PARAQUAT AND CEPA STIMULATION OF OLEORESIN PRODUCTION IN LODGEPOLE PINE CENTRAL STUMP-ROOT SYSTEM[1]

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ABSTRACT

Lodgepole pines (*Pinus contorta* Dougl.) between 11.4 and 14.0 cm DBH at 2 locations in western Montana were treated with paraquat or 2-chloroethylphosphonic acid (CEPA) to induce oleoresin soaking. Chemicals were applied by pouring into a hole drilled in the stump/taproot or by pouring a CEPA solution on the soil around the trees. After 15 months, the trees were harvested, divided into two root and four stem sections up to 1.4 m above ground, and analyzed for density (g/cc) and for rosin acids, turpentine, and moisture content. No differences in density were found due to CEPA and paraquat treatments.

The proportions of rosin acid and turpentine in the wood were always greater in roots than in stems of control trees. Paraquat treatment caused increases in oleoresin in all but the lower root section. Paraquat treatment increased rosin acid content by 70% and turpentine content by 64% on a moisture free basis in the first 30-cm stem section.

When CEPA was poured on the ground, the maximum rosin acid and turpentine increases, of 88 and 43% respectively, were found in the top three stem sections, but rosin acid and turpentine contents decreased by up to 38 and 42% respectively, in the lowest root section. When CEPA was introduced directly into the tree, it was apparently transported bidirectionally causing increases in oleoresin in the lowest root section and upper stem sections but decreases in the center sections (first root and stem sections).

Operationally, stump (stem up to 1.4 m)/root treatments with paraquat will increase oleoresin in both the root and stem. CEPA treatment by pouring CEPA on the ground would be the simplest treatment, but oleoresin would increase only in the stem. CEPA introduced by bore hole treatment would result in no net increase in oleoresin in the stem alone, root alone or stem plus root combined.

Keywords: Turpentine, rosin acids, resin acids, fatty acids, ethylene.

INTRODUCTION

Lodgepole pine is one of the most widely distributed commercial timber species in North America, but it has historically been underutilized across most of its

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

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range because the lodgepole pine resource is distant from urban markets. Products that can command a high price per ton are needed to offset high shipping costs. Tall oil precursors (resin acids plus fatty acids, together called rosin acids, and unsaponifiables) and turpentine that make up oleoresin are two such products that can be obtained in the kraft sulfate pulping process. The quantity of oleoresin within trees can be increased by treating trees with paraquat and/or CEPA (2-chloroethylphosophonic acid). Preliminary tests (Rowe et al. 1976; Sandberg et al. 1977) have indicated that oleoresin soaking occurs in stems of lodgepole pine treated with paraquat. In the tests of Rowe et al. (1976), a 1% or 5% aqueous paraquat solution containing 0.1% Tween-20 was placed in 10-cm-wide ax frills on four lodgepole pines. Diameter growth was diminished for 100 to 690 cm above the wound. In the area from 0.5 m below to 1 m above the treatment site, tall oil and turpentine contents on the treated sides of trees increased 3.9-and 15.9-fold in comparison with control wood on the opposite side from the affected area. In a much more detailed study (Conner et al. 1980), increases in oleoresin in lodgepole pine after treatment with 5 ml of 5% paraquat in a 7-cm ax frill 1 m above ground was determined. Nonvolatile diethyl-ether extractives (NVEE) in the treated area contained 103 mg/g resin acids and 10 mg/g fatty acids (oven-dry extractives free wood basis) compared to 2 mg/g and 14 mg/g, respectively, for control sapwood.

Data are available for yields of stump-root treatment for increasing oleoresin yield from two studies. Brown and Pienaar (1982) imposed two treatments on slash pines (*Pinus elliottii* Engelm.): (1) a 1.3-× 30.5-cm radially bored hole at the root collar was filled with 30 ml of 0.5% paraquat formulated in 2.5% sodium carboxymethyl cellulose (150 mg paraquat per tree) and (2) two ½ in. × 12 in. tangentially bored holes at the root collar each receiving about 30 ml of 0.25% paraquat in the same formulation (150 mg paraquat per tree). After 2 years, the 1- and 2-hole treatments increased oleoresin yield 2.8- and 4.3-fold, respectively. The higher yield from the two holes was due to intersection of more rays in the tangential direction. In the second study on slash pine, Stubbs et al. (1983) drilled two parallel, downward sloping holes into the taproot and applied paraquat in concentrations ranging from 0.05 to 0.5%. A 4.8-fold increase in resin acids was reported for the 0.5% paraquat concentration. Increases in resin acids at high levels of paraquat begin to decline at 0.3% paraquat, decreasing from around 19% (of wood dry weight) to 15% at 0.5% paraquat.

