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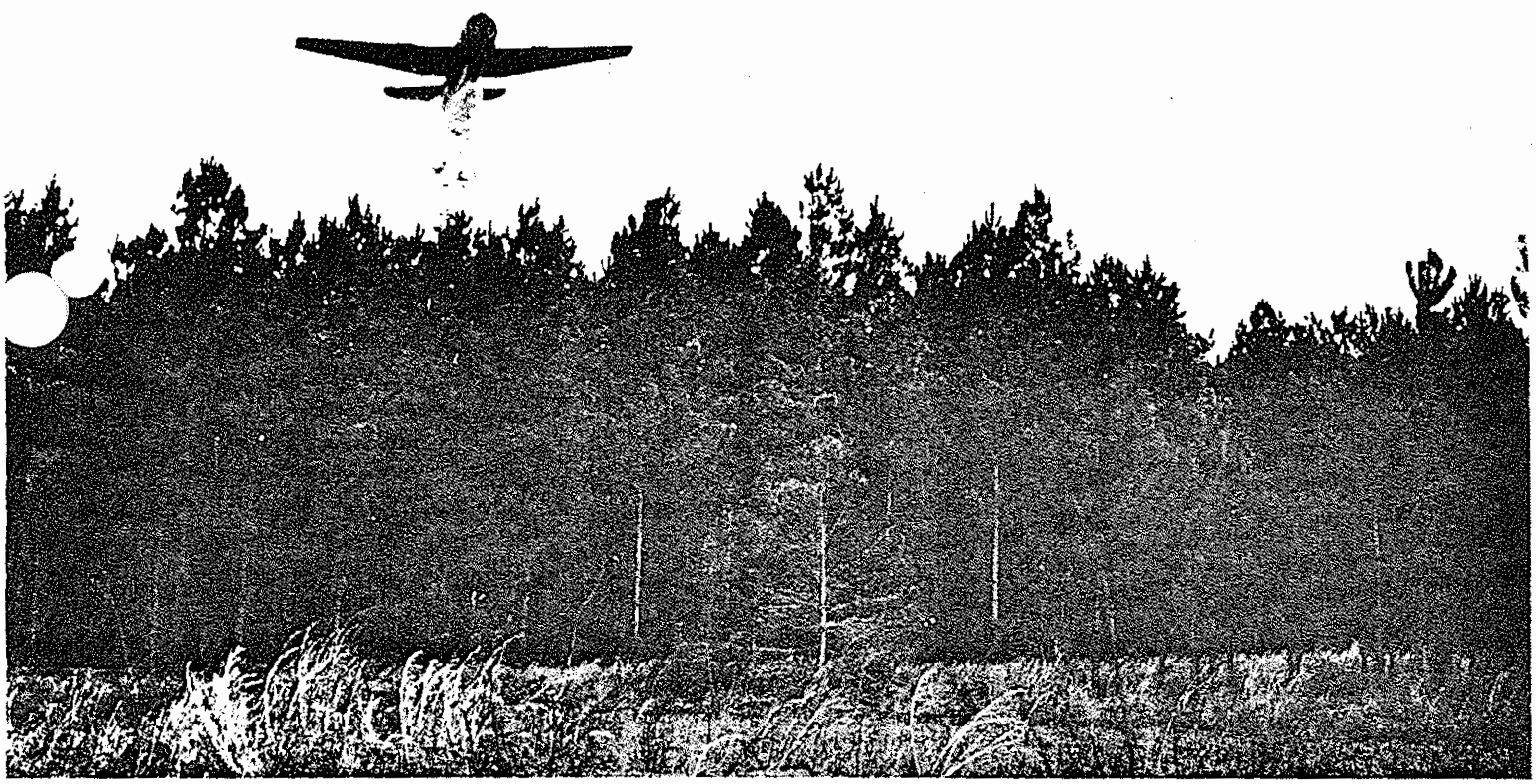

**U. S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE**

**Southeastern Forest Experiment Station**

**Asheville, N. C.**

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The successful use of aircraft for delivering suppressants and retardants on wildland fires in the West led to the tests reported in this paper. It seemed reasonable that if delivery equipment and techniques, developed principally in California, could be used in rugged western terrain, they could be even more useful in the relatively flat terrain of the Southeast. Accordingly, a U. S. Forest Service TBM tanker was obtained on loan in January 1958 for calibration tests in the South by the Southeastern Forest Experiment Station and for cooperative training on test fires by the U. S. Forest Service, Region 8; North Carolina Division of Forestry; and the Georgia Forestry Commission. The aircraft was available operationally for most of the spring fire season; but because a wet spring lowered fire incidence, it was not used on any wildfires.

Most of the operational drops in the West were on wildfires in brush and grassy fuels that had little or no timber overstory. Consequently, no information was available about the amount and distribution of slurry[1/] that could be expected to reach surface and understory fuels in timbered stands. The two objectives of this study were: (1) to determine through calibration tests the distribution and penetration patterns of slurry drops from a TBM in pine timber types with and without understory vegetation, and (2) to make preliminary evaluation of the effectiveness of TBM-delivered borate and wet water[2/] in retarding or suppressing test fires in several major fuel types.

## THE CALIBRATION TESTS

A series of calibration test drops were made on eight representative fuel types in Georgia and North Carolina, in order to determine the extent of crown penetration and distribution of fire retardants dropped from a TBM tanker (table 1).

The Georgia types, which included an open field, two slash pine plantations of different stocking, and a dense natural stand of slash pine reproduction, were located on the George Walton Experimental Forest. Only very sparse understory vegetation was present under the Georgia types, and pine litter covered the ground. A 15-year-old slash pine plantation with 400 stems per acre is shown in figure 1 and the slash pine reproduction in figure 2.

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1/ Slurry is a soupy mixture of kaolin, borate, or similar substances and water.

2/ Solution of liquid wetting agent and water.

The North Carolina tests were carried on in four of the heaviest and most widespread fuel types in the coastal plain. All four had a pond pine overstory and a dense understory vegetation (figures 3, 4, 5, and 6). The low and high pocosin[3] types were located in the Croatan National Forest and two cane types were on the Hofmann Forest. Fires in these four types are difficult to control, because of the density of the understory vegetation, large blocks unbroken by natural barriers, and poor trafficability.

Table 1.--Fuel types on which calibration drops were made

| Name (and fuel type) | Description | Overstory: Stems per acre | Overstory: Average height | Overstory: Age | Overstory: Crown closure | Average shrub height |
|---|---|---|---|---|---|---|
| | | Number | Feet | Years | Percent | Feet |
| GEORGIA | | | | | | |
| Open field (A) | Grass and broomsedge cover | -- | -- | -- | -- | -- |
| Slash pine plantation (B) | Initial spacing 15' x 15', no understory vegetation | 325 | 55 | 20 | 64 | -- |
| Slash pine plantation (C) | Initial spacing 10' x 10', no understory vegetation | 400 | 45 | 15 | 69 | -- |
| Slash pine reproduction (D) | Slash pine reproduction, uneven distribution, varying heights | 1,400 | 25 | 10 | 66 | -- |
| EASTERN NORTH CAROLINA | | | | | | |
| Low pocosin (E) | Pond pine overstory, brush, principally ericaceous, dense, easy to walk in | 40 | 10 | -- | Open | 2.5 |
| High pocosin (F) | Pond pine over dense brush, chiefly gallberry, smilax, bay, and cane, very difficult to walk in | 200 | 40 | 25 | 50 | 10 |
| Open cane (G) | Pond pine over reeds, grasses, beakrushes, chiefly with some gallberry, very easy to walk in | 20 | 25 | -- | Open | 4 |
| Overstoried cane (H) | Pond pine overstory, largest percent of understory in cane with some gallberry, smilax, with considerable pine needle drape, difficult to walk in | 200 | 35 | 20 | 50 | 7 |

3/ In the Southeast, pocosin means "swamp-on-a-hill." High and low refer to the height of the pond pine overstory.

