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The primary objective of this study is to explore the possibilities of two methods to reduce the weight of small commercial timber prior to logging. The two methods studied are injection of cacodylic acid and sour-felling. Treatments were applied in November, 1965 and May, 1966, with final harvest of the stand occurring in September and October, 1966. The weight reduction, as indicated by the moisture content, was compared to untreated trees. Results are based on wood samples taken from all trees and a weighed truckload of logs from each treatment.

The data indicate small differences among the same treatments due to seasonal application. Reductions in weight range from ten to 20 percent when compared to the untreated trees. Some indication of economic potentials is presented.

Sour-felled trees were readily attacked by insects but chemical

treatments suffered negligible attack. Felling and woods operations were not adversely influenced. Backflash, while present to a limited degree, may be a result of application method and could be reduced by other means of treating.

Pre-harvest Measures to Reduce the Weight of Second-growth Douglas-fir

by

Harvey Allen Holt

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INTRODUCTION

Depletion of virgin stands of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) will soon require the forest industry to shift from old-growth to second-growth utilization. The nature of the trees involved in second-growth harvests makes many management practices marginal economically, since the small trees provide low volume per log and low grade products. This study is directed towards the exploration of two possible methods of shifting the economic balance of managing small timber to a more favorable position. Both involve pre-harvest drying.

The first method involves tree killing by chemical treatment, with the anticipation that the moisture lost by air-drying of the standing dead tree will constitute a significant weight reduction. The second method may be termed sour-felling, transpiration-drying, or biological seasoning. In this method trees are felled as normally, but they are left untrimmed and unbucked with the expected drying resulting from the transpiration of the live crown. Breakage, fire hazard, ease of felling, grade reduction due to insects or decay, and bark loss are important considerations in both practices.

LITERATURE REVIEW

Sour-felling

Sour-felling is the procedure of felling in the growing season and leaving crowns intact for awhile to effect seasoning by transpiration (8). In his forest dictionary, Aro records the words syrfälla (1, p. 66) and syrfällning (1, p. 248) as meaning: "to fell a tree and leave it untrimmed" and "allowing trees to lie and season as felled with tops intact," respectively. These words are of Swedish origin and are not yet a part of common forest terminology.

The practice of sour-felling is not common in North America but has been practiced for centuries in the European countries (3). Its use has been restricted generally to small trees to be used for fuel, charcoal production, and pulpwood. European species include birch (*Betula* spp.) (3, 8, 9, 17, 23), beech (*Fagus sylvatica* L.) (5, 9), Norway spruce (*Picea abies* (L) Karst.) (2, 9), larch (*Larix* spp.) (13), oak (*Quercus* spp.) (5), and Scots pine (*Pinus sylvestris* L.) (5). North American species include Douglas-fir (16), aspen (*Populus* spp.) (25), and sugar maple (*Acer saccharum* Marsh.) (6).

Effect on moisture content. Numerous European reports have indicated appreciable reductions in weight by this treatment. Birch cordwood, cut from April to August at an average moisture content of

70 to 80 percent, can be reduced in a few weeks to 45 percent. This is a weight reduction of 408 to 340 kilograms per cubic meter (17). Beltram (3) noted that in open, dry situations, late August fellings of birch lost about 200 kilograms per cubic meter after 15 to 20 days; in damp, shaded valleys the loss amounted to 130 kilograms per cubic meter after 30 to 40 days. Winter fellings lost much less weight. Similar conclusions are given by Callin (8). Sour-felling was very effective during the summer months but after the first drying season there was little change in wood moisture content.

Bielczyk and Eminowicz (5) report that sour-felling reduced the moisture content of Scots pine sapwood from 60 to 30 percent during the growth period but left the heartwood moisture content almost unchanged. In oak the moisture content of the sapwood fell from 86 to 60 percent during the first eight weeks only; heartwood was unchanged. In beech, the moisture content fell from 65 to 45 percent during the first four weeks, but no decrease occurred thereafter.

There has been only limited application of sour-felling in North America. Sugar maple has been found to respond favorably for charcoal production. The moisture content of sour-felled maple trees was 13 percent lower than in trees felled and trimmed at the same time. This was a loss of 25 percent of the water present at the time of felling. Sour-felling, in this instance, permitted carbonizing within a month of felling, while the trees that were felled and trimmed still required several months of air drying (6). It has also been noted that drying aspen pulpwood by leaving the crown intact was comparable to or even better than chemical treatment for weight reduction (25). Sapwood of pole-size Douglas-fir responded to similar treatment by drying to an average moisture content of about 60 percent in four months. Much variation in drying was noted in this study (16).