The objectives of the experiment described here were to compare oleoresin content of the central stump-root system of small lodgepole pine trees under four conditions:

1. Untreated controls
2. Paraquat (1,1'-dimethyl-4,4'dipyridilium dichloride) injected into but not through the root collar in bore holes
3. CEPA (2-chloroethylposphonic acid) injected into but not through the root collar in bore holes
4. CEPA applied to the soil close to the stump.

METHODS

Twelve lodgepole pines between 11.4 and 14 cm DBH were identified near Seeley Lake (SL) and 12 more near Lost Trail Pass (LTP) in western Montana.

TABLE 1. *Average dimensions of lodgepole pine treated with 2-chloroethylphosphonic acid (CEPA) and paraquat at Seeley Lake and Lost Trail Pass.*

		DBH	Height	Root length	Crown length	Crown width	Weight of root + stem to 1.4 m height	Weight of stem, 1.4 m ht. to 5.1 cm top diameter outside bark
	n	*cm*	*m*	*cm*	*m*	*m*	*kg*	*kg*
Seeley Lake								
Control	3	12.2	12.2	69.4	6.3	2.2	32.9	56.8
CEPA-ground	3	12.4	12.2	52.5	5.4	1.7	32.2	59.3
CEPA-drill	3	12.8	12.5	56.7	4.4	1.8	31.2	63.8
Paraquat drill	3	12.6	11.8	59.3	5.6	1.8	31.7	59.2
Average	12	12.5	12.2	59.5	5.4	1.9	32.5	59.8
Lost Trail Pass								
Control	3	12.3	11.1	72.8	5.6	1.8	28.4	51.1
CEPA-ground	3	12.9	8.9	54.2	6.2	1.6	29.1	38.2
CEPA-drill	3	13.3	12.2	50.8	5.9	1.7	25.7	60.1
Paraquat drill	3	12.5	11.3	61.0	7.7	2.2	27.3	44.7
Average	12	12.7	10.9	59.7	6.4	1.8	27.6	48.5

The SL site is at 47.2° latitude, 113.5° longitude, and 1,349 m elevation; soil is sandy clay loam. The LTP site is at 45.6° latitude, 113.9° longitude, and 2,225 m elevation; soil is sandy and contains small rocks. The 12 trees at SL averaged 12.5 cm DBH, 12.2 m in height. Those at LTP averaged 12.7 cm DBH and 10.9 m in height (Table 1).

The experimental design was a split plot, 4 × 6 factorial with treatments replicated three times. At each location there were three untreated control trees and three trees for each of three treatments: (1) 3.5 ml of 1.2% paraquat poured into each of two 6 mm diameter × 10 cm holes (4.2 mg paraquat per hole) drilled parallel to each other and tangentially into the tree at 45° from groundline downward into the root collar 1.5 cm from the pith of the tree. This technique, compared to other systems of applying paraquat to living tissue, was adopted by Hercules Company for increasing oleoresin in the stumps of southern pines. At a specified time after treatment, trees are harvested with stump and root attached by the method of Koch (1976). (2) 3.5 ml of 1% CEPA poured into each of two holes (3.5 mg CEPA per hole) drilled the same as for the paraquat treatment. CEPA has been shown to increase oleoresin in red pine (Wolter 1977), in the naval stores industry (McReynolds and Kossuth 1984, 1985). It is believed that the mode of action of both CEPA and paraquat is through increased levels of ethylene in living tissue (Wolter and Zinkel 1976; Kossuth 1984). (3) 4 liters of 0.1% CEPA (0.4 g per stem) poured on the ground adjacent to the stem around the complete circumference of the tree. It was expected that CEPA would degrade to ethylene in the soil, which would stress the root system resulting in oleoresin production in the roots. CEPA at pH 3.5 and above breaks down to release gaseous ethylene. By pouring a solution on the ground around the taproot, it was hoped the gas would be released and trapped around the taproot, thereby stimulating oleoresin synthesis within the taproot. The amount of CEPA to use was based on what was expected to be a physiologically stimulating but not a toxic level for lodgepole pine roots. Trees were treated on 19 June at LTP and on 24 June 1984 at SL. At those times, height growth had just begun at LTP; it was one-third to one-half complete at SL.

