INORGANIC CHEMICALS as Aids in BURNING HARDWOOD TREE STUMPS

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INORGANIC CHEMICALS AS AIDS IN BURNING HARDWOOD TREE STUMPS

C. S. WALTERS and K. R. PETERSON[1]

IN THE PAST 10 YEARS phloem necrosis and Dutch elm disease have killed thousands of elm trees in Illinois and other states east of the Great Plains. Thousands more probably will die in the future, since there is little hope that the two diseases can be controlled with the methods currently in use. Many of the dead trees are in cities and must be cut promptly to reduce the physical hazard, thereby leaving an unsightly stump.

Tree stumps are difficult to extract from the ground because Nature designs the cantilever system to resist the terrific forces that are imposed at the groundline reaction point. Explosives and heavy equipment cannot be used to remove the stumps on city property, and digging them out is too costly and arduous. Burning stumps has been tried, but for the most part the results have not been satisfactory for the homeowner.

The burning process is not a direct one, but involves a series of interdependent thermochemical factors. The conditions which favor combustion of wood rarely are present in the environment of a stump, and they are impractical for the homeowner to achieve.

There is thus a great need for a practical and economical way of eradicating tree stumps on residential property. That is why we undertook our investigation. Our principal objective was to test a limited number of chemicals for their ability to promote glowing combustion of stumpwood. We realized that finding the most effective mixture of chemicals was probably a matter of chance, since the environment under which stumpwood is burned is highly variable.

Previous Studies and Reports

COMBUSTION OF WOOD

The literature concerning the burning of wood and how it is affected by chemicals impregnated into the wood, dates back more than 400 years before the birth of Christ. At that time Herodotus reported that the Egyptians steeped wood in alum solution to make it resistant

[1] C. S. Walters, Professor, and K. R. Peterson, Assistant Professor, of Wood Technology and Utilization.

to fire (1).[1] Since then, hundreds of reports have been written on the subject. Most of them, however, have dealt with measures that tend to make wood resistant to burning rather than with those that make wood burn.

So far as we have been able to ascertain, the only data that have been published on controlled stump-burning tests have been two reports issued by the University of Illinois (10, 11). Other reports about making wood burn deal almost exclusively with fuelwood, and particularly with seasoned wood.

FUELWOOD BURNED UNDER CONTROLLED CONDITIONS

According to Hawley (3), the combustion of fuelwood is controlled by the size and distribution of the pieces of wood, by the air supply, and by the way in which the heat of combustion is dissipated or retained. When wood is burned in the fireplace, the air supply may be regulated by the damper or by the size and arrangement of the sticks placed in open piles. The dissipation of the heat is controlled by the damper and the walls of the fireplace. This type of burning involves an exothermic reaction in which the gases and vapors produced during pyrolysis are burned, and charcoal is formed. The charcoal is then burned to ash. When a large piece of wood is ignited, it burns as long as the necessary heat penetrates from the outside to the inside of the wood.

Fuelwood can be dried and burned under controlled conditions. It is impractical to dry tree stumps in contact with soil, however, and the conditions required for combustion of stumpwood are difficult for the homeowner to control.[2]

BURNING PROCEEDS BY ZONES

Browne (1), in his very comprehensive report, discusses the differences between flaming combustion of wood and glowing combustion. When wood is heated in air, the course of combustion is progressive, proceeding through several stages which are determined by temperature and which Browne refers to as zones. In Zone A, a stage with temperatures below 200° C., pyrolysis is slow. The gases produced at this stage of burning are not ignited.

Temperatures in Zone B range from about 200° to 280° C., a state at which the mixture of gases produced still are not readily ignitible.

[1] Numbers in parentheses refer to literature cited on page 28. The particular reference to Herodotus occurs on page 19 of the first citation.

[2] A method for burning stumps in a metal "stove" or brick enclosure is described in Mimeo F-261 (revised). A single copy is free from the Forestry Department, 219 Mumford Hall, Urbana, Illinois.

The gases start burning, however, in Zone C (280° — 500° C.), where they evolve as a result of secondary pyrolysis and are ignited by a pilot flame to burn outside the wood. The charcoal that has formed may or may not burn, depending on whether a supply of oxygen is available at the surface of the wood and whether enough heat penetrates the layer of charcoal to advance the wood underneath to an exothermal point.

In Zone D, at surface temperatures above 500° C., the layer of charcoal on the outside of the wood burns, while the interior of the wood still may be at various stages of burning, ranging from Zones A to D. When the surface temperature rises over 1,000° C., the charcoal (carbon) is consumed at the surface as fast as Zones A to C penetrate the wood.

CHEMICALS ENCOURAGE COMBUSTION

As already pointed out, charcoal needs both oxygen and heat to glow. It is reasonable to assume that an adequate supply of oxygen is available to the burning stump. Supplying enough heat is often more of a problem. Theories of glow prevention indicate that the presence of chemicals may improve conduction or absorption of heat through the charcoal and wood. They may also lower ignition temperatures in the various zones and hasten the burning of carbon.

Browne points out that the net heat liberated by the combustion of wood depends on the ratio of carbon monoxide to carbon dioxide in the combustion products. Chemicals impregnated into wood, however, could alter the ratio, thereby stimulating or retarding glowing combustion. It appears that such chemicals could have a catalytic effect, inhibiting the formation of carbon monoxide and promoting the formation of carbon dioxide, or of carbon dioxide and hydrogen. In such an event, combustion would be encouraged.

Although burning tree stumps may be a totally different problem than destroying soot in heating systems, the two problems become similar in nature when stumpwood is converted to charcoal, since both soot and charcoal are forms of carbon.

Nicholls and Staples (9) concluded that the action of soot-removing chemicals is restricted to metallic salts or those formed by burning metals. The action of the chemicals was to lower the temperature at which the soot burned.

The chlorides sublime at relatively low temperatures, and in the Nicholls-Staples tests were particularly effective in lowering the ignition temperature of soot. Some of the chlorides set free chlorine gas when burned, and the chlorine apparently increased the ease with which the soot united with oxygen. Chlorides of manganese, iron, and copper were particularly effective as soot burners. Lead salts, particularly lead iodide, also gave good results in burning soot.

Nicholls and Staples concluded that oxygen had to be in the furnace gases for a soot remover to be effective, and that the burning process was limited to that of oxidation. They further concluded that the use of salts high in oxygen, for example dioxides and chlorates, did not increase the effectiveness of burning. In their studies the fuel ash apparently was an effective aid in burning soot, since ashes high in alkalies and metals were found to act as soot removers.

HISTORY OF CHEMICAL STUMP REMOVERS

One of the earliest known reports on the destruction of stumps with chemicals was Coggins' account (2) of tests in which sulphuric and nitric acids were used in varying proportions for destroying stumps. Coggins concluded, however, that sound stumps could not be destroyed with either or both acids, that the method was wasteful of time, and that handling acid was dangerous.

In 1939 Mrs. A. Henn (4) recommended boring a vertical hole 1 inch in diameter in the center of a stump and placing 1 ounce of potassium nitrate (saltpeter) in the hole. The hole was then to be filled with water and sealed with a wood plug. The stump allegedly burned, "roots and all," following ignition 6 or 8 months after treatment.

Howell (5), Jackson (7), Morriss (8), and others have recommended modifications of Henn's method. Both the original method and some modifications were tested by the University of Illinois Agricultural Experiment Station in 1949, and the results were reported as unsuccessful (10).