Detrimental influences. Sour-felling produces the desirable effect of drying, but it does create certain hazards in utilization. It has been reported that sour-felling was unsuitable for large trees due to excessive crown breakage on felling. Nevertheless, this procedure was better than girdling on the lower sites and on trees less than 22 to 23 meters in height (13). Others have concluded that felling and leaving the trees to season with crowns intact had no special advantages over normal felling and leaving the tops on did not assist drying (2, 23).

Sour-felled pine and spruce with rough bark create a hazard if felled before bark beetle swarming is over (2, 9). Graham (16) does not recommend the procedure for pole-size Douglas-fir because of damage from ambrosia beetles. On the other hand, Johnson (22), in considering ambrosia beetle attacks in young-growth western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), concluded that it may be possible to reduce the insect attack by leaving the trees intact when the logs must be left in the woods during beetle flight.

Chemical Pre-killing

The use of herbicides as a silvicultural tool in forestry is not a new concept. Cope and Spaeth (11), in 1931, felt that results secured with sodium arsenite for silvicultural purposes were sufficiently promising to justify further study. As the pulpwood market for hardwoods developed, the interest in chemical treatments to facilitate debarking became more intensive.

It should be noted that the interest in chemical treatment developed due to the potential extension of the sap-peeling season and possible induction of spontaneous debarking in the woods. The resulting weight loss due to drying has been a favorable by-product. Only literature pertaining to this weight reduction will be mentioned for this study.

Effect on moisture content. Extensive work on pre-harvest drying has been conducted by J. D. Hale and D. C. McIntosh (18, 19, 25, 26, 27), who report extremely favorable results for many species. They found a considerable reduction of weight in jack pine (*Pinus banksiana*, Lamb.) and balsam fir (*Abies balsamea* (L.) Mill.) treated with sodium arsenite. Reduction was usually greatest in the top bolts. Black spruce (*Picea mariana* (Mill.) B. S. P.) was not appreciably lighter, possibly due to the narrow band of sapwood. White spruce (Picea glauca (Moench) Voss), which has a thick band of sapwood, was comparable to jack pine in moisture loss. Jack pine treated in June and felled in October of the same year was ten pounds per cubic foot lighter than untreated trees. Assuming 88 cubic feet (2.5 cubic meters) of solid wood per cord of jack pine, there was a reduction of about 900 pounds per cord (113 kilograms per cubic meter) in four months. Late treatments, in August and September, caused no reduction in moisture content until a year later. Jack pine treated in June and July and cut in September a year later lost 17 pounds per cubic foot (272 kilograms per cubic meter), while those treated in August and cut in September a year later had a loss of 12 pounds per cubic foot (192 kilograms per cubic meter). Cedar (Thuja occidentalis L.) of post and pole-size, had a reduction of about 15 percent in one summer. Buoyancy of logs from species showing weight reduction was, generally, substantially improved. The authors expressed the belief that leaving the trees standing for longer periods would increase the weight reduction; sodium arsenite and ammonium sulphamate produced the same loss of weight. It has been reported that black spruce treated in October and cut in November of the same year was 28 percent lighter than untreated trees (40). This included the bark weight, but it was noted that with rough handling a substantial amount of bark would be lost.

Chemical debarking studies of western species have also proven successful in weight reduction and have given some indication of moisture loss patterns within trees. The moisture loss of ponderosa pine (Pinus ponderosa Laws.) pulpwood reduced the weight 33 percent within four to six months; top bolts had the greatest loss (42). A 32 percent weight reduction by moisture loss in the top logs and a 12 percent reduction in butt logs of grand fir (Abies grandis (Dougl.) Lindl.) has been induced by treatment with sodium arsenite. These trees averaged 24 inches d.b.h. (38). Treatments with sodium arsenite and ammonium sulphamate were highly successful in bark removal and reduction of wood weight of western hemlock. The response of Douglas-fir, while favorable, was slower and less uniform. Reduction of moisture after a year was 17 percent in hemlock and 20 percent for Douglas-fir. Pulping quality was not affected. Response of the trees to treatment could not be related to crown size or distribution, or to diameter in trees ten inches or greater (43).

Deciduous species have generally exhibited limited reduction of weight. Northeastern broad-leaf tree species showed no reduction in weight during summer and autumn after treatment. Aspen did not dry appreciably and white birch (Betula papyrifera Marsh.) was actually heavier when treated than when untreated (19, 25, 27). The little change or slight increase has also been demonstrated by others (34, 41). It is suggested this is due to increased osmotic pressure of parenchyma cells resulting in greater water uptake. Simultaneously, water loss by transpiration has been retarded by foliage killing (34). Larch, treated with sodium arsenite, showed very little reduction, which, it was concluded, may be due to the high concentrations of sugars and resins (38).

Southern experiments, in treating red and white oak, hickory (Carya spp.), sweet gum (Liquidambar styraciflua L.), shortleaf (Pinus echinata Mill.) and loblolly pine (Pinus taeda L.) have shown that the average moisture content is reduced to approximately 45 percent within four months after treatment applied in March, May, and June. The moisture content is reduced to approximately 60 percent in the same interval when treated in August (39).