In southern pine, the "oleoresin soaking" response is maximized in about 18 months after treatment if applied in the spring. Trees for this work were harvested 15 months after treatment, during which two growing seasons had elapsed. Because of the high elevation, winter conditions would have prohibited harvest at a later date. Therefore, on 12 September at LTP and 14 September 1985 at SL, the trees were topped at 1.4 m and as much of the main taproot as possible was excavated. Each tree was divided into six sections: (1) 30 cm of stump-root section beginning at the bore hole or groundline (R_1), (2) the remaining excavated root (R_2), (3) the first 30 cm of stem from the bore hole or groundline (S_1), (4) the second 30 cm of stem (S_2), (5) the third 30 cm of stem (S_3), and (6) the remaining top stem section (Top).

For each stem section, the diameter inside the bark at both ends and the length were measured for determining green (fresh) volume. Volume of each section was determined with the formula:

$$\pi\left(\frac{D_L + D_U}{4}\right)^2 \times L$$

where D_L and D_U are the lower and upper diameters in cm and L is the section length in cm. Root and stem sections were cut into 2.54-cm disks, debarked, weighed, and ground to pass a 6-mm screen. About 1,000 g were frozen for laboratory analysis. Density of the stem section (g/cc) was determined by dividing the weight of wood (using fresh, oven-dry or moisture-free weight) by the green volume of the section. Oven-dry weight was determined by weighing 50 g of green wood chips, drying them in a forced air dryer at 100 C for 25 hours and reweighing them. The oven-dry weight does not include moisture or turpentine, which are volatilized in the drying process.

Moisture-free weight, which includes the turpentine component, was determined through the rosin acid extraction procedure. Water from an extracted wood sample was collected in a Barret water trap and measured in ml. The moisture-free weight was the fresh weight minus only the weight of the water collected in the extraction procedure.

Rosin acid (resin acids plus fatty acids) and moisture content were determined by a modification of Shephard's (1975) method, in which free acids are extracted with xylene and titrated. Ten grams of chips were placed in a column, and 120 ml of xylene were refluxed through the chips. A Barret trap was installed to condense the water as it volatilized from the wood. After 2 hours, the xylene was titrated, and free (non-esterified) acid content was measured using 0.25% methanolic KOH. The percentage of the wood that was rosin acids was estimated as:

$$\%\ \text{rosin acids} = \frac{\text{ml KOH} \times 7.56}{\text{g Wood (fresh, oven-dry or moisture free)}} \times 100$$

Turpentine content was determined by a modified procedure (Kossuth and Munson 1981) of the Pulp Chemicals Association (Drew et al. 1971). An internal standard of 250 μl n-tetradecane was added to each 50 g sample of wood chips, which were digested in 0.5N NaOH and refluxed for 90 min. Turpentine was measured in an oil receiving trap attached to the flask where the wood chips were digested. The percentage of the wood that was turpentine was estimated as:

$$\%\ \text{turpentine} = \frac{\text{ml turpentine} \times 0.8533}{\text{g wood (fresh, oven-dry or moisture free)}} \times 100$$

Results are presented on a fresh weight (FW), oven-dry weight (ODW), and moisture-free (MF) basis for comparison with other published studies in which results are reported on one of these bases. In the text rosin acid and turpentine contents are discussed primarily on an MF basis and comparisons are made with values in control trees. Data were subjected to ANOVA and Duncan's Multiple Range Test.

RESULTS

Density and moisture content [percent of fresh (green) weight]

Averaged across all treatments and the control, the density on an FW, ODW, and MF basis did not differ among the stem sections (S_1, S_2, S_3, and Top); neither was density for each stem section separately and on a whole stem-root basis affected by treatment. On a whole stem-root basis, however, trees at Lost Trail Pass were significantly less dense that those at Seeley Lake (Table 2).

For both locations combined, moisture content was similar in the R_1, S_1, S_2, and S_3 sections, slightly lower in the Top section, and significantly lower in the R_2 section than in the center sections of the tree. Treatments did not significantly alter moisture content of all root and stem sections combined. At Seeley Lake moisture was low, 37 and 39% in trees around which CEPA was poured on the ground in the S_2 and Top sections, respectively. The low values did not differ statistically from control trees.