Since 1953, approximately 400 water-soluble, inorganic compounds or mixtures of them have been laboratory- or field-tested for their ability to promote glowing combustion of wood. This report presents the methods and results of the tests.

Preliminary Tests of Chemicals

CHEMICAL SCREENING TESTS

The compounds listed at the top of page 7 were chosen from hundreds of chemicals that have been tested by the U. S. Forest Products Laboratory (6) as fire retardants, because they showed the strongest tendency to promote glowing combustion of wood.

Cupric chloride, $CuCl_2$	Sodium molybdate, Na_2MoO_4
Ferric chloride, $FeCl_3$	Lead acetate, $Pb_2OH(C_2H_3O_2)_3$
Manganese dichloride, $MnCl_2$	Cupric sulfate, $CuSO_4$
Sodium dichromate, $Na_2Cr_2O_7$	Chromium trioxide, CrO_3

A 5-percent aqueous solution of each chemical was prepared. Several drops of solution, or of a combination of solutions, were pipetted on the center of a 9-centimeter disk of filter paper, and the paper was dried at 105° C. for 1 hour. Each disk was placed on an asbestos-wire gauze square and ignited. The flame was extinguished as soon as it ignited the treated spot. Results of the burning tests were judged on the ability of the chemical treatment to promote glowing combustion that destroyed the treated portion of the paper disk. The results were rated "good" (a vigorous reaction that destroyed the entire area), "fair," or "poor." Each treatment was tested in triplicate and an "average" rating was assigned the series of tests. Table 1 lists 23 formulations that received the "good" rating.

The nine formulas that appeared to give the best results were retested in quintuplicate. In these tests the scoring ranged from 1 (fair) to 5 (excellent). The sum of the five numerical ratings was

Table 1. — Chemical Composition of Formulas Rated "Good" in Paper-Disk Assay of Their Ability to Promote Glowing Combustion

Formula	Percentage (by weight) of compound in formula							
	$FeCl_3$	$CuCl_2$	$Na_2Cr_2O_7$	$PbOH(C_2H_3O_2)_3$	$MnCl_2$	Na_2MoO_4	$CuSO_4$	CrO_3
C.......	....	....	....	....	....	....	75.0	25.0
G.......	....	....	75.0	....	....	....	25.0	....
I.......	....	....	....	....	....	....	50.0	50.0
J.......	....	....	50.0	....	....	....	....	50.0
K.......	....	....	49.0	....	....	....	49.0	2.0
5.......	6.3	37.5	56.2	....	....	....	....	....
6.......	18.8	62.4	18.8	....	....	....	....	....
7.......	33.0	....	34.0	....	....	33.0	....	....
8.......	6.2	37.6	....	56.2	....	....	....	....
13.......	25.0	75.0	....	....	....	....	....	....
18.......	75.0	....	....	25.0	....	....	....	....
20.......	6.2	18.8	....	56.2	18.8	....	....	....
21.......	18.8	56.2	....	18.8	6.2	....	....	....
27.......	56.2	6.2	....	37.6	....	....	....	....
28.......	....	25.0	75.0	....	....	....	....	....
31.......	....	25.0	....	75.0	....	....	....	....
36.......	56.2	....	....	31.3	12.5	....	....	....
43.......	....	....	25.0	....	75.0	....	....	....
45.......	....	....	75.0	....	....	25.0	....	....
47.......	....	....	....	50.0	50.0	....	....	....
48.......	....	....	....	75.0	25.0	....	....	....
51.......	....	18.8	56.2	12.5	12.5	....	....	....
69.......	....	....	37.6	....	56.2	6.2	....	....

Table 2. — Rating Indexes and Chemical Composition of Nine Formulations Rated Best in Paper-Disk Burning Tests

Formula	Rating index[a]	Percentage (by weight) of compound in formula					
		$FeCl_3$	$CuCl_2$	$Na_2Cr_2O_7$	PbOH $(C_2H_3O_2)_3$	$MnCl_2$	Na_2MoO_4
51..........	24	.....	18.75	56.25	12.50	12.50	.....
20..........	23	6.25	18.75	.....	56.25	18.75	.....
36..........	21	56.25	.....	.....	31.25	12.50	.....
6..........	20	18.75	62.50	18.75	.....	.....	.....
5..........	14	6.25	37.50	56.25	.....	.....	.....
8..........	14	6.25	37.50	.....	56.25	.....	.....
27..........	10	56.25	6.25	.....	37.50	.....	.....
21..........	9	18.75	56.25	.....	18.75	6.25	.....
69..........	9	.....	.....	37.50	.....	56.25	6.25

[a] Rating based on five burning tests scored as follows: Excellent, 5; very good, 4; average, 3; good, 2; fair, 1.

used to rank each formulation. Table 2 shows the composition and ratings for the nine formulations.

BLOCK TESTS

One hundred eight basswood (*Tilia americana* L.) blocks 1 inch square and 4 inches along the grain were used to test two compounds and two mixtures of compounds. Each chemical was tested in triplicate, using three dosage levels and three diffusion periods.

The two mixtures and two compounds selected for testing were: Formula 51,[1] Formula K, sodium nitrate, and ammonium nitrate. Formula 51 was selected because of its high rating in the screening tests. Formula K and sodium nitrate were included because they had produced good results in field tests, even though they had not appeared in the top nine formulations. Ammonium nitrate was included because it has a higher solubility rating than the sodium salt, and there was reason to believe that it would yield satisfactory results.

A 3/8-inch hole 1 inch deep was bored parallel to the longitudinal axis in one end of each block. The blocks were brought to "green" condition by soaking 48 hours in distilled water, and the chemical was placed in the hole.

The dosages were: 0.5 gram (0.0011 pound) per cubic inch of block; 1.0 gram (0.0022 pound) per cubic inch; and none (controls). The "green" blocks were placed in a pan containing about 1/2 inch of water with the solid end in the water. Thirty-six blocks were removed

[1] Subsequently manufactured as "Stumpfyre" under license from the University of Illinois Foundation, U. S. Patent No. 2,947,110.

Table 3. — Size and Treatment of American Elm Stumps and Evaluation of 1956 Burning Tests