Myles and Jarvis (30), report that the usual procedure in eastern Canada has been to cut and pile, and to let pulpwood season to keep freight costs down. Chemical treatment of jack pine, balsam fir, spruce, and poplar with sodium arsenite has permitted continuous production while capitalizing on benefits of dry wood. From rail weights of several thousand cords, it was found that weights of treated trees were reduced by 300 to 500 pounds per cord (38 to 63 kilograms per cubic meter). This resulted in a savings in weight, seasoning, capital investment, and insurance.

No major operational problems have been encountered in this pre-harvest killing operation. Sawing cost is normal, fire danger is expected to be reduced to ground fire only, and mills have no objections--some even prefer the treated wood at times. The wood quality is unaffected for pulpwood and splint wood use and the operation has some very useful silvicultural aspects.

Detrimental influences. The occurrence of insects and fungal attack of treated trees has been discussed widely, including some of the studies mentioned above (18, 20, 25, 26, 27, 38, 39, 42, 43). In only a few instances was it found that the quality of the product was reduced by the insects and fungi. Thompson (39), states that insect and fungal attack attained serious proportions regardless of whether treatment was administered in March, May, or June. This greatly reduced the merchantability. He notes that subsequent work done in the same area indicates a substantial decrease in insect and fungal damage in pines if they are treated in December, January, and February; but this did not hold for the oaks. Blue stain was moderate to severe in jack pine but varied with the chemical used. Trees which had the greatest weight reduction also had the heaviest insect attack, and trees treated with ammonium sulphamate were much more infested than arsenic-treated trees. This did not affect the pulping quality (18, 25, 26).

Sutherland (38) states that ambrosia beetles were present chiefly in grand fir, and saprot destroyed one to one and one-half inches of sapwood on western red cedar and grand fir, respectively. These trees were held a year and a half before cutting. It was also noted that breakage was greater in treated trees. An increase in breakage of trees treated with sodium arsenite and cut a year later was also noted by Berntsen (4) in sitka spruce (Picea sitchensis (Bong.) Carr), western hemlock, and red alder (Alnus rubra Bong.).

Many of the past chemical investigations included the use of chemicals which are so excessively toxic as to be unsafe for handling, or so ineffective as to be economically useless. The principal chemicals used in the early experiments were sodium arsenite and ammonium sulphamate. Problems involved toxicity to the workers, wildlife, and backflash--the effect of the chemical on untreated trees. Stout (37) reports that sodium arsenite applied to red pine (Pinus resinosa Ait.) during the early part of the growing season will be more likely to produce backflash than later in the season. He found that the mean backflash for April, May, and June treatments was about 63 percent but for July only 10 percent. The trees damaged were significantly larger in diameter than the treated or the undamaged trees.

A class of silvicides that seems to have great potential for killing conifers with few harmful side effects is that of the organic arsenicals, of which dimethyl arsinic acid or, more commonly, cacodylic acid is a member. Compounds of arsenic differ chemically and biologically, and should not be classed as one type of compound. Evidence indicates that pentavalent organic arsenicals, such as cacodylic acid, are non-accumulating in animals with arsenic metabolism similar to man (12). Like sodium arsenite, advantages include fast action, lack of phytotoxicity in the soil, and effectiveness in small amounts (36). It appears that cacodylic acid kills by desiccating the meristematic tissues of the buds and new twigs, and by affecting the abscission layer of the leaf petiole. It tends to be translocated to actively growing tissue. The hormone-type silivcides cause death associated with abnormal growth, and their influence is much slower (35).

Use of cacodylic acid as a silvicide was first reported in 1963 (35). Considerable experimentation has since been conducted with cacodylic acid at Oregon State University. Small dosages have proven extremely effective for chemically thinning 25-year-old Douglas-fir, with no insect or backflash problems (31).

METHODS AND PROCEDURES

Site Selection

The study area is located in the coastal mountains of western Oregon, just north of Blodgett on Horton Creek. It is about 20 acres in size, of west aspect, gently rolling topography, and is generally a middle site III for Douglas-fir (24). The heights of the trees involved range from 80 to 120 feet; with older trees up to 180 feet. The forested part of the stand is relatively well stocked, but approximately one-half of the area is occupied by bracken fern and stages of reproduction.

The stand is 55 to 65 years old, with a few trees, left from prior high-grade harvests, ranging up to 150 years old. The diameters of selected trees range from eight to 70 inches, with the mode in the 11 to 12 inch diameter class (See Figure 1).