Figure 1.—Fifteen-year-old slash pine plantation. There are 400 stems per acre and crown closure averages 69 percent.

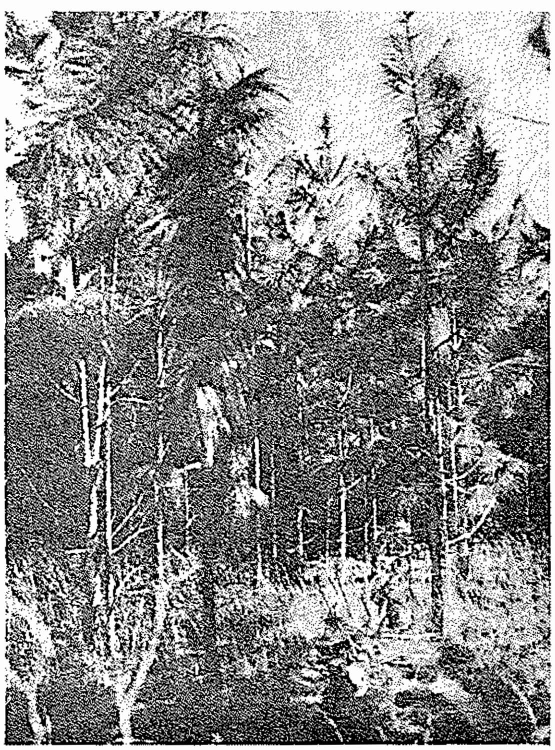

Figure 2.—Ten-year-old slash pine reproduction stand. There are 1,400 stems per acre and crown closure is 66 percent.

Figure 3.—Low pocosin type.

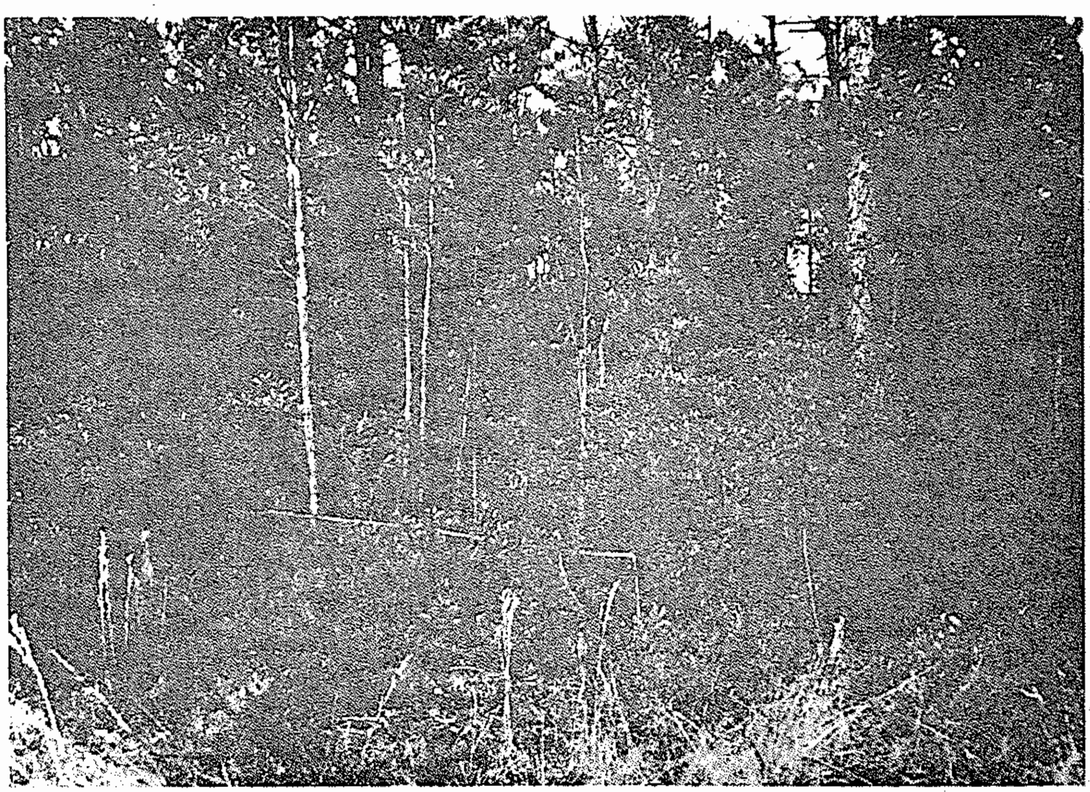

Figure 4.—High pocosin type.

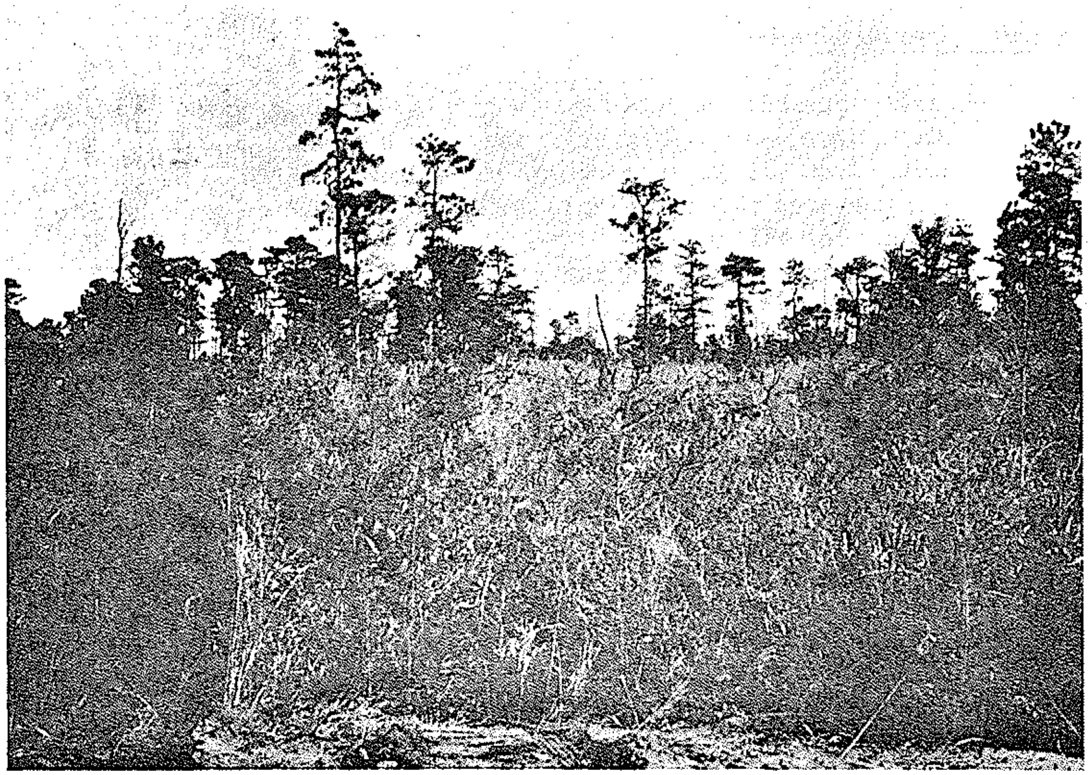

Figure 5.—Open cane.