Stump No.	Aver. diameter	Perimeter	Surface area	Chemical: Kind	Chemical: Amount	No. of holes	Aver. amt. of chemical per hole	Volume destroyed by burning[a]	Satisfactory ratings awarded
	Inches	*Feet*	*Sq. in.*		*Pounds*		*Pound*	*Percent*	*Percent*
1	32	14.0	864	Formula 51	18	41	.44	84	75
9	17	5.8	254	"	6	12	.50	58	30
10	22	6.9	407	"	10	20	.50	90	95
13	16	7.5	354	"	5	15	.33	96	100
20	20	11.2	450	"	8	19	.42	81	65
22	14	6.0	249	"	4	12	.33	78	60
Average	20.2	8.6	430		8.5	19.8	.42	83	71
3	27	16.6	951	Formula K	15	41	.37	58	5
21	27	15.8	737	"	15	33	.45	39	0
23	16	10.5	435	"	5	21	.24	73	50
27	17	13.7	404	"	6	19	.32	27	0
28	31	16.0	909	"	20	42	.48	88	80
32	25	....	630	"	13	29	.45	54	5
Average	23.8	14.5	678		12.3	30.8	.38	58	23
4	42	23.4	1,248	Ammonium nitrate	37	59	.63	53	25
7	22	27.8	1,050	"	10	45	.22	23	0
8	15	7.3	294	"	5	12	.42	64	15
11	24	21.0	956	"	11	43	.26	42	15
18	17	7.5	292	"	6	14	.43	32	0
24	18	12.6	550	"	7	23	.30	36	0
Average	23.0	16.6	732		12.7	32.7	.38	41	9
5	17	7.9	294	Sodium nitrate	6	12	.50	23	0
19	15	7.0	253	"	5	12	.42	40	5
26	14	7.2	298	"	4	14	.29	89	95
29	34	16.7	1,164	"	24	53	.45	51	5
30	22	13.5	608	"	5	31	.16	19	0
31	16	7.6	320	"	10	14	.71	87	80
Average	19.7	10.0	490		9.0	22.7	.42	53	31
2	33	21.0	944	None (controls)	..	46	...	68	40
6	26	16.3	817	"	..	31	...	77	70
12	12	5.2	156	"	..	7	...	20	0
14	18	10.8	414	"	..	17	...	25	5
15	27	12.8	799	"	..	37	...	47	5
16	13	4.9	205	"	..	9	...	6	0
17	20	12.4	521	"	..	23	...	40	0
25	12	6.1	194	"	..	10	...	24	0
Average	20.1	11.2	506		..	25.0	...	37	15
Average	21.3	12.0	563	.....	10.6	25.5	.40	..	..

[a] Average estimated percentage of original volume. Average for each stump based on 20 estimates. Percentages obtained by decoding angular transformation of data.

at the end of 2 days, air-dried, and burned. Other groups were burned after 5-day and 8-day diffusion periods.

Each air-dried block was ignited with a Bunsen-burner flame applied to the solid end for 5 minutes. The results were rated "good," "fair," or "poor," depending upon how much of the block was burned.

The results of the paper-disk and wood-block tests were used to design a field test.

Field Tests — Methods and Results

DESIGN OF 1956 STUMP TESTS

Twenty-four American elm (*Ulmus americana* L.) stumps, ranging from 12 to 42 inches in diameter, were treated and burned in a field test of the two mixtures and two compounds described in the previous section. In addition, eight untreated stumps were included in the burning tests (Table 3).

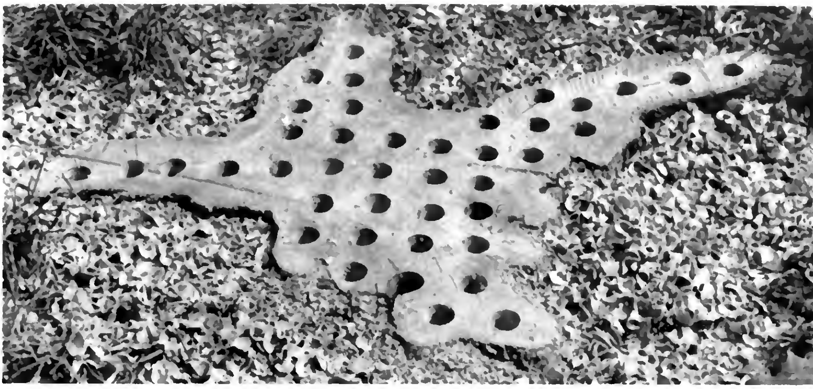
All stumps were cut as close to the ground as practical. The "average" diameter,[1] perimeter, and cross-sectional area of each stump were measured. Perimeter measurements followed the outline of the flat surface of the root extensions. It was assumed that each stump was 12 inches deep, including the inch or two aboveground. Although some stumps may have extended deeper than this, destruction of the top 12 inches would usually constitute satisfactory results.

Vertical holes 2 inches in diameter and about 6 inches deep were bored with a twist drill in all 32 stumps (Fig. 1). The holes were spaced 4 inches apart, using a hardboard template to locate the centers. The holes were freed of chips before the chemicals were placed in them.

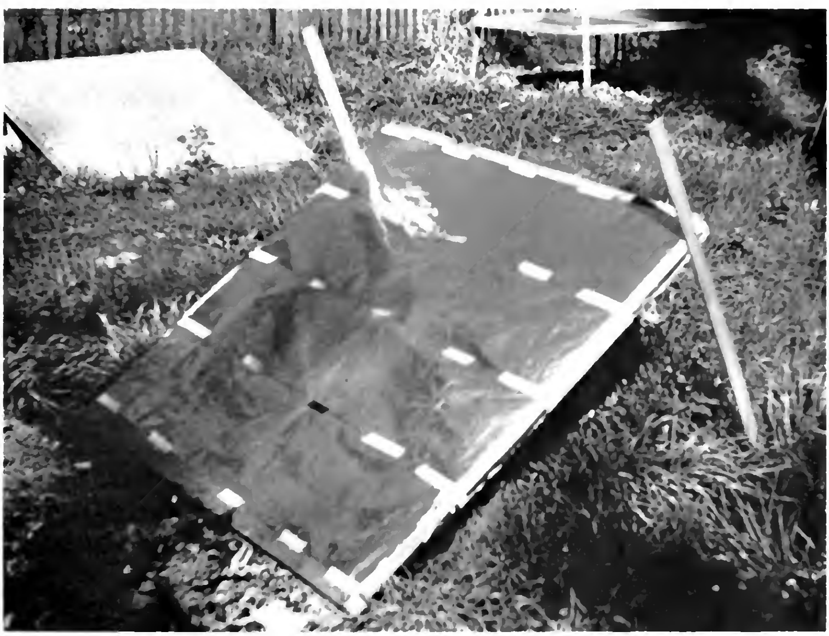
Treatments were randomly assigned to stumps. Dosage originally was based on stump diameter, but this basis was abandoned because of the inaccuracy involved in determining "average" diameter for stumps with irregular, cross-sectional shapes. The dosage used was about 1 gram (0.0021 pound) of chemical per cubic inch of wood contained in the top 12 inches of the stump.

Chemical mixtures were blended in a large feed-mixing machine. The total chemical for each stump to be treated was weighed and distributed more or less equally among the holes about the third week of June. The holes were then filled with water. All stumps, treated and untreated, were covered with reflector shields (Fig. 2) to protect them from rain during the diffusion period.

[1] The average of two diameters, one measured at right angles to the other.



Most of the aboveground portion of this stump was removed with a power saw. Two-inch holes for the chemical were bored to a depth of about 6 inches. Some of the holes were not close enough to the bark, and an extra hole or two in some areas would have been desirable. (Fig. 1)



This reflector shield is about 4 feet square, made of hardboard and framed with pine strips; the under (reflecting) side is covered with household-type aluminum foil fastened with pressure-sensitive paper tape. The supporting stakes should have been heavier. The shields were kept as close to the stump as practical, as shown by those in the background. (Fig. 2)

Dry kindling was piled on each stump and ignited. A liberal amount was used, varying with the cross-sectional area of the stump. (Fig. 3)

The experiment had been designed to test 2-week and 4-week diffusion periods. Rainy weather, however, made burning impractical at the end of 2 weeks, so this part of the experiment was abandoned. After 4 weeks the weather was again rainy. In addition, the holes in the treated stumps were full of liquid, while those in the untreated stumps contained little if any. The liquid resulted from the hydroscopic nature of the chemical, not rain. Attempts to remove it with wicks of paper toweling were unsuccessful. The combination of the rainy weather and the liquid in the treated stumps made it impractical to burn the stumps after the 4-week diffusion period, so this part of the experiment was also abandoned. Finally, most of the liquid was removed with a battery syringe about 3 months after the stumps were treated.