Rosin acids

For all trees combined, rosin acid content was significantly greater in the first 30 cm of root than in the rest of the tree (Table 3). Rosin acid content was next greatest in the R_2 and S_1 tree sections and least in the upper three sections of the stem (Table 3).

Paraquat treatment increased rosin acid content of S_1 sections by 70% (Table 3). Paraquat increased rosin acid content by 19 to 61% in the other sections, except the lower root, where a 6% decline was associated with paraquat application.

CEPA application in drilled holes increased rosin acid content by 34% in the R_2 root section and by 38% in the S_3 section. In the R_1 and S_1 sections, CEPA treatment decreased rosin acid content by 21 and 23%, respectively, on an MF basis.

Pouring CEPA on the ground caused decreases in rosin acid content of 38% in the R_2 section and 23% in the R_1 section. It caused no change in the S_1 section and caused an increase in rosin acid content of 24% in the S_2 section, 88% in the S_3 section, and 29% in the Top.

Summed over roots alone, or stem sections alone, paraquat increased rosin acid content the most. However, the greatest rosin acid increases and decreases in

TABLE 2. *Density (grams/cc of green volume) of wood of control and treated trees by Section[a] on a fresh weight (FW), oven-dry weight (DW) and moisture free (MF) basis.*

	Lost Trail Pass			Seeley Lake		
	FW	DW	MF	FW	DW	MF
Control[b]						
S_1	0.90	0.52	0.53	0.91	0.48	0.48
S_2	0.90	0.52	0.53	0.88	0.49	0.50
S_3	0.90	0.51	0.52	0.86	0.48	0.49
Top	0.86	0.49	0.50	0.89	0.50	0.51
Average[c]	0.89	0.51	0.52	0.89	0.48	0.49
CEPA drill						
S_1	0.83	0.47	0.49	1.00	0.55	0.56
S_2	0.85	0.48	0.50	0.94	0.52	0.53
S_3	0.81	0.45	0.47	0.91	0.51	0.52
Top	0.83	0.46	0.48	0.87	0.50	0.52
Average	0.83	0.47	0.48	0.93	0.52	0.53
CEPA ground						
S_1	0.91	0.48	0.50	1.00	0.58	0.60
S_2	0.96	0.50	0.51	0.96	0.58	0.59
S_3	0.93	0.47	0.48	0.91	0.54	0.55
Top	0.88	0.55	0.57	0.86	0.53	0.55
Average	0.92	0.48	0.49	0.93	0.56	0.57
Paraquat						
S_1	0.79	0.46	0.48	0.90	0.51	0.52
S_2	0.86	0.50	0.51	0.95	0.54	0.56
S_3	0.89	0.50	0.52	0.92	0.52	0.54
Top	0.84	0.47	0.48	0.93	0.54	0.55
Average	0.84	0.48	0.49	0.93	0.53	0.54
Overall[d]	0.87b	0.48b	0.50b	0.92a	0.52a	0.53a

[a] S_1, S_2, S_3 = first, second and third 30 cm sections above ground line; Top = remaining top stem section; R_1 = first 30 cm root below ground line, R_2 = remaining root section.
[b] For each value n = 3 trees per treatment.
[c] For each value n = 12: 3 trees × 4 stem sections per tree.
[d] For each value n = 48: 3 trees × 4 stem sections per tree × 4 treatments. FW, DW, and MF values were significantly greater at SL than LTP at the 0.05 level.

individual sections were caused by pouring CEPA on the ground. Rosin acids increased 88% in the S_3 section and decreased 38% in the R_2 section on an MF basis (Table 3).

On a whole stem-root basis, rosin acid content was greater at LTP than at SL (Table 4). Rosin acid content there was higher in each of the four stem sections but not in either of the root sections.

Turpentine

For all trees combined, turpentine content followed a pattern similar to rosin acids, but the statistical differences were not as clear-cut (Table 5). The first 30 cm of root had the highest turpentine content, followed by the remaining root sections and the first 30 cm of stem. Upper stem sections had lower turpentine contents than root sections. Overall, turpentine content at LTP was greater than at SL, but the difference was not statistically significant.