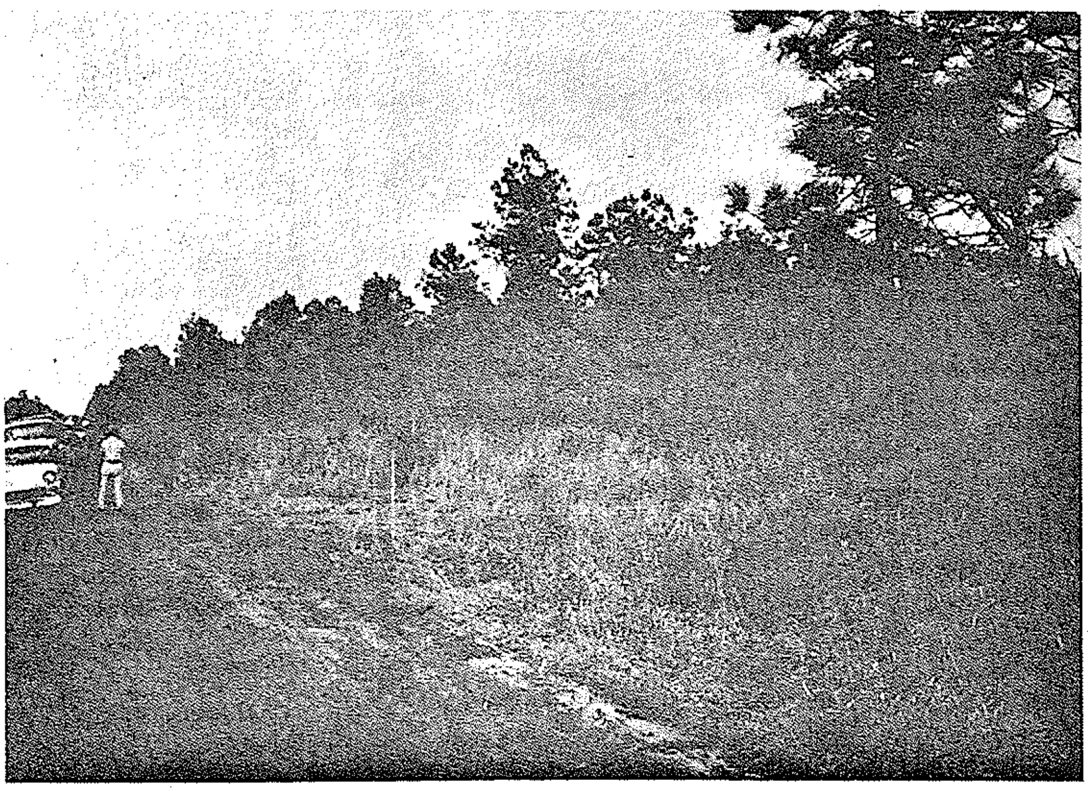

Figure 6.—Overstoried cane.

## Equipment and Material Used

The aerial tanker used in the tests was a single-engine torpedo bomber (TBM) of about 2,000 horsepower, formerly used by the Navy and now converted to drop liquids (1, 8, 9). With the bomb bay fittings and doors removed, the interior of the plane was fitted with a two-section aluminum tank having an approximate capacity of 440 gallons. Two hinged doors, each about 900 square inches in area, made up almost the entire bottom of the tank. They were hydraulically operated and were actuated by a pilot-controlled electric release mechanism. They could be operated singly or simultaneously and could be closed in flight when the sections were empty.

The material used for the calibration tests was a kaolin slurry made by mixing 1,250 pounds of kaolin (KCS Hydrite) with enough water to prepare 440 gallons. Kaolin slurry has approximately the same consistency as borate slurry, is cheaper than borate, and adheres well to vegetation. When dry it is much whiter than borate and thus offers a distinct advantage in observing test patterns.

## Procedure

In Georgia, three rectangular plots 120 feet by 288 feet were laid out in each fuel type. Each plot was divided into a grid of rectangles 18 feet by 20 feet. Pre-weighed, paraffin-coated paper cups, 6 inches in diameter, were placed at the grid intersections. No attempt was made to place all the cups under the same crown closure. Flags were fastened to treetops at one end of the grid to aid the pilot. After each drop the cups were re-weighed and the application rate in gallons per 100 square feet was determined for each cup location.

Three drops were made in each of the Georgia types:

1. Single 220--only 220 gallons released.

2. Double 220--two drops of 220 gallons were released with one superimposed on the other in successive runs.

3. Single 440--440 gallons released at one time.

So far as possible, the tests were conducted under uniform operating conditions (table 2). The plane was operated at a speed of 115 miles per hour at optimum altitude during release. Operational days were confined to those with surface winds 10 miles per hour or less and days when the vegetation foliage was dry.

The procedure used in North Carolina was basically the same as that in Georgia except that the cups were set at a grid spacing of 18 feet by 18 feet. Also the length of the grid was increased to 396 feet, because it was noted that the pilot sometimes overshot the shorter grid in Georgia. Instead of flags to mark the plot for the pilot, two weather-type balloons 3 feet in diameter were suspended on either side of the grid at its midpoint. Only 440-gallon drops were made in North Carolina.

## Results

A single 220-gallon drop on an open field (Type A) from an altitude of 75 feet gave a pattern 350 feet long and 80 feet wide (table 3, figures 7 and 8). A similar drop from an altitude of 70 feet on a slash pine plantation with no understory (Type C) gave a pattern 360 feet by 72 feet. Although the patterns do not differ greatly in dimensions, 86 percent of the load reached the ground in a readily observable pattern in Type A, whereas only 61 percent reached the ground in Type C. The difference in total gallons represents the amount of kaolin retained on the pine crowns in Type C.

Table 2.--Operational data for TBM kaolin calibration tests in Georgia and North Carolina, 1958

| Drop number | Date | Fuel | Load | Flight direction | Height of plane[1] | Wind: Direction | Wind: Speed | Relative humidity | Air temperature | Accuracy |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Type | Gallons | | Feet | | Miles per hour | Percent | Degrees F. | |
| 1 | Feb. 10 | A | 220 | N-S | 75 | NW | 6 | 35 | 48 | Good-left |
| 2 | Feb. 12 | A | Double 220 | N-S | 50 | N | 5 | 36 | 41 | Good-left |
| 3 | Feb. 10 | A | 440 | N-S | 85 | NW | 5 | 33 | 48 | Long-left |
| 4 | Feb. 20 | B | 220 | S-N | 75 | SW | 7 | 43 | 47 | Good |
| 5 | Feb. 5 | B | Double 220 | W-E | 85 | SW | 8 | 45 | 65 | Long-left |
| 6 | Feb. 20 | B | 440 | S-N | 75 | SW | 4 | 55 | 40 | Good |
| 7 | Feb. 12 | C | 220 | E-W | 70 | NW | 6 | 29 | 46 | Good |
| 8 | Feb. 12 | C | Double 220 | S-N | 70 | NNW | 7 | 28 | 48 | Long-right |
| 9 | Feb. 12 | C | 440 | N-S | 60 | N | 4 | 29 | 45 | Good-left |
| 10 | Feb. 21 | D | [2] Double 220 | SW-NE | 60 | SW | 2 | 58 | 38 | Good-left |
| 11 | Feb. 21 | D | 440 | NE-SW | 75 | SW | 3 | 49 | 44 | Long-left |
| 12 | Mar. 24 | E | 440 | NE-SW | 100 | W | 13 | -- | 55 | Good-long |
| 13 | Mar. 24 | F | 440 | SW-NE | 100 | NE | 7 | -- | 55 | Good-right |
| 14 | Mar. 28 | G | 440 | SW-NE | 76 | NW | 7 | 46 | 58 | Good-long |
| 15 | Mar. 28 | H | 440 | SW-NE | 91 | NW | 3 | 44 | 55 | Good |

1/ Above ground. All drops at 115 miles per hour air speed.
2/ The single 220 drop in Type D was omitted because of poor accuracy of the drop.