A day or so after the liquid was removed, the stumps were burned. First, the reflector shields were removed, then a liberal amount of kindling was piled on each stump and ignited (Fig. 3). About 2 hours after the kindling was ignited, it had burned to a bed of coals, and the reflector shields were replaced over the stumps.

Table 4. — Size and Treatment of American Elm Stumps With Formula 51, and Evaluation of 1957 Burning Tests

Stump No.	Surface area	No. of holes	Amount of chemical	Reflector shield	Volume destroyed by burning[a]	Satisfactory ratings awarded
	Sq. in.		*Pounds*		*Percent*	*Percent*
1	511	16	4.00	Yes	85	94
8	593	21	5.25	"	93	100
12	237	9	2.25	"	78	81
14	397	12	3.00	"	88	94
19	695	14	3.25	"	66	62
Average	487	14			83	86
5	522	15	3.75	No	94	100
7	314	11	2.75	"	42	37
10	644	16	4.00	"	93	100
13	554	13	3.25	"	94	100
20	672	25	6.25	"	47	6
Average	541	16			78	69
2	536	16	None	Yes	16	0
3	415	14	"	"	37	25
11	303	10	"	"	11	6
16	741	21	"	"	89	100
17	442	12	"	"	29	0
Average	487	15			36	26
4	503	18	None	No	25	0
6	467	16	"	"	19	0
9	348	12	"	"	30	0
15	370	13	"	"	31	6
18	1,036	29	"	"	36	12
Average	545	18			28	4
Average all stumps	515	16				

[a] Average for each estimated percentage of original volume. Average for each stump is for 16 estimates. Percentages obtained by decoding angular transformation of data.

DESIGN OF 1957 STUMP TESTS

Treatment in 1957 was about the same as in 1956, with the following exceptions: Only Formula 51 was used, and the test was designed to show the effect of the chemical alone, the shields alone, and the interacting effect of the two together (Table 4). The dosage was also smaller, being about 115 grams (0.25 pound) of chemical per hole, or 0.27 gram (.0006 pound) per cubic inch of wood in the top 12 inches of the stump. Twenty American elm stumps, including five control stumps, were in the tests.

EVALUATION OF BURNING TESTS

At the end of the burning period, about 2 weeks, the ash was removed from the stump remains and evaluators were asked to judge the results by estimating the percentage of each stump destroyed. Each evaluator also indicated whether the results were "satisfactory" or "unsatisfactory," basing his decision on the assumption that the stump was located on his home grounds.

The term "stump" was identified for the evaluators as ". . . including the wood left aboveground, the projection of the cross-section to a depth of not more than 12 inches below ground, and the side roots to a depth of 4 inches."

In 1956 half of the 20 evaluators were "foresters" and half were "homeowners." Foresters were members of the Forestry Department. Homeowners were members of other departments of the University or of the Botany Department, Illinois State Natural History Survey. The classification was made because most of the foresters were generally familiar with the tests, had actually removed stumps from their home grounds, and were believed to be more familiar with the root structure of trees. The authors did not participate in the evaluations.

In 1957, 16 evaluators judged the results of burning tests. The evaluators were not classified as they were in 1956.

The percentages of wood destroyed, as estimated by the evaluators, and their ratings of "satisfactory" or "unsatisfactory" were used as indexes of the effectiveness of treatment. Angular transformations were made for the percentage data before they were analyzed by an analysis of variance. The "satisfactory-unsatisfactory" ratings were coded "1" and "0," respectively, and the coded data were analyzed by an analysis of variance.

AMOUNT OF STUMP DESTROYED

1956 tests. Table 5 shows the average volume of stump burned in 1956, expressed as a percentage of the original volume. Table 6 is an analysis of variance for angular transformations of the percentage data.

In percentage of wood destroyed, Formula 51 was the best treatment. Average percentage for Formula 51 was 83; for Formula K, 57; for sodium nitrate, 53; for ammonium nitrate, 41; and for untreated stumps, 37. Standard errors for the averages were less than 1 percentage point. The "treatments" component was significant at the 5-percent level of confidence (Table 6).

Homeowners' estimates of the volume destroyed averaged 55 percent for all treatments; foresters' estimates, 53 percent. The difference between these means was not significant, as shown by the nonsignificant variance ratio for "Groups" in Table 6. This is why evaluators were not grouped when the 1957 tests were designed.

The percentages for stumps within a treatment varied significantly.

Table 5. — Average Volume of Elm Stumps Burned, as an Estimated Percentage of Original Volume, 1956 Tests

Chemical treatment	Percentage as estimated by—		Average[a]
	Homeowners	Foresters	
Formula 51	82	84	83
Formula K	57	58	57
Sodium nitrate	55	50	53
Ammonium nitrate	44	39	41
None (controls)	38	35	37
Average	55	53	. .

[a] Percentages obtained by decoding angular transformations. Final averages for chemicals based upon 120 observations; final average for controls based upon 160 observations.

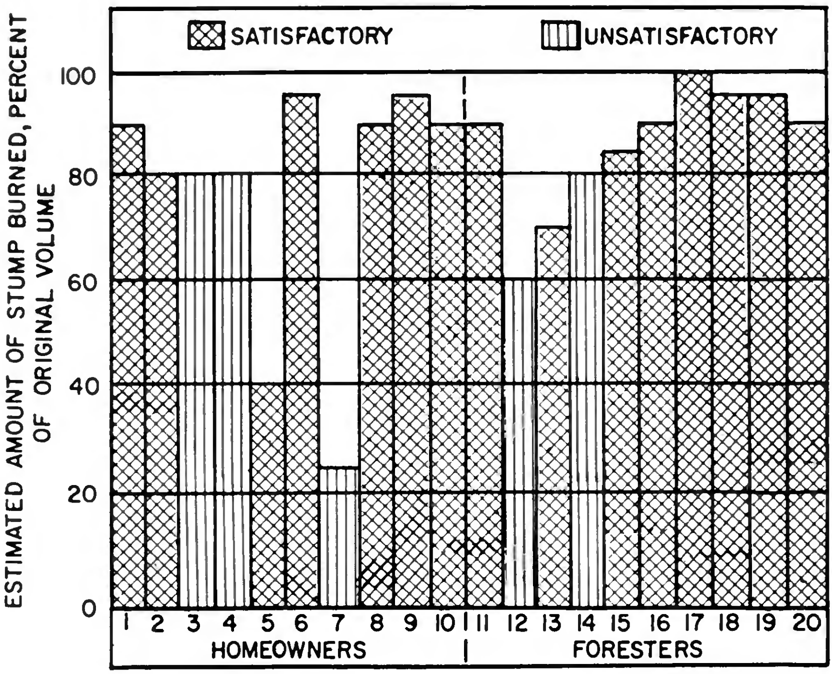
Table 6. — Analysis of Variance for Angular Transformations of Data Concerning Percentage of Stump Destroyed in 1956 Burning Tests

Source of variation	Degrees of freedom	Mean square	Variance ratio (F)	Significance[a]
Treatments (T)	4	15,717	3.9	*
Groups (G)	1	217	3.5	NS
TG	4	139	1.5	NS
Stumps, in treatments (S)	27	4,001	64.5	***
Individuals, in groups (I)	18	1,334	14.7	***
Homeowners	(9)	2,208	24.3	***
Foresters	(9)	460	5.1	***
TI	72	91	1.5	**
GS	27	85	1.4	NS
SI (error)	486	62	. . .	. . .
Total	639			

[a] *, significant at .05 level; **, significant at .01 level; ***, significant at .001 level; NS, not significant.