TABLE 3. *Percent rosin acids by tree section and treatment on a fresh weight (FW), oven-dry weight (DW) and moisture free (MF) basis after treatment with CEPA or paraquat.*[a]

Tree section[b]		Control	CEPA drill	% Diff.	CEPA ground	% Diff.	Paraquat drill	% Diff.	Overall[c]
Top	FW	0.70a	0.69a	−1	0.90a	+29	0.92a	+31	0.80c
	DW	1.24a	1.23a	0	1.60a	+29	1.62a	+31	1.42c
	MF	1.21a	1.18a	−2	1.56a	+29	1.60a	+32	1.39c
S_3	FW	0.51b	0.71ab	+39	0.92a	+80	0.81ab	+59	0.74c
	DW	0.92b	1.27ab	+38	1.70a	+85	1.45ab	+58	1.33c
	MF	0.89b	1.23ab	+38	1.67a	+88	1.43ab	+61	1.31c
S_2	FW	0.82a	0.83a	+1	0.99a	+21	0.97a	+18	0.90c
	DW	1.44a	1.47a	+2	1.77a	+23	1.70a	+18	1.59c
	MF	1.41a	1.45a	+3	1.75a	+24	1.68a	+19	1.57c
S_1	FW	1.21b	0.86b	−29	1.11	−8	1.98a	+64	1.29b
	DW	2.13b	1.53b	−28	2.02b	−5	3.41a	+60	2.27b
	MF	1.95b	1.50b	−23	1.95b	0	3.31a	+70	2.18b
R_1	FW	1.86a	1.41a	−24	1.32a	−29	2.69a	+45	1.83a
	DW	3.24a	2.46a	−24	2.44a	−25	4.38a	+35	3.13a
	MF	3.14a	2.47a	−21	2.42a	−23	4.34a	+38	3.09a
R_2	FW	1.45a[d]	2.03a	+40	0.88a	−39	1.44a	−1	1.45b
	DW	2.53a	3.35a	+32	1.55a	−39	2.35a	−7	2.44b
	MF	2.50a	3.32a	+34	1.55a	−38	2.34a	−6	2.42b
Average[c]									
	FW	1.09a	1.09a	0	1.02a	−6	1.47	+35	
	DW	1.92a	1.88a	−2	1.85a	−4	2.48a	+29	
	MF	1.85a	1.86a	0	1.81a	−2	2.45a	+32	

[a] n = 6 for stem and root sections by treatment: 3 trees per each of 2 locations. n = 36 for Average; 6 stem and root sections for each of 3 trees per each of 2 locations.

[b] S_1, S_2, S_3 = first, second and third 33.3 cm sections above ground line; Top = stem section 100–137 cm above ground line; R.

Paraquat treatment increased turpentine content on an MF basis by 64, 20, 30, and 8%, respectively, in the S_1, S_2, S_3, and Top sections (Table 5). It decreased turpentine content by 15% in the R_2 section.

Applying CEPA to drilled holes decreased turpentine content by 9 and 20% in the S_1 and R_1 sections, respectively, but increased it by 24% in the R_2 section. The CEPA-drill trees showed only a 2 and 14% increase above control trees in turpentine content in the S_2 and S_3 sections, respectively.

Pouring CEPA on the ground caused declines in turpentine content of 16, 32, and 42% in the S_1, R_1, and R_2 sections, respectively. It increased turpentine contents in the S_2, S_3, and Top sections by 15, 43, and 12%, respectively.

DISCUSSION AND CONCLUSIONS

One might expect the density of treated wood with increased oleoresin content to be greater than that of untreated wood. We found no significant difference in density (Table 2), probably because the maximum oleoresin content was just under twice that of the control, totaling 5.68% of the weight of moisture-free wood. Variations among the trees in our small sample precluded declaring of statistical significance for differences that small.

Other studies with pines, including slash pine (Drew 1976), loblolly pine (*P. taeda* L.) (Holton and Winston 1976), spruce pine (*P. glabra* Walt.) (Peters and

TABLE 4. *Percent rosin acids of control and treated trees at two locations on a fresh weight (FW), oven-dry weight (DW) or moisture free (MF) basis.*

	Lost Trail Pass			Seeley Lake		
	FW	DW	MF	FW	DW	MF
Control[a]	1.41	2.41	2.31	0.78	1.42	1.39
CEPA drill	1.24	2.16	2.11	0.93	1.61	1.60
CEPA ground	1.06	1.99	1.95	0.99	1.70	1.68
Paraquat	2.04	3.36	3.31	0.90	1.61	1.58
Overall[b]	1.20a	2.46a	2.42a	0.90b	1.59b	1.56b

[a] For each value n = 18: 3 trees × 4 stem + 2 root sections per tree.
[b] For each value n = 72: 12 trees × 4 stem + 2 root sections per tree. FW, DW, and MF values were significantly greater at LTP than at SL.