Table 3.--Results of calibration tests in Georgia and eastern North Carolina

| Drop (amount) | Fuel[1/] | Contour line[2/] | Area between adjacent contour lines | Length of pattern | Average width of pattern | Amount of slurry on ground | |
|---|---|---|---|---|---|---|---|
| | | | | | | Approx. total | Total load |
| | Type | Gallons per hundred square feet | Square feet | Feet | Feet | Gallons | Percent |
| 220 | A | 0.0 | 24,105 | 350 | 80 | | |
| | | .5 | 6,687 | 252 | 54 | | |
| | | 1.0 | 3,525 | 162 | 30 | | |
| | | 2.0 | 1,555 | 80 | 15 | 192 | 86 |
| Double 220 | A | .0 | 10,523 | 360 | 72 | | |
| | | .5 | 8,139 | 342 | 54 | | |
| | | 1.5 | 5,391 | 288 | 22 | | |
| | | 2.0 | 3,110 | 189 | 18 | | |
| | | 3.0 | 1,037 | 144 | 7 | 287 | 65 |
| 440 | A | .0 | 25,142 | 378 | 90 | | |
| | | .5 | 5,184 | 252 | 54 | | |
| | | 1.0 | 4,043 | 216 | 36 | | |
| | | 1.5 | 2,333 | 189 | 27 | | |
| | | 2.0 | 985 | 144 | 15 | | |
| | | 2.5 | 778 | 72 | 5 | 234 | 53 |
| 220 | B | .0 | -- | -- | -- | | |
| | | .25 | 4,014 | 162 | 70 | | |
| | | .50 | 3,740 | 126 | 50 | | |
| | | 1.00 | 1,267 | 54 | 40 | | |
| | | 2.00 | 228 | 25 | 10 | (3/) | (3/) |
| Double 220 | B | .0 | -- | -- | -- | | |
| | | .5 | 5,184 | 216 | 50 | | |
| | | 1.0 | 2,229 | 180 | 18 | | |
| | | 1.5 | 1,710 | 170 | 15 | | |
| | | 2.0 | 1,296 | 108 | 10 | (3/) | (3/) |
| 440 | B | .0 | 15,707 | 360 | 80 | | |
| | | .50 | 5,288 | 306 | 25 | | |
| | | 1.00 | 3,940 | 216 | 20 | | |
| | | 2.00 | 1,502 | 126 | 18 | | |
| | | 3.00 | 574 | 60 | 5 | 192 | 44 |
| 220 | C | .0 | 21,410 | 360 | 72 | | |
| | | .50 | 4,510 | 216 | 27 | | |
| | | 1.00 | 1,814 | 126 | 19 | | |
| | | 2.00 | 1,192 | 45 | 15 | 135 | 61 |
| Double 220 | C | .0 | -- | -- | -- | | |
| | | .5 | 8,502 | 306 | 54 | | |
| | | 1.0 | 2,903 | 180 | 45 | | |
| | | 1.5 | 2,488 | 160 | 20 | | |
| | | 2.0 | 829 | 140 | 10 | (3/) | (3/) |

Table 3.--Results of calibration tests in Georgia and eastern North Carolina (cont'd)

| Drop (amount) | Fuel 1/ | Contour line 2/ | Area between adjacent contour lines | Length of pattern | Average width of pattern | Amount of slurry on ground: Approx. total | Amount of slurry on ground: Total load |
|---|---|---|---|---|---|---|---|
| | Type | Gallons per hundred square feet | Square feet | Feet | Feet | Gallons | Percent |
| 440 | C | 0.0 | 17,107 | 369 | 81 | | |
| | | .5 | 8,294 | 234 | 54 | | |
| | | 1.0 | 3,888 | 198 | 15 | | |
| | | 2.0 | 518 | 54 | 9 | 173 | 39 |
| Double 220 | D | .0 | 16,485 | 342 | 72 | | |
| | | .5 | 5,547 | 252 | 45 | | |
| | | 1.0 | 3,266 | 198 | 20 | | |
| | | 2.0 | 1,555 | 126 | 15 | 163 | 37 |
| 440 | D | .0 | -- | -- | -- | | |
| | | .5 | 4,873 | 252 | 36 | | |
| | | 1.0 | 2,229 | 198 | 18 | | |
| | | 1.5 | 1,552 | 126 | 10 | (3/) | (3/) |
| 440 | E | .0 | 17,314 | 378 | 72 | | |
| | | .5 | 7,154 | 252 | 47 | | |
| | | 1.0 | 3,473 | 189 | 25 | | |
| | | 1.5 | 1,037 | 72 | 18 | 155 | 35 |
| 440 | F | .0 | 9,643 | 351 | 81 | | |
| | | .25 | 8,605 | 252 | 72 | | |
| | | .50 | 4,976 | 207 | 27 | | |
| | | 1.00 | 2,022 | 180 | 10 | 101 | 23 |
| 440 | G | .0 | 11,664 | 342 | 90 | | |
| | | .5 | 10,524 | 288 | 54 | | |
| | | 1.0 | 3,784 | 126 | 36 | | |
| | | 1.5 | 1,140 | 108 | 15 | 171 | 39 |
| 440 | H | .0 | 13,219 | 360 | 75 | | |
| | | .5 | 9,383 | 297 | 54 | | |
| | | 1.0 | 4,510 | 216 | 36 | | |
| | | 1.5 | 1,867 | 162 | 14 | | |
| | | 2.0 | 414 | 79 | 12 | 200 | 45 |

1/ Refers to types described in table 1. The single 220 drop in Type D was omitted because of poor accuracy of the drop.

2/ Lines of equal kaolin concentration. The zero contour line represents the outer limit of visible kaolin coating on the surface litter.

3/ Indeterminate because a large portion of the outermost contour line fell outside the cup grid.