Figure 4 shows the differences in opinions expressed by the various evaluators when they examined Stump No. 1. Evaluator No. 7 estimated that only 23 percent of the stump's original volume was destroyed, whereas Evaluator No. 17 judged that the entire stump was destroyed. Evaluators 2, 3, 4, and 14 all estimated that 80 percent of the stump was destroyed, but they disagreed as to whether 80 percent destruction was an acceptable result. Although Evaluator No. 2 thought the results were satisfactory, the other three rated them unsatisfactory.

In the analysis of variance, individual evaluators within a group ("I" in Table 6) differed significantly in their opinions as to the amount of wood destroyed. The significance was at the 0.001 level of reliability. When the whole group was divided into "Foresters" and "Homeowners," individuals within each subgroup differed significantly



How 20 evaluators judged Stump No. 1 as to percentage destroyed by burning and as to whether the result was satisfactory or unsatisfactory. (Fig. 4)

at the same level. This means that the homeowners disagreed among themselves as to the amount of wood in each stump that had been destroyed by burning, and so did the foresters. However, the test of significance indicated that variation was greater among the homeowners. These results could, of course, have been reasonably predicted. One would expect individuals within a group to vary in their evaluations. One would also expect the variation to be less among the foresters, since they are generally more experienced in estimating the cubic volume of geometric forms and they are more familiar with the underground form of tree stumps.

The only interaction of factors that was statistically significant was the interaction of treatment and individuals ("TI," Table 6). That is, the estimates of individual evaluators varied with a change in treatment. In other words, the evaluators were not consistent in their evaluations of the different treatments. No bias was involved, for the evaluators had not been told how each stump was treated. The inconsistencies might be expected, however, from the wide range in the burning results. It was much easier for an evaluator to estimate the volume of wood destroyed as the percentage approached 100, complete destruction, than it was to estimate the percentage when only a small portion of the stump had been burned. Since the evaluators had not seen each stump before it was burned, individual concepts of the original form undoubtedly contributed to the variation among estimates.

1957 tests. Table 7 is a summary of the results of the 1957 burning tests. The average percentage of volume destroyed by burning was 80 for elm stumps treated with Formula 51 and only 32 for stumps containing no chemical. An analysis of variance (Table 8) indicated that the effect of the chemical was highly significant.

Reflecting shields were used because they were believed to stimulate burning. The variance ratio in Table 8, however, shows that the effect of shields was not significant. Although the reflecting properties of the shields apparently did not aid burning, the shields did protect the smouldering fire from rain, and they made the burning stump less hazardous to children and animals that frequented the test area.

The test of the CS, chemical by shield, interaction also proved nonsignificant (Table 8). Thus, it appears that the chemical made the real contribution to the burning process.

Table 7. — Average Volume of Elm Stump Destroyed as Percent of Original Volume, 1957 Tests

Treatment	Percentage destroyed		Average
	Shield	No shield	
Chemical (Formula 51)	83[a]	78[a]	80
No chemical	36[a]	28[a]	32
Average	61	54	57

[a] Based on 80 observations, or examinations of 5 stumps per treatment by 16 persons. Percentages obtained by decoding angular transformations.

Table 8. — Analysis of Variance for Angular Transformations of Data Concerning Percentage of Stump Destroyed in 1957 Burning Tests (Treated Stumps Contained Formula 51)

Source of variation	Degrees of freedom	Mean square	Variance ratio (F)	Significance[a]
Chemical (C)	1	1,111,090	21.14	***
Shield (S)	1	20,995	0.40	NS
CS	1	541	0.01	NS
Error	16	52,555	....	...
Total	19			

[a] ***, significant at the .001 level; NS, not significant.

SATISFACTORY-UNSATISFACTORY ASSAY OF BURNING RESULTS

1956 tests. Table 9 shows the percentage of total ratings judged satisfactory in the assay of the 1956 burning results. Table 10, an analysis of variance for the data, shows "Treatment" was a very highly significant source of variation. Seventy-one percent of the ratings awarded to the results obtained with Formula 51 were classified satisfactory (Table 9). The next best rating was given the sodium nitrate treatment, 31 percent. Only 15 percent of the ratings for stumps burned without a chemical were classified as satisfactory.

Foresters called 30 percent of the ratings satisfactory; homeowners, 28 percent (Table 9). This difference was not significant (Table 10).

The GS, group by stump, interaction was very highly significant. This means that the groups were not consistent in awarding ratings to the different stumps within a treatment. In addition the TI, treatment

Table 9. — Percentage of Total Ratings Judged Satisfactory, in Assay of 1956 Stump-Burning Tests

Chemical treatment	Percentage judged satisfactory by—		Average[a]
	Homeowners	Foresters	
Formula 51	67	75	71
Formula K	22	25	23
Sodium nitrate	30	32	31
Ammonium nitrate	13	5	9
None (controls)	12	17	15
Average	28	30	..

[a] Percentage for each chemical based upon 120 observations; average for controls based upon 160 observations.

Table 10. — Analysis of Variance for Coded[a] Ratings Awarded in Satisfactory-Unsatisfactory Assay of Stump-Burning Results, 1956 Data

Source of variation	Degrees of freedom	Mean square	Variance ratio	Significance[b]
Treatment (T)	4	7.32	430.9	***
Groups (G)	1	0.08	4.5	NS
TG	4	0.12	7.1	NS
Stumps, in treatments (S)	27	1.78	104.8	***
Individuals, in groups (I)	18	0.42	24.8	***
Homeowners	(9)	0.36	21.4	***
Foresters	(9)	0.48	28.3	***
TI	72	0.92	54.2	***
GS	27	1.14	67.2	***
SI (error)	486	0.02	....	...
Total	639			

[a] Satisfactory ratings coded "1"; unsatisfactory ratings coded "0."
[b] ***, significant at .001 level; NS, not significant.

by individual, interaction, was significant at the 0.001 level of probability. This means that the individual evaluators were not consistent in assaying results as they judged the various treatments.

1957 tests. Table 11 shows the average ratings awarded the two variables tested in the 1957 tests — chemical and shield. Table 12 is an analysis of variance for the data. Essentially the same results are shown by the ratings as were shown in Table 7 by the percentage data, and the same conclusions are drawn from the data and their analysis.

WHAT IS A SATISFACTORY RESULT?

The results discussed in previous paragraphs raise the question as to whether there was a minimum amount of wood that had to be destroyed for results to be judged "satisfactory." In other words, was there a correlation between the percentage of stumps destroyed and the awarding of a satisfactory rating?