Roberts 1976), ponderosa pine (*P. ponderosa* Laws.) (Rowe et al. 1976), red pine (*P. resinosa* Ait.) (Rowe et al. 1976), and lodgepole pine (Rowe et al. 1976; Conner et al. 1980) have shown that the turpentine fraction increases by several fold more than the rosin acid fraction. In our study, the increase in rosin acids tended to be greater than that of turpentine. In the studies of Rowe et al. (1976) and Conner et al. (1980), lodgepole pines received 3 to 40 times the concentrations of paraquat that we applied. In young pine tissue, resin acids apparently are synthesized before turpentine (Fahn 1970). It may be that low levels of chemical stimulation used in this study favored increases in rosin acids.

The pattern of change in rosin acids and turpentine was, as one would expect, an increase in the treatment area (R_1) and in an acropetal direction in the stem (Tables 3, 5). CEPA applied in bored holes appears to have been transported downward to the R_2 and upward to the S_3 sections before a high enough pH was reached to convert CEPA to ethylene. The evidence for this is that only in the R_2 and S_3 sections were large increases in rosin acids and turpentine found (Table 3). It has been proposed that the mode of action of paraquat in stimulating oleoresin synthesis is through stimulating the production of ethylene (Wolter and Zinkel 1976). Wolter and Zinkel (1976) observed increases in ethylene production after treatment of red pine with paraquat, and ethylene stimulates oleoresin synthesis and/or traumatic resin canal differentiation (Wolter and Zinkel 1984). The release of ethylene only after CEPA moved to these sections would explain the increase in oleoresin only in the two sections. Because of the decrease in oleoresin in the R_1 and S_1 sections, it appears that the rosin acids and turpentine were either transported per se or remetabolized into transportable energy forms and moved from the site of CEPA application to a new sink for oleoresin production.

The apparent redistribution (S_1, R_1, R_2 sections) and increase in oleoresin (S_2, S_3, Top sections) in trees around which CEPA was poured on the ground was different than for the trees treated with CEPA in the bore hole (Tables 3, 5). It appears the roots took up the CEPA, transported it acropetally, and redistributed or metabolized the oleoresin fraction from the roots (R_2 and R_1 sections) and S_1 section. These three sections had no change or a decrease in oleoresin (Tables 3, 5). CEPA apparently did not degrade to ethylene in significant quantities until it reached the S_2 section, where the increases in rosin acids and turpentine were similar. Apparently most of the CEPA degraded in the S_3 section, assuming ethylene is the primary reactant, because this section had the greatest increase in both rosin acids (88%) and turpentine (43% MF basis).

TABLE 5. *Percent turpentine by tree section and treatment on a fresh weight (FW), oven-dry weight (DW) and moisture free (MF) basis after treatment with CEPA or paraquat.*[a]