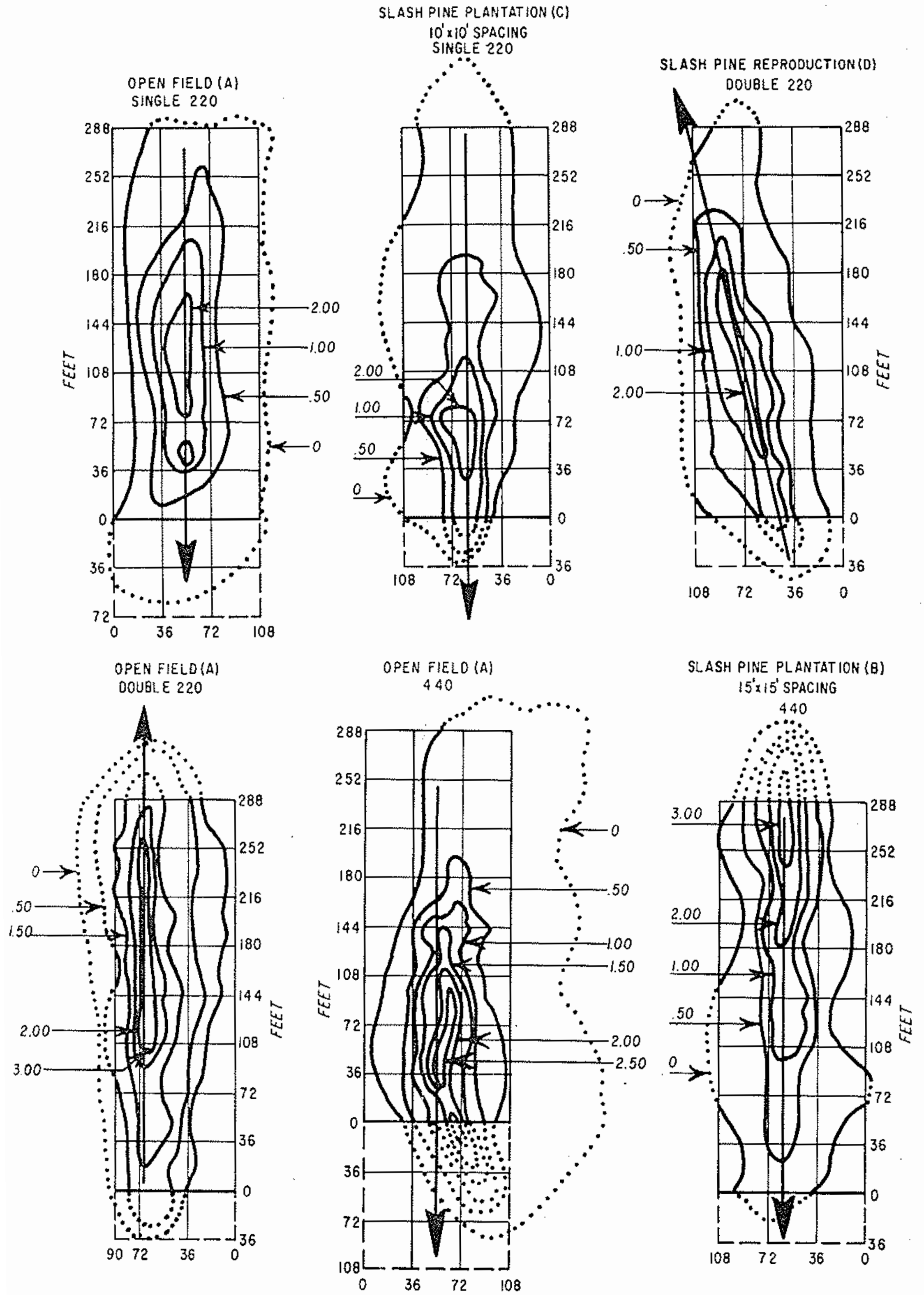


Figure 7.—Sample distribution patterns of calibration tests in Georgia. Contour lines represent concentration of kaolin in gallons per 100 square feet. Heavy arrows indicate direction of flight. Dotted portions of patterns are estimated.

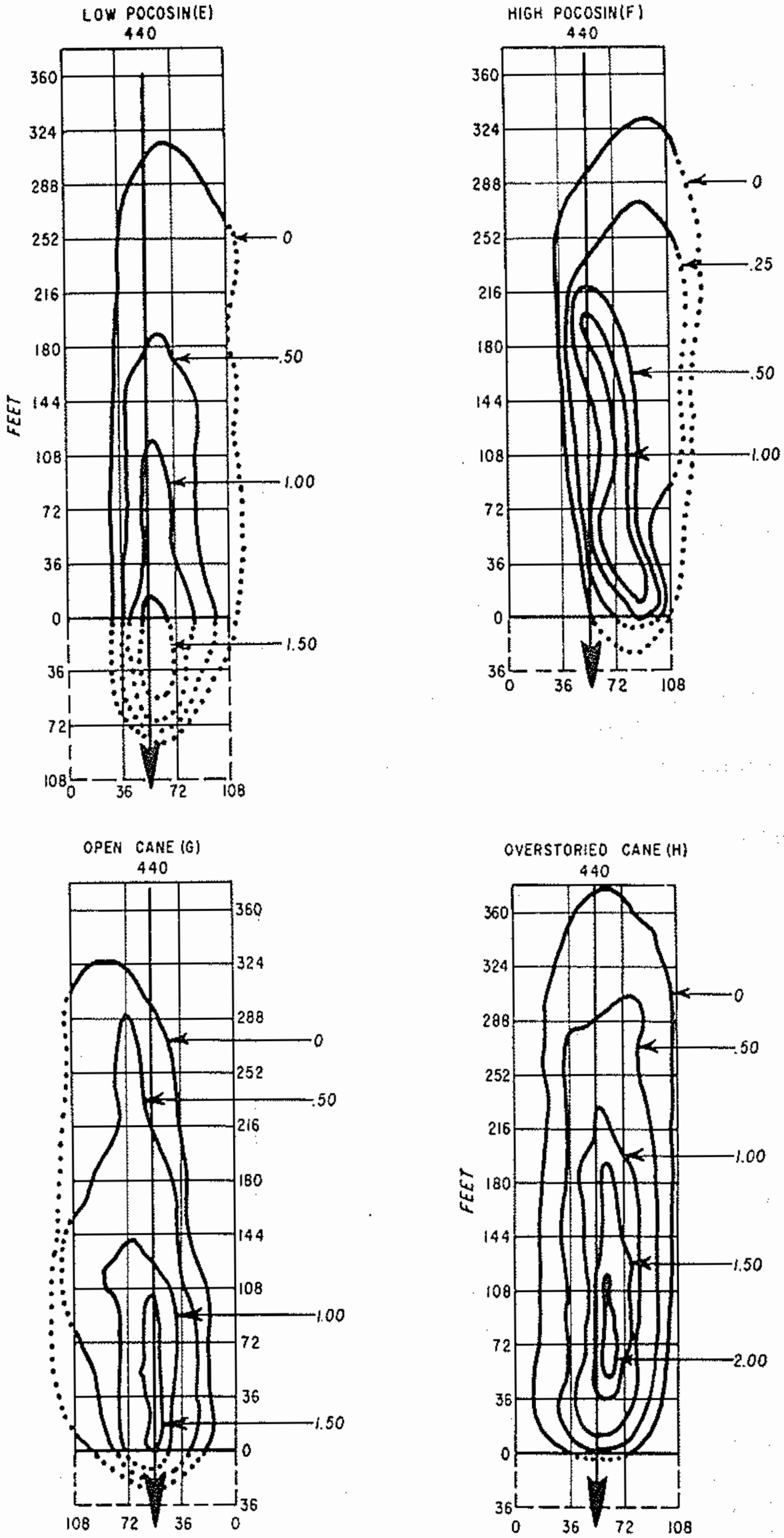


Figure 8.—Sample distribution patterns of calibration tests in North Carolina. Contour lines indicate concentration of kaolin in gallons per 100 square feet. Heavy arrows indicate direction of flight. Dotted portions of patterns are estimated.

A comparison of the 440-gallon drops in Types B, C, E, F, G, and H with a 440-gallon drop in Type A shows that the over-all pattern size remains fairly constant even though the altitude from which the drops were made varied between 60 and 100 feet. About 53 percent of the total load reached the ground in the open (Type A), whereas the amount that reached the ground in Types B, C (slash pine types), and E, F, G, and H (pond pine types) were 44, 39, 35, 23, 39, and 45 percent of the total load, respectively. The differences in the amounts that reached the ground in the several vegetation types and in the open area represent the amount of slurry which was retained on the overstory and understory vegetation. Figures 9 through 13 give an indication of the extent of kaolin slurry coating in some of the North Carolina types.

A double 220-gallon drop in the open from an altitude of 50 feet gave a pattern 360 feet long and 72 feet wide. A similar drop in Type D gave a pattern 342 feet long and 72 feet wide. Sixty-five percent of the total load reached the ground in the open whereas only 37 percent of the total load reached the ground in Type D.