Figure 5 shows the relationship between the number of satisfactory and unsatisfactory ratings awarded 1956 and 1957 tests and the volume of stump destroyed. Frequency distributions for both kinds of ratings are shown with their straight-line equations. As one would expect, the frequencies for the unsatisfactory ratings were highest when the results were poor and only a small portion of the stump was

Table 11. — Percentage of Total Ratings Judged Satisfactory in Assay of 1957 Stump-Burning Tests

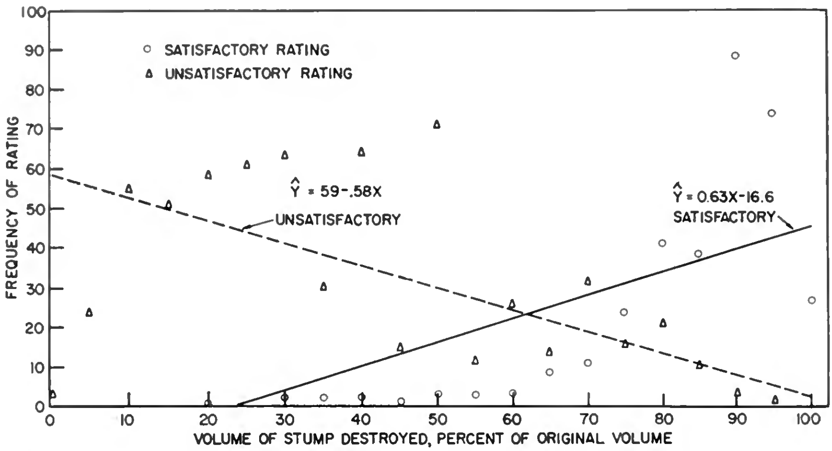
Treatment	Percentage judged satisfactory		Average
	Shield	No shield	
Chemical	86[a]	69[a]	78
No chemical	26[a]	4[a]	19
Average	59	46	..

[a] Percentage based on 80 ratings; 16 individual observations of each of 5 stumps.

Table 12. — Analysis of Variance for Coded[a] Ratings Awarded in Satisfactory-Unsatisfactory Assay of Stump-Burning Results, 1957 Data

Source of variation	Degrees of freedom	Mean square	Variance ratio (F)	Significance[b]
Chemical	1	500.0	20.1	***
Shield	1	51.2	2.1	NS
C x S	1	12.8	0.5	NS
Error	16	24.9	...	...
Total	19	....	...	...

[a] Satisfactory ratings coded "1"; unsatisfactory ratings coded "0."
[b] ***, significant at .001 level of probability; NS, not significant.



Number of satisfactory and unsatisfactory ratings awarded as a function of the volume of stump destroyed, 1956 and 1957 data combined. (Fig. 5)

destroyed. The reverse was true for the satisfactory ratings, with frequencies being highest when results were good and large portions of the stumps were destroyed.

The linear regressions for the two sets of data cross at about 62 percent. Thus, it appears that at least two-thirds of the stump had to be destroyed before most of the evaluators were willing to rate the results as satisfactory.

Individuals, of course, may disagree with the "average" results, as they did in the study. For example, four ratings plotted in Figure 5 classified stumps only half destroyed as "satisfactory," and 10 ratings classified stumps that were 85 percent destroyed as "unsatisfactory."

Other Tests and Analyses

RELATIVE IMPORTANCE OF COMPOUNDS IN PROMOTING GLOWING COMBUSTION

Twenty-three formulations that were rated "good" in the paper-disk assays of their ability to cause glowing combustion (Table 1) were examined to see whether one compound was superior to another in this property.

Eight compounds were used in the 23 mixtures (Table 13). Sodium dichromate not only appeared in 11 mixtures, but also was used in greatest quantity. Next, on the basis of quantity used, was lead acetate, which appeared in 10 mixtures. Cupric chloride and ferric chloride were also used in 10 mixtures, but in smaller quantities. Formula 51 contained four of the first five compounds listed in Table 13.

Table 13. — Relative Importance of Compounds in 23 Formulations[a] Rated "Good" in Paper-Disk Assay of Ability to Cause Glowing Combustion

Compound	Frequency of appearance in formulations	Total parts, by weight	Percent of total parts	Percent of Formula 51, by weight
$Na_2Cr_2O_7$	11	551.8	24.0	56.2
$PbOH(C_2H_3O_2)_3$	10	437.5	19.0	12.5
$CuCl_2$	10	362.5	15.8	18.8
$FeCl_3$	10	301.7	13.1	....
$MnCl_2$	8	256.2	11.1	12.5
$CuSO_4$	4	199.0	8.7	....
CrO_3	4	127.0	5.5	....
$NaMoO_4$	3	64.2	2.8	....
Total	..	2,300.0	100.0	....

[a] See Table 1 for components in formulations.

SPECTROCHEMICAL ANALYSES OF FORMULA 51, WITH AND WITHOUT SURFACTANT

A number of short-term laboratory experiments were made to learn more about the components in Formula 51 that diffused into the wood.

Two 6-gram samples of "Stumpfyre" (a commercial product with the same composition as Formula 51)[1] were dried to constant weight at 105° C. and reweighed. The dried samples were diluted with distilled water and filtered. The resulting precipitates and filtrates were dried to constant weight and weighed again. Weights of the filtrates and precipitates were expressed as percentages of the oven-dried weights of the samples. Spectrographic analyses were then made of the filtrates and precipitates.

A third 6-gram sample of the commercial mixture was dried to constant weight, then divided into two subsamples of about equal weight. The subsamples, designated "A" and "B," were diluted with hot distilled water. To Sample B we added 1 milliliter (0.9 gram) of a commercial surfactant,[2] to determine whether it would improve the liquid's "wettability" rating and its flow into the wood. The two subsamples were filtered and the filtrates and precipitates were dried to constant weight for spectrographic analysis.

Results from only the third 6-gram sample are presented in this report (Table 14). The spectrographic analyses for all three sets of filtrates and precipitates were fairly consistent for lead, sodium, and manganese. Some differences occurred, however, in the analyses for chromium and copper. These differences were attributed to sampling

[1] See footnote 1, page 8.

[2] This surface active agent was a liquid household detergent, containing a mixture of the ammonium salt of a modified alkyl sulfate and an alkyl ethanol amide.

Table 14. — Percent of Metal Present in Soluble and Insoluble Portions of Formula 51, With and Without a Surfactant

Metal	Percent in filtrate		Percent in precipitate	
	Surfactant	No surfactant	Surfactant	No surfactant
Cr	3-30(X)	3-30(X−)	3-30(X+)	3-30(X+)
Cu	1-10(X)	1-10(X)	3-30(2X)	3-30(2X−)
Mn	1-10(X)	1-10(X)	3-30(6X)	3-30(5X)
Na	3-30(2X)	3-30(2X)	1-10(X)	1-10(X)
Pb	T[a]	T[a]	1-10	1-10

[a] T = less than 1 percent.

error, since the commercial preparation from which the samples were drawn probably was not a homogeneous one.

Shown in Table 14 are the ranges in metal content of the filtrates and precipitates from the subsample without a surfactant and from the one with a surfactant. The two sets of filtrate values are about the same, as are the values for the precipitates. Adding the surfactant apparently had little effect on the movement of metal ions.

A rough quantitative analysis is also shown for each cell in Table 14. For example, the percent of manganese in the insoluble precipitates ranged between 3 and 30 percent, with the average amounts being about 5 or 6 times (5X and 6X) the average amounts in the filtrates.