Tree section[b]		Control	CEPA drill	% Diff.	CEPA ground	% Diff.	Paraquat drill	% Diff.	Overall[c]
Top	FW	0.28a[d]	0.28a	0	0.31a	+11	0.30a	+7	0.29cd
	DW	0.50a	0.49a	−2	0.56a	+12	0.52a	+4	0.52cd
	MF	0.48a	0.47a	−2	0.54a	+12	0.52a	+8	0.50cd
S_3	FW	0.21b	0.24ab	+14	0.29a	+38	0.28ab	+33	0.26d
	DW	0.38b	0.43ab	+13	0.54a	+42	0.50ab	+32	0.46d
	MF	0.37b	0.42ab	+14	0.53a	+43	0.48ab	+30	0.45d
S_2	FW	0.27b	0.27b	0	0.31ab	+15	0.33a	+22	0.34cd
	DW	0.47b	0.48ab	+2	0.55ab	+17	0.57a	+21	0.52cd
	MF	0.46b	0.47ab	+2	0.53ab	+15	0.55a	+20	0.51cd
S_1	FW	0.35b	0.30b	−14	0.28b	−20	0.56a	+60	0.37bc
	DW	0.63b	0.54b	−14	0.50b	−21	0.98a	+55	0.66bc
	MF	0.58b	0.53b	−9	0.49b	−16	0.95a	+64	0.64bc
R_1	FW	0.61a	0.43a	−30	0.41a	−33	0.83a	+36	0.57a
	DW	1.07a	0.74a	−31	0.74a	−31	1.36a	+27	0.98a
	MF	0.93a	0.74a	−20	0.63a	−32	1.34a	+44	0.94a
R_2	FW	0.53ab	0.64a	+21	0.28b	−47	0.44ab	−17	0.47b
	DW	0.92ab	1.06a	+15	0.50b	−46	0.73ab	−21	0.80b
	MF	0.85ab	1.05a	+24	0.49b	−42	0.72ab	−15	0.78b
Average									
	FW	0.38ab	0.36ab	−5	0.31b	−18	0.46a	+21	
	DW	0.66a	0.63a	−5	0.56a	−15	0.77a	+17	
	MF	0.61ab	0.62ab	+2	0.55b	−10	0.76a	+25	

[a] For each value n = 6: 3 trees × 2 locations. For each Average value n = 36: 6 stem and root sections × 3 trees × 2 locations.
[b] S_1, S_2, S_3 = first, second and third 30 cm sections above ground line; Top = remaining top stem section; R_1 = first 30 cm root below ground line, R_2 = remaining root section.
[c] For each value n = 24: 3 trees × 4 treatments × 2 locations. Column values not followed by the same letter are significantly different (0.05 level) for FW, DW, or MF determinations.
[d] Numbers in the rows not followed by the same letter are significantly different at the 0.05 level.

In almost all sections in which there was an increase in oleoresin (rosin acids plus turpentine), the rosin acid fraction increased proportionately more than the turpentine fraction. Conversely, when there was a decrease in oleoresin, the turpentine fraction decreased proportionately more than the rosin acid fraction (Tables 3 and 5). This suggests that the rosin acid fraction in lodgepole pine (perhaps only under these low chemical treatment levels) is preferentially synthesized and the turpentine fraction preferentially remetabolized or transported under the influence of ethylene. Age of trees could be a factor, but the trees in Rowe et al.'s (1976) study were around 120 years old and those in Conner et al.'s (1980) study were around 30 years old, and turpentine increased proportionately more than rosin in these two studies. If the decreases in oleoresin in the CEPA treated trees represent a redistribution of oleoresin, these sections would also be expected to have significantly lower levels of stored starch and carbohydrates. It has been demonstrated that starch reserves are decreased after paraquat treatment (Brown et al. 1976, 1979; Finnerty and Falco 1977; Clason 1976, 1977). The source of carbon for increases in oleoresin comes from currently produced photosynthate [about 50% (Brown et al. 1979)], and from local starch reserves as well as from the mobilization of starch (Finnerty and Falco 1977). A lowered overall starch content would be of benefit in the pulping process.

The paraquat treated trees at SL had approximately half the increase in oleoresin as did the LTP paraquat treated trees. Since paraquat moves acropetally with water of the transpiration stream (Brown and Nix 1975), it may be that this force was not as great in SL trees as in trees at LTP. SL trees had already completed one-third to one-half of their shoot extension at the time of treatment, but LTP trees were just beginning to grow. At SL less of the paraquat may have moved from the treatment site and the residual amount may have been slightly toxic in the treatment area, thereby preventing a large accumulation of oleoresin at the treatment site.

On a whole stump/root basis (stem up to 1.4 m height), the paraquat bore hole treatment gave the largest increase in oleoresin. CEPA poured into bore holes stimulated larger increases in the lower root and third stem section, but those increases were negated by decreases in oleoresin in other sections. Pouring CEPA on the ground caused increases in oleoresin in the top three stem sections and decreases below this. The increases from this treatment are encouraging, because soil application should be much simpler and less expensive than boring holes and applying chemicals in them. However, the overall increases at these levels do not appear to be economically profitable. Further research should center on higher treatment levels applied in the spring.

REFERENCES

Brown, C. L., and L. E. Nix. 1975. Uptake and transport of paraquat in slash pine. For. Sci. 21: 359–364.