Discussion

It is evident from the results that in all types the over-all pattern size for 220, double 220, or 440 gallons does not vary greatly. The variations in the size of the several patterns may be attributed to varying air speed, differences in drop altitude, crabbing of the airplane, wind, and accuracy (in the case of the double 220-gallon drops).

In Types B, C, and D, which are slash pine stands of various ages, spacings, and densities but with similar crown closures, the percent of the total load that reached the ground, with one exception, varied only by 7 percent.

Even though the overstory crown closure was less in the North Carolina pocosin and cane types, slightly less slurry reached the ground than in the Georgia slash pine types. The reduction was due to the dense shrub and cane vegetation under the North Carolina types. Almost complete coating of the understory was observed in an area 250 feet long by 40 feet wide, or roughly the area encompassed by the 0.5 gallon per 100 square feet kaolin contour. In Types E and F (low and high pocosin), which have a predominantly broad-leaved shrub understory, less slurry reached the ground than in Types G and H (cane types), which have a larger percentage of canes and grasses in the understory. Probably the more vertical habit of the canes and grasses permitted a larger amount of the slurry to reach the ground.

Although the test results indicate the application rates of kaolin slurry that penetrated different fuel types, they do not offer any information about the minimum application rates necessary to retard or extinguish fires in these types. With this in mind, a series of test fire drops were planned on Types E, F, G, and H in eastern North Carolina.

Figure 9.—Aerial view of low pocosin type after a drop of 440 gallons of kaolin slurry. (N. C. Division of Forestry photo.)

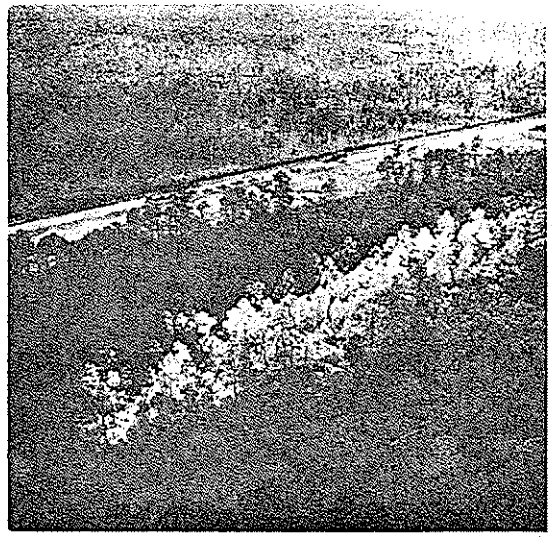

Figure 10.—Aerial view of high pocosin type after a drop of 440 gallons of kaolin slurry. (N. C. Division of Forestry photo.)

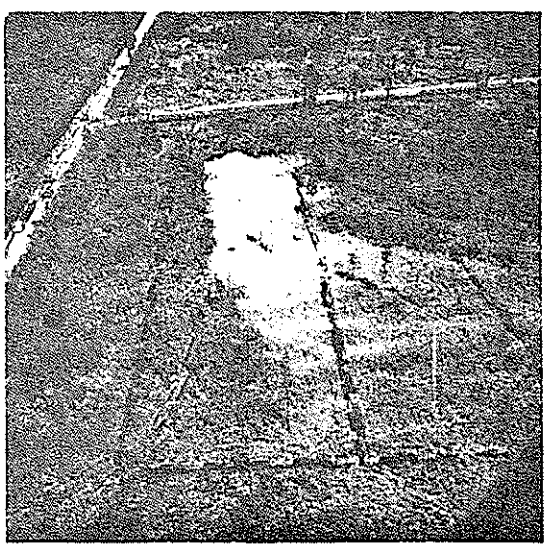

Figure 11.—Open cane after 440-gallon kaolin calibration drop. (N. C. Division of Forestry photo.)

Figure 12.—Overstoried cane after 440-gallon kaolin calibration drop. (N. C. Division of Forestry photo.)

Figure 13.—Low pocosin type, showing extent of kaolin slurry coating from a 440-gallon drop.

## DROPS ON TEST FIRES

### Procedure

One borate plot and one wet-water plot, each approximately 400-feet square, were laid out in the four fuel types in North Carolina. One or more firelines were plowed around each plot to provide fire protection and to define the plots for the pilot.

The borate slurry used in the test fire drops was prepared in 440-gallon batches by mixing approximately 1,600 pounds of borate with water in an injector mixer as described by Miller and Wilson (6).

The wet-water solution was prepared by adding one quart of a liquid wetting agent to a 440-gallon load of water. Vibration of the aircraft served to mix the chemical adequately. The solution approximated the heaviest concentration recommended by the manufacturer to obtain deep penetration of forest fuels.

The borate drops were planned to simulate indirect attack. Consequently, the borate line was laid down from 15 seconds to 20 minutes prior to arrival of the flame front. The wet-water drops were made on the flame line to simulate direct attack.

## Burning Conditions

The fire drop tests were conducted on two afternoons between 1:30 p. m. and 6:45 p. m. when fire danger was medium (table 4). Air temperatures ranged from 60° to 80° F. and relative humidities were between 24 and 39 percent. Wind was steady from the NE and ranged up to 8 m.p.h. Fuel moistures did not exceed 7 percent. Ground water tables were near the surface and water was standing in the plowed firelines. All plots except the borate plot in the low-pocosin type were easily ignited. Fire spread rapidly from the start; and, in the case of the wet-water plots, it was necessary to have the air tanker circling overhead as a precautionary measure before fires were set. In all cases, however, fires had gained maximum intensity before reaching the treated lines. The fires ranged in intensity from low-medium to high-medium except for one which was very low intensity (table 5).

## Results and Discussion

In all fire tests the drops were placed with sufficient accuracy to provide useful information on their effectiveness in retarding and suppressing fire. Both the borate and wet-water patterns appeared to be similar to the calibration patterns found for kaolin for equal loads dropped in similar fuel types.

Table 4. --Operational data for TBM borate and wet-water drops on test fires in North Carolina, 1958

| Fuel type | Date | Air temperature | Relative humidity | Wind | | Fuel moisture | Fire danger | | Time | | [1] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Direction | Velocity | | Buildup index 8-100-0 | Burning index 8-100-0 | Fire set | Drop | Height of plane |
| | | Degrees F. | Per-cent | | Miles per hour | Per-cent | | | | | Feet |
| E | Apr. 18 | 70 | -- | -- | 0 | [2] 5.5 | [2] 6 | [2] 1 | 6:45 p. m. | 6:46 p. m. | 80 |
| E | Apr. 18 | 77 | 32 | NE | 3 | 5.5 | 6 | 5 | 5:20 p. m. | [3] 5:30 p. m.<br>5:33 p. m. | 80<br>80 |
| F | Apr. 18 | 75 | 32 | NE | 2-3 | 4.5 | 6 | 7 | 3:11 p. m. | 3:10 p. m. | 85 |
| F | Apr. 18 | 80 | 32 | NE | 4.5 | 4.5 | 6 | 10 | 4:20 p. m. | 4:30 p. m. | 90 |
| G | Apr. 10 | [4] 73 | [4] 24.5 | [4] NE | [4] 8 | [4] 7 | [4] 10 | [4] 16 | 1:40 p. m. | 1:50 p. m. | 100 |
| G | Apr. 10 | 69 | 32 | NE | 3 | 7 | 10 | 16 | 3:15 p. m. | 3:18 p. m. | 80 |
| H | Apr. 10 | 60 | 39 | NE | 1-2 | 6 | 10 | 16 | 5:10 p. m. | 4:45 p. m. | 75 |
| H | Apr. 10 | 60 | 39 | NE | 8 | 6 | 10 | 8 | 5:50 p. m. | 6:00 p. m. | 80 |

1/ Above ground. All drops at 115 miles per hour air speed.