The insoluble precipitate amounted to about 20 percent of the weight of an undried sample, and the filtrate about 60 percent. The remaining 20 percent probably was mostly water, although chlorine in the form of hydrogen chloride, as well as other components, may have evaporated during the drying process.

EFFECT OF SURFACTANT ON LIQUID ABSORPTION

As described above, one sample of Formula 51 was divided into two subsamples which were diluted in hot water; and a commercial surfactant was added to one of the subsamples. These liquids are referred to as Liquid A (without the surfactant) and Liquid B (with the surfactant).

Ten wafers of basswood about 2 inches square and ¼ inch along the grain were dried to constant weight at 105° C. Half were soaked for 30 seconds in Liquid A and half, in Liquid B. Each wafer was weighed before and after soaking and again after it was returned to oven-dry condition. Average absorptions were determined for each group of wafers.

The surfactant increased the rate at which the liquid penetrated the wood. Average absorption of Liquid B was 1.545 grams, or more

Table 15. — Effect of Surface Active Agent on Absorption of Liquid Form of Formula 51 by Wafers of Basswood

Liquid[a]	Average weight of wafers (gm.)[b]			Average absorption (gm.)[b]	
	Untreated, oven-dry	Freshly treated	Treated, oven-dry	Liquid	Dry chemical
A..........	5.552	6.315	5.618	0.763(x)	0.066(y)
B..........	5.685	7.230	5.805	1.545(2.02x)	0.120(1.82y)

[a] Liquid A: 10 gm. commercial grade of Formula 51 and 100 ml. water. Liquid B: same as A plus 1 cc. surfactant (see footnote 1, page 21).
[b] Based on measurements for six specimens per treatment.

than twice that of Liquid A (Table 15). When absorption was calculated on the basis of dry chemical, retention was 0.120 gram — again about double the value for Liquid A.

CHEMICAL DOSAGE AND STUMP SIZE

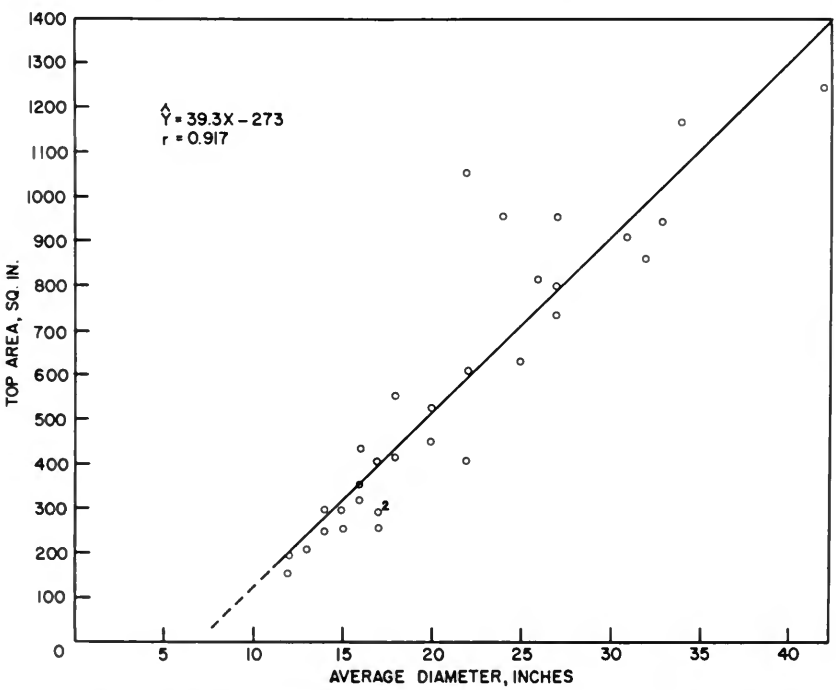
Dosage in laboratory tests on small blocks ranged from 0.5 to 1.0 gram (0.0011 pound to 0.0022 pound) per cubic inch of wood. Average dosage for the 1956 stump tests was 1 gram (0.0022 pound) per cubic inch of wood in the top 12-inch portion of the stump; and for the 1957 treatment, 0.27 gram (0.0006 pound) per cubic inch. The results of burning indicated that these amounts were adequate for Formula 51. The question arose, however, as to which of several measurements should be used as the independent variable in correlating stump size with chemical dosage.

Diameter, perimeter, top area, and number of holes bored in the stump could be used as indexes of stump size. Of these, top area appeared to be the most satisfactory index, although it was somewhat less practical to measure than "average diameter," which required two measurements at right angles to each other. The measurement of diameter was not always precise when stumps were irregular in cross section (Fig. 6), and we did not know whether there was good correlation between average diameter and the cross-sectional area of the top for all stumps. Dosage was therefore based on top area.

Figure 7 shows the relationship between top area and average diameter (Table 3). Figure 8 shows stump perimeter in relation to average diameter. The correlation between surface area and average diameter ($r = 0.917$) was much better than that between perimeter and average diameter ($r = 0.761$).

The equation derived for calculating the surface area in square inches is $\hat{Y} = 39.3X - 273$, with $\hat{Y}$ equaling the area and X, the

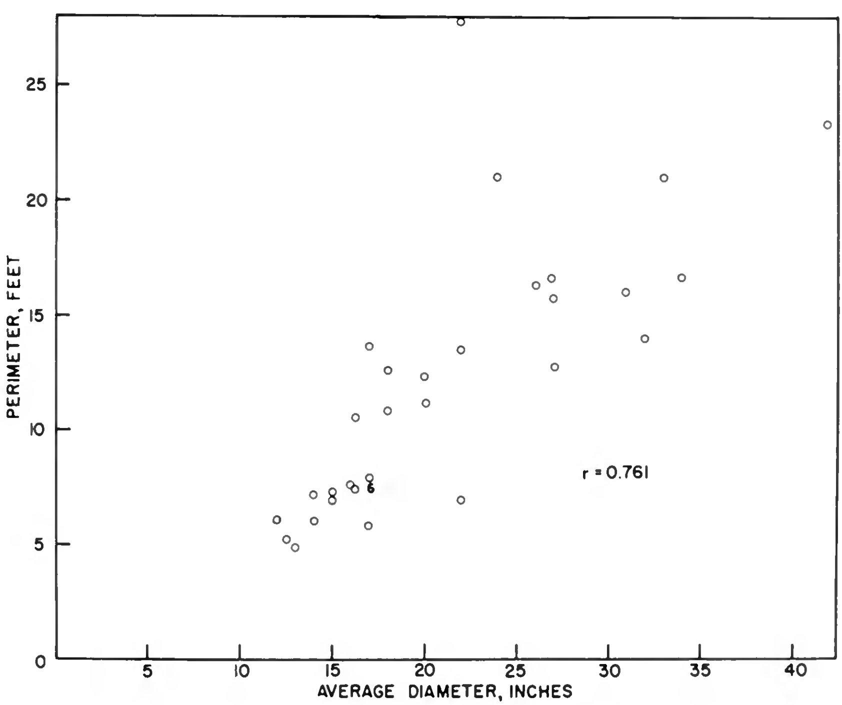
The irregular pattern of many American elm stumps makes it difficult to correlate size and chemical dosage. The stump which occupied this spot was about 42 inches across at its widest point. (Fig. 6)