———, and L. V. Pienaar. 1982. Observations on growth of paraquat-treated slash pine. S. J. Appl. For. 5:145–150.

———, T. R. Clason, and J. L. Michael. 1976. Paraquat induced changes in reserve carbohydrates, fatty acids and oleoresin content of young slash pine. Pages 8–19 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

———, H. E. Sommer, and R. Birchem. 1979. Additional observations on utilization of reserve carbohydrates in paraquat induced resinosis. Pages 4–11 *in* M. H. Esser, comp./ed. Sixth Annual Lightwood Research Conference Proceedings. Atlanta, GA. Jan. 17–18.

Clason, T. R. 1976. Observations of paraquat induced oleoresin formation in slash pine (*Pinus elliottii* Engelm.). Ph.D. thesis, Univ. of Georgia, Athens, GA.

———. 1977. Silvicultural implications of paraquat induced oleoresin biogenesis. Pages 100–105 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Atlantic Beach, FL. Jan. 18–19.

Conner, A. H., M. A. Diehl, and J. W. Rowe 1980. Tall oil precursors and turpentine in jack and eastern white pine. Wood Sci. 12:194–200.

Drew, J. 1976. Paraquat treatment of slash pines at Orange Park (progress report). Pages 135–142 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

———, J. Russell, and H. W. Bajak, eds. 1971. Sulfate turpentine recovery. Pulp Chem. Assoc., New York. 147 pp.

Fahn, A. 1970. Morphological and anatomical changes related to resin stimulation. Final Report, Project No. A10-FS-15. The Hebrew University of Jerusalem, Department of Botany, Jerusalem, Israel. 133 pp.

Finnerty, W. R., and P. K. Falco. 1977. Seasonal variation of resin acids and other metabolites in *Pinus elliottii*. Pages 112–120 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Atlantic Beach, FL. Jan. 18–19.

Holton, R. W., and R. D. Winston. 1976. Turpentine and tall oil analyses of 8% paraquat-treated Virginia, loblolly, and shortleaf pines in the Tennessee Valley. Pages 77–80 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

Koch, P. 1976. New technique for harvesting southern pine with taproot attached can extend pulpwood resources significantly. Pages 403–420 *in* Appl. Polm. Symposium 28. Wiley & Sons, New York.

KOSSUTH, S. V. 1984. Biomass chemicals: Improvement in quality and quantity with physiological regulators. Biomass 6:47–59.

———, AND J. W. MUNSON. 1981. Automated terpene analysis with an internal standard. Tappi 64: 174–175.

PETERS, W. J., AND D. R. ROBERTS. 1976. Paraquat-induced lightwood develops in all southern pines. Pages 55–65 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

MCREYNOLDS, R. D., AND S. V. KOSSUTH. 1984. CEPA in sulfuric acid paste increases oleoresin yields. S. J. Appl. For. 8:168–172.

———, AND ———. 1985. CEPA in liquid sulfuric acid increases oleoresin yields. S. J. Appl. For. 9:170–173.

ROWE, J. W., A. H. CONNER, M. A. DIEHL, AND H. WROBLENSKA. 1976. Effects of treating northern and western conifers with paraquat. Pages 66–76 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

SANDBERG, K. R., F. W. HERRICK, AND A. A. SELDERS. 1977. Paraquat treatment of northwest conifers for lightwood induction. Wood Sci. 10(1):28–30.

SHEPARD, C. 1975. Analytical procedures for determining the extractions of paraquat treated trees. Pages 78–84 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 22–23.

STUBBS, J., D. R. ROBERTS, AND D. W. OUTCALT. 1983. Chemical stimulation of lightwood in southern pines. USDA Gen. Tech. Rep. SE-25. 51 pp.

WOLTER, K. E. 1977. Ethelene—potential alternative to bipyridilium herbicides for inducing lightwood in red pine. Pages 90–99 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Atlantic Beach, FL. Jan. 18–19.

———, AND D. F. ZINKEL. 1976. Metabolic, hormonal, photosynthetic, and lightering response of red pine treated with paraquat. Pages 31–40 *in* M. H. Esser, comp./ed. Lightwood Research Coordinating Council Proceedings. Jacksonville, FL. Jan. 20–21.

———, AND ———. 1984. Observations on the physiological mechanisms and chemical constituents of induced oleoresin synthesis in *Pinus resinosa*. Can. J. For. Res. 14:452–458.