2/ Deppe fire danger station 10 miles away. 2:00 p. m. buildup index. Burning index and fuel moisture at time fire set. Other weather measurements on site.

3/ Double 220-gallon drop.

4/ Portable fire danger station on site. 2:00 p. m. buildup index. Other weather measurements at time fire set.

Table 5.--Results of TBM borate and wet-water fire drop tests in North Carolina, 1958

| Fuel type | Date | Material dropped: Name | Material dropped: Amount | Type of fire | Average flame height above ground | Estimated fire intensity 1/ | Relative fire intensity | Effective line: Retarded | Effective line: Estimated minimum application rate | Effective line: Extinguished | Effective line: Estimated minimum application rate |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Gallons | | Feet | B.t.u. per second per foot | | Feet | Gallons per 100 sq. ft. | Feet | Gallons per 100 sq. ft. |
| E | Apr. 18 | Borate | 440 | Head | 1 | 6 | Very low | 2/ 300 | 0.5 | 2/ 300 | 0.5 |
| E | Apr. 18 | Wet water | 220<br>220 | Head | 12 | 770 | Low-med. | 3/ 200<br>200 | .8<br>.8 | 3/ 200<br>200 | .8<br>.8 |
| F | Apr. 18 | Borate | 440 | Head | 25 | 2,100 | Med. | 250 | .3 | 230 | .4 |
| F | Apr. 18 | Wet water | 440 | Flank-head | 25 | 2,100 | Med. | 300 | .2 | 250 | .3 |
| G | Apr. 10 | Borate | 440 | Head | 20 | 2,400 | Med. | 300 | .4 | 250 | .6 |
| G | Apr. 10 | Wet water | 440 | Flank | 20 | 2,400 | Med. | 300 | .5 | 280 | .6 |
| H | Apr. 10 | Borate | 440 | Head | 15 | 520 | Low-med. | 300 | .5 | 280 | .6 |
| H | Apr. 10 | Wet water | 440 | Flank | 25 | 3,100 | High-med. | 350 | .2 | 300 | .5 |

1/ From the equation $h = 0.45\ I^{0.46}$, where h = flame height in feet and I = fire intensity in B.t.u./sec./foot of fire front. This equation appears in chapter 3, "Combustion of Forest Fuels," by G. M. Byram, in the book Forest Fire Control and Use by K. P. Davis.

2/ Full pattern was effective because of low fire intensity.

3/ Drops laid end to end totaling 400 feet of effective line.

In the high-pocosin type, which is rated a heavy fuel in North Carolina, borate retarded 250 feet and extinguished 230 feet of medium-intensity headfire. The minimum application rates of borate via airdrop to ground needed to retard and extinguish this much line were estimated to be about 0.3 gallon and 0.4 gallon per 100 square feet, based on the calibration drops. In the overstoried cane (which is also a heavy fuel), borate retarded 300 feet and extinguished 280 feet of low-medium intensity headfire. Minimum application rates were estimated to be 0.5 and 0.6 gallon per 100 square feet, respectively.

A 440-gallon load of borate dropped in the open cane, a medium fuel, retarded 300 feet and extinguished 250 feet of medium-intensity headfire. Estimated minimum application rates necessary to achieve these results were 0.4 and 0.6 gallon per 100 square feet, respectively. In the low pocosin type, with a fuel volume similar to the open cane type, fire was extinguished over 300 feet of line (nearly the full length of the borate pattern) because unfavorable burning conditions produced a fire of very low intensity.

In all four fuels, pattern widths were observed to be more than adequate to stop the test headfires of all intensities. In no case was there a gap in the pattern large enough to allow the test fires to cross into uncoated fuels.

In both medium and heavy fuels, fire was crowning along portions of the line when it reached the borate-treated strip. In no case did fire carry through the crowns past the treated strip.

The fire-retardant properties of borate were well demonstrated in the high pocosin type. Immediately after the drop, a fire was set about 100 feet upwind of the retardant line. The fire moved rapidly through the dense 7-foot tall underbrush and often ran to and above the crowns of the 35-foot pond pines. The average flame height was 25 feet above ground. When the fire reached the borate line, it quickly dropped to the ground and crept along until finally it was extinguished by the coated fuel. This decrease in flame height corresponds to a reduction in fire intensity from approximately 2,100 B.t.u. per second per foot of fireline (medium intensity) to essentially zero in just a few minutes. Figures 14, 15, and 16 show the sequence of events during indirect attack on fire in open cane.

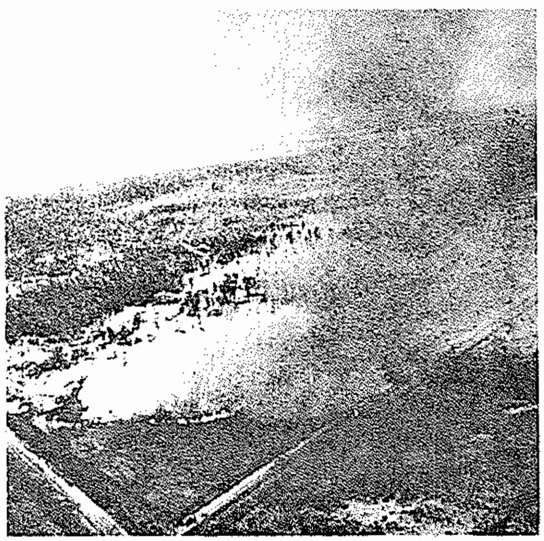

Figure 14.—Open cane in the borate fire test plot. The loaded TBM is just arriving. Flames average 20 feet high. (N. C. Division of Forestry photo.)

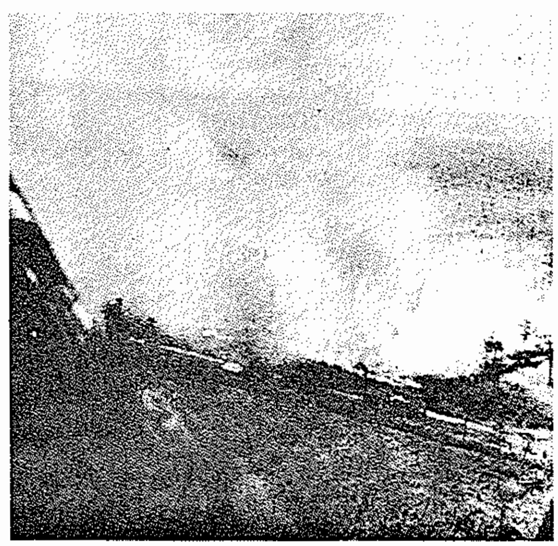

Figure 15.—Open cane in the borate fire test plot. The TBM pilot has just released his 440-gallon load aimed just ahead of the fire. Altitude 100 feet above ground. (N. C. Division of Forestry photo.)

Figure 16.—Open cane in the borate fire test plot about two minutes after drop. Fire has burned into borate line and is fairly well controlled in the area visible in the picture. (N. C. Division of Forestry photo.)

Figure 17.–Open cane in the wet-water fire test plot. The pilot has just released his 440-gallon load aimed directly at the line of 20-foot flames marked by light smoke. The fire was burning hot with little smoke. (N. C. Division of Forestry photo.)