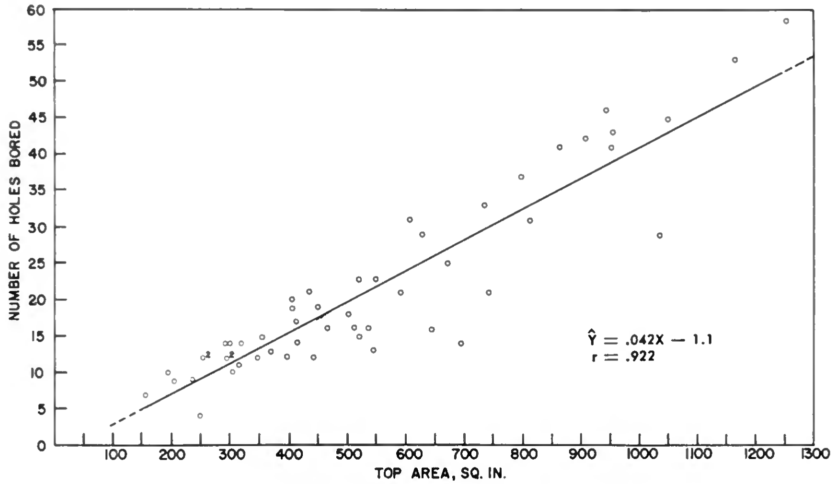
Relationship between cross-sectional area of stump top and the average of two diameter measurements made at right angles to each other. (Fig. 7) average diameter. Thus, the surface area of a stump having an average diameter of 20 inches would be expressed as $\hat{Y} = (39.3)(20) - 273$, or 513 square inches. The difference between this value and the area of a 20-inch circle (314 inches) is due to the irregular pattern of the stump's top caused by the root swell.

Figure 9 shows the relationship between the number of holes bored in the 1956 and 1957 test-stumps and cross-sectional area of the stump top. As shown in Table 3, the number of holes ranged from seven for a stump 12 inches in diameter (156 inches of top area) to 59 for a 42-inch stump (1,248 square inches of top area). We believe that the minimum number of holes needed for effective treatment is determined by the equation, $\hat{Y} = .042X - 1.1$, in which $\hat{Y}$ equals the number of holes and X, surface area in square inches.

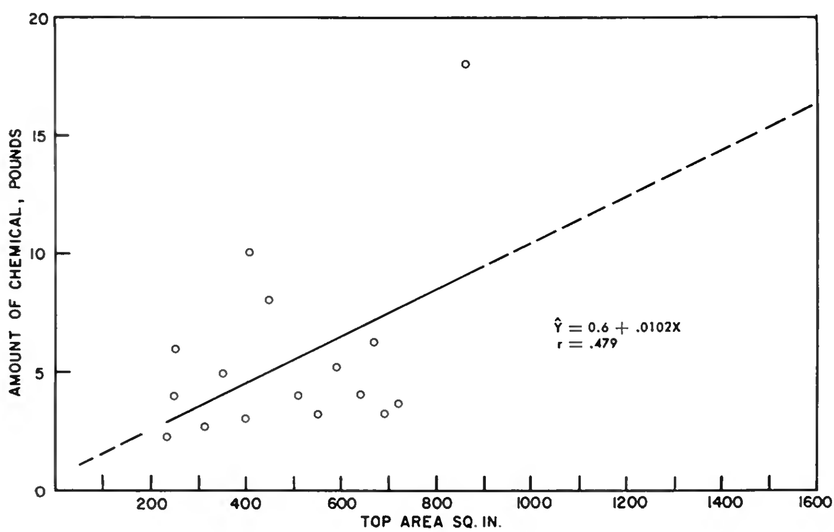
Figures 7, 9, and 10 will enable one to determine dosage for round or irregularly shaped stumps. If a stump is fairly round, average diameter can be determined, this can be converted to cross-sectional



Relationship between stump perimeter and average diameter of stump top. (Fig. 8)



Relationship between cross-sectional area of stump top and number of holes bored, 1956 and 1957 data combined. (Fig. 9)



Amount of Formula 51 applied to stumps as a function of size (cross-sectional area of stump top). (Fig. 10)

area of the top by use of Figure 7, and correct dosage can then be determined from Table 10. If the stump is irregularly shaped, holes can be bored on 4-inch centers, the surface area can be determined by using Figure 9, and the amount of chemical needed, by using Figure 10.

Summary and Conclusions

Stumps that remain from cutting trees are difficult to remove from residential areas because explosives or heavy machinery cannot be used, and hand methods are too arduous and expensive. There is a great need in Illinois and elsewhere for a practical and economical means of removing the stumps of disease-killed elm (*Ulmus* spp.) trees. Commonly recommended methods involving the use of potassium nitrate (saltpeter) to promote combustion have not achieved satisfactory results. Other compounds known to cause glowing combustion of wood in fire-retardant studies were screened for use in burning tree stumps.

Eight compounds, as well as over 400 combinations of them, were tested for their ability to promote glowing combustion of paper disks. The most promising combinations were further tested with small blocks or wafers of wood. Finally, in 1956, 24 American elm (*Ulmus americana* L.) stumps were treated either with ammonium nitrate, sodium nitrate, Formula K, or Formula 51.[1] The stumps were ignited about 3 months after treatment. Eight untreated control stumps were included in the burning tests.

Results of the burning tests were judged by 20 evaluators, who estimated the percentage of wood destroyed and rated each test as "satisfactory" or "unsatisfactory." Formula 51, a mixture of 4.5 parts sodium dichromate, 1.5 parts cupric chloride, 1 part lead acetate, and 1 part manganese dichloride, gave superior results, destroying, on the average, 83 percent of the stump. The average percentage value for Formula K was 57; for sodium nitrate, 53; for ammonium nitrate, 41; and for untreated stumps, 37.

In 1957, a second series of experiments with 20 American elm stumps tested the interacting effect of Formula 51 and reflecting shields on burning. The shields had an insignificant effect on burning results, whereas the chemical had a highly significant effect. The interacting effect of using both chemical and shields was not significant. In these tests the average percentage of stump destroyed was 80 for stumps treated with Formula 51, and 32 for the untreated ones.

Of 120 ratings given to stumps burned after treatment with Formula 51 in 1956, 71 percent were classified as satisfactory. The next best treatment — sodium nitrate — was considered satisfactory in only 31 percent of the ratings. In 1957, 78 percent of 80 ratings for treated stumps were satisfactory, whereas only 19 percent of the ratings for stumps burned without chemical treatment were satisfactory.

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[1] Subsequently named Stumpfyre, U. S. Patent No. 2,947,110.

The relationship between number of satisfactory ratings and amount of stump destruction showed that at least 62 percent of a stump had to be destroyed before most evaluators were willing to rate results as satisfactory.

Twenty-three of the best chemical formulations were examined to see whether one compound was more important than another in promoting combustion. Sodium dichromate appeared most frequently, followed by lead acetate, cupric chloride, ferric chloride, and manganese dichloride. Formula 51 contained four of these compounds.

When a surfactant was added to an aqueous dilution of Formula 51, basswood wafers absorbed 2.02 times as much liquid and 1.82 times as much dry chemical as wafers treated in wafers containing no surfactant. The surfactant also increased the rate at which the liquid penetrated the wood.

First-order equations were calculated for several relationships concerning stump size (in terms of cross-sectional area or number of holes bored on 4-inch centers) and chemical dosage.

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