.0000	80.0000	UG/G	2610.0000	130.0000	UG/G
1720.0000	80.0000	UG/G	1810.0000	90.0000	UG/G
1660.0000	80.0000	UG/G	2410.0000	120.0000	UG/G
2140.0000	100.0000	UG/G	2410.0000	120.0000	UG/G
1820.0000	90.0000	UG/G	2560.0000	130.0000	UG/G
1810.0000	90.0000	UG/G	1930.0000	100.0000	UG/G
2020.0000	100.0000	UG/G	2360.0000	120.0000	UG/G
2 MONTH EXPOSURE			2 MONTH EXPOSURE		
1620.0000	80.0000	UG/G	2130.0000	100.0000	UG/G
1490.0000	80.0000	UG/G	2200.0000	110.0000	UG/G
1600.0000	80.0000	UG/G	2260.0000	120.0000	UG/G
1450.0000	80.0000	UG/G	1500.0000	80.0000	UG/G
1550.0000	80.0000	UG/G	2520.0000	130.0000	UG/G
1700.0000	80.0000	UG/G	2270.0000	120.0000	UG/G
1980.0000	100.0000	UG/G	1900.0000	100.0000	UG/G
1510.0000	80.0000	UG/G	2180.0000	110.0000	UG/G
1600.0000	70.0000	UG/G	2390.0000	150.0000	UG/G
1560.0000	70.0000	UG/G	1810.0000	90.0000	UG/G
3 MONTH EXPOSURE			3 MONTH EXPOSURE		
1320.0000	60.0000	UG/G	2060.0000	100.0000	UG/G
1250.0000	60.0000	UG/G	2320.0000	120.0000	UG/G
1370.0000	60.0000	UG/G	3020.0000	150.0000	UG/G
1290.0000	70.0000	UG/G	2660.0000	130.0000	UG/G
1190.0000	60.0000	UG/G	2710.0000	130.0000	UG/G
1420.0000	70.0000	UG/G	2750.0000	130.0000	UG/G
1940.0000	100.0000	UG/G	2980.0000	150.0000	UG/G
1920.0000	90.0000	UG/G	3190.0000	160.0000	UG/G
1650.0000	70.0000	UG/G	2690.0000	130.0000	UG/G
1910.0000	100.0000	UG/G	2770.0000	140.0000	UG/G
4 MONTH EXPOSURE			4 MONTH EXPOSURE		
1910.0000	100.0000	UG/G	2690.0000	130.0000	UG/G
1780.0000	90.0000	UG/G	2740.0000	130.0000	UG/G
1600.0000	80.0000	UG/G	2640.0000	130.0000	UG/G
2000.0000	100.0000	UG/G	2830.0000	140.0000	UG/G
1420.0000	70.0000	UG/G	2900.0000	140.0000	UG/G
1660.0000	80.0000	UG/G	2350.0000	120.0000	UG/G
1500.0000	70.0000	UG/G	2690.0000	130.0000	UG/G
1310.0000	70.0000	UG/G	3210.0000	160.0000	UG/G
1680.0000	80.0000	UG/G	2770.0000	140.0000	UG/G
2300.0000	120.0000	UG/G	3000.0000	150.0000	UG/G

END

DATE
FILMED
10 / 7 / 93