Results of the wet-water drops in direct attack were similar to the results from the borate drops for similar fuels and fire intensities (table 5). In heavy fuels, wet-water drops retarded an average of 325 feet and extinguished 275 feet of medium-intensity flank fire. Estimated minimum application rates 4/ of wet water to retard and extinguish fire were 0.2 and 0.4 gallon per 100 square feet. The wet-water drop in the open cane, a medium fuel, retarded 300 feet and extinguished 280 feet of medium-intensity flank fire. Minimum application rates to retard and extinguish fire were estimated to be 0.5 and 0.6 gallon per 100 square feet, respectively. Crown fire was knocked to the ground and was extinguished within the effective pattern area (figures 17, 18, and 19).

In all of these tests borate and wet water retarded and extinguished approximately equal lengths of fire front in similar fuel types (table 5); however, timing was somewhat different. Fire burning into a borate line was knocked to the ground and then gradually decreased in rate of spread and intensity until finally it was extinguished; wet water dropped directly on the flame line achieved about the same results almost immediately. Of course borate can also be used in direct attack, but it is considerably more expensive than wet water. One of borate's values lies in the residual coating of retardant left on the fuels after the water in the slurry has evaporated.

Figure 18.—Open cane in the wet-water fire test plot. Cloud of wet water is settling over the fireline enveloping it almost completely. (N. C. Division of Forestry photo.)

Figure 19.—Open cane in the wet-water fire test plot one minute after drop. Fire almost completely extinguished within pattern. (N. C. Division of Forestry photo.)

4/ Based on kaolin calibration tests.

In the low-pocosin type, two 220-gallon loads of wet water laid end to end in quick succession were dropped on a line of fire 400 feet long. The two drops together knocked down and extinguished a substantially greater length of line (400 feet) than a single 440-gallon drop (up to 300 feet). The width of pattern of each 220-gallon drop was adequate to extinguish the depth of fire front in this type with a margin of safety.

Two additional fire drops with borate were made on March 1 near Waycross, Georgia, in a medium-stocked stand of longleaf and slash pine with predominantly palmetto-gallberry understory. Although general weather conditions were similar to those for the North Carolina pine drops, the ground fuel (litter) was considerably drier. Carrying a full load of 440 gallons, the TBM laid a borate swath about 75 feet ahead of a flank fire by dropping half its load end-to-end in each of two runs. A similar pattern was laid in front of a head fire. Both fires were of about equal intensity, advancing at the rate of 5 chains per hour.

Only the very center of each drop pattern, an area encompassing 1,000 to 2,000 square feet, actually stopped the advancing fire. Palmetto fronds in this area were heavily coated with borate and although the application rate on the surface litter under the palmetto was less, the fuel was well covered. The fire was cooled in the remaining pattern area and brought down from the palmetto fronds to the pine needle litter on the ground but the fire continued to advance, though at reduced intensity.

The penetration rate of aerial slurries through palmetto-gallberry fuels was not calibrated; however, observations showed considerably more borate was intercepted than in other understory brush species tested. This was largely due to the protective effect of the palmetto fronds. Consequently, patterns of equal application rates for equal loads and lengths of fireline extinguished and retarded were shorter in the Georgia palmetto fuels than in the broadleaf brush fuels in North Carolina.

## CONCLUSIONS

1. Equal volumes of borate and of wet water in similar fuels retarded and suppressed approximately equal lengths of fireline. However, because borate was not delivered on test fire fronts, a direct comparison of the effectiveness of borate slurry and wet water cannot be made.

2. Wet water and borate may be about equally effective for direct attack on low to medium intensity fires. However, for wet water to be as effective as borate it would have to be dropped on or close in front of the fire, because wet water will evaporate relatively quickly. The pilot must have an unobstructed view of the flame line when dropping wet water.

3. Borate probably would be more effective than wet water for indirect attack when the retardant line is laid down ahead of the flame line; also, for direct attack on days when the flame line is obscured by smoke and there is a chance that the pilot might overshoot his target.

4. Effective lines from which to backfire can be built from the air in light, medium, or even heavy fuels with either 220- or 440-gallon loads of borate slurry.

We realize that the air tanker is only another tool in fire control. However, in inaccessible areas or where trafficability is poor, air tankers with a capacity of 400 gallons or less may be effective in extinguishing small fires and containing larger fires of medium intensity until ground equipment can arrive. Planes such as the Stearman and N3N, with capacities of 100-125 gallons, have been used successfully in the West (2, 3, 5). Certainly they deserve an adequate trial in the South. Relatively flat topography and numerous small airstrips would make their potential even more promising. As in the West, Stearman-type aircraft are used extensively in the South for agricultural flying and presumably would be available on a contract basis.

Other small aircraft, such as float-type planes, have been successfully used in Canada (7) and the United States (4). Perhaps in the Southeastern coastal plain, where there are numerous lakes, rivers, and sounds, this type would be effective.

Larger aircraft with 1,000 to 2,000 gallon capacity also deserve to be tried. The PBY, for example, has been used successfully in California (1). It should be even more effective in the Southeast, where topography is much less of a problem.

Because these tests were exploratory in nature, no attempt was made to keep detailed time and cost figures. However, cost-benefit considerations will ultimately determine whether or not aerial fire suppression methods will be used in the Southeast, and also how extensively.

## SUMMARY

In the spring of 1958, 15 calibration drops of kaolin slurry from a TBM tanker were made in natural and planted pine timber types in the coastal plain of North Carolina and Georgia. In addition, the effectiveness of borate and of wet-water drops was observed on test fires in coastal North Carolina. Two additional borate fire drops were made in palmetto-gallberry fuels in Georgia.

Over-all pattern size for 220-, double 220-, or 400-gallon kaolin calibration drops made from altitudes between 50 and 100 feet above ground was about 370 feet by 75 feet in all fuel types. Patterns were fairly uniform with no gaps of low concentration.

The amount of slurry that reached the ground in a readily discernible pattern varied with the size of load, height of drop, cover type, and wind velocity. In the open, 86 percent, 65 percent, and 53 percent of 220-, double 220-, and 440-gallon loads, respectively, reached the ground. The low proportion of slurry measured from the 440-gallon drop in the open probably was caused by the 10- to 35-foot greater drop height compared to the other two drops in the open. Catch for 440-gallon drops averaged 41 percent under medium-density pine plantations with no understory, 37 percent under open pond pine with dense understory vegetation, and 34 percent for medium-dense pond pine stands with dense understory. The differences in amounts reaching the ground in the several types, as compared to the open, represent the amounts retained on the overstory and understory vegetation. Almost complete coating of the understory vegetation and surface litter was observed where the application rate on the ground was about 0.4 gallon or more per 100 square feet.

In the fire drop tests, indirect attack with 440 gallons of borate slurry retarded an average of 275 feet and extinguished 255 feet of medium-intensity headfire, in medium-dense pond pine timber with dense brush and reed understory. Estimated minimum application rates on the ground of about 0.4 and 0.5 gallon per 100 square feet were required to achieve these results.

Borate drops on fires similar to those mentioned above but in very open pond pine timber with dense brush and cane understory retarded 300 feet and extinguished 275 feet of fireline. Estimated minimum application rates to retard and extinguish fire were 0.5 and 0.6 gallon per 100 square feet, respectively. These estimates are not applicable to palmetto-gallberry fuel types of the coastal plains, where heavier application rates are apparently needed.

Direct attack with 440 gallons of wet water achieved about the same results as indirect attack with borate in similar fuel types and under similar burning conditions. Minimum application rates were approximately the same for both agents.

Two 220-gallon loads of wet water laid end to end extinguished a total of 400 feet of medium-intensity headfire or 200 feet on each pass in medium-density fuels.

Pattern widths for both 220- and 440-gallon loads appeared to be sufficiently wide to retard and extinguish specified lengths of line in the four fuel types. In no case was there a gap in the pattern wide enough to allow fire to cross into uncoated fuel.

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