The stand was marked for commercial thinning. The trees were marked and numbered consecutively from one to four hundred. The trees were numbered on two sides so that at least one number would be visible after felling and to facilitate finding specific trees in the stand during field observations. These trees were then divided into groups of five based on their propinquity, and each group of five trees was color coded with one of five colors. Clustering the uniformly-treated trees into groups of five dispersed throughout the stand gave a random sampling of sites and environments and facilitated application.

Fig. 1. A view of the study area.

Several trees more than the required number were marked to allow for substitution where confounding of any type was suspected. Trees were replaced if dead at time of treatment, or if damage from various causes was important enough to bias results, or to raise questions as to causes of erratic behavior.

Old-growth trees were included in each treatment to present a possible indication of expanded applicability of the treatments under study. The larger trees were evenly and randomly divided among the treatments at the time of randomization within treatments.

Treatments

After the stand was marked and the trees divided into their specific groups, the treatments were randomly assigned to the groups of trees, with a total of 80 trees per treatment.

Both approaches, chemical killing and sour-felling, were tested concurrently at two different times of the year, in the fall and the spring. The five treatments were as follows:

1. Fall chemical treatment
2. Spring chemical treatment
3. Fall sour-felling treatment
4. Spring sour-felling treatment
5. Control (no treatment)

It was anticipated that treating at the two seasonal intervals would provide more information than one application. This provided consideration of time lapse involved from treatment to harvest, and the physiological changes associated with growth initiation. The early growing season has usually been an appropriate time for successful chemical application. The actively growing crown could also have marked influence on the rate of transpiration drying.

Chemical treatments consisted of injecting cacodylic acid into the tree with the hatchet-and-oil can technique. Axe cuts were centered about a foot apart around the basal portion of each designated tree, and cacodylic acid was then poured into the cut. The axe cuts penetrated into the sapwood, and were below stump height to avoid log degrade. Cacodylic acid in the form of Silvisar 510, was provided by the Ansul Company.[1] Application was difficult on old trees due to the thick bark.

Sour-felling treatments involved only felling the designated trees. They were not bucked, topped, or treated with chemicals at any time. They were bucked in the usual manner at final harvest.

The control trees were not treated in any way, and were felled and bucked normally at the time of harvest.

Fall treatments were applied in mid-November, and spring treatments were applied at the end of April and first of May. Final harvest of the stand occurred from mid-September to mid-October.

Evaluation

Trees with exterior signs indicating abnormality were not included in the study. Conks and excessive bole scars were considered abnormal. This was a biased attempt to reduce variation, but it was felt that reduction of variance by such a selection was desirable

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[1] Silvisar 510 Tree Killer is Ansul's trade name for a solution containing the equivalent of 50 percent by weight cacodylic acid or 5.7 pounds per gallon.

for a test of hypothesis.

Chemically treated trees were rated on a five point scale prior to felling to evaluate response to the herbicide. Trees were rated as follows:

1. Healthy tree
2. Tree appearing abnormal; foliage discoloration
3. Tree with top whorls dead
4. Tree with only a few branches of the crown with needles on them; death imminent
5. Tree completely devoid of live crown.

Sampling

Progress of response to treatments was observed periodically. The occurrence of death, insect attack, needle fall, backflash, and other items of interest were noted. Four litter traps were put out in March and the litter was collected periodically from that time until final harvest. Nylon netting was staked down under selected trees which would be free of litter from a different treatment. Two were placed under trees chemically treated in the fall, one under a tree designated for spring chemical treatment, and one under a control group of trees. From the litter collected on this material, hundred-gram samples of needles were forwarded to the Ansul Company for arsenic analysis. A five gram sample of dead ants found at the base of a tree injected in May and a control sample were also included for analysis.[2]

All moisture samples were sealed in polyethylene bags upon collection and were weighed the same day. They were later dried at 105° C. until there was no appreciable change in the weight of the samples.

The situation and conditions accompanying this study had a strong influence on sampling technique and the general conduct of the experiment. The trees were the property of a private land owner, who was dealing with a private logging concern for sale of the timber. As a result, the study was conducted in such a manner as to limit any practice which would reduce the value of the timber.

The overriding economic influence essentially restricted the collection of moisture samples to the stump and top area, above six inches. The nature of the treatments also limited chances for sampling. Chemically treated trees were not accessible while standing. The influence of sour-felling depends on the connection of bole and crown. A break in this chain would confound the results, and would have required the deletion of that tree from the final analysis.

No moisture samples were taken during the application of fall

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[2] For results see Appendix, Table 6.

treatments due to rain. When the spring treatments were applied core samples, at breast height, were taken from 30 trees, with ten from each of the fall treatments and ten from the control trees. These were the only samples taken from the merchantable portion of the trees.

It was originally planned to record the length and end diameters of each log at the time of felling and bucking. Each log would then be assigned a number in addition to its tree number. As each log was loaded its number would be recorded with the corresponding reading on the truck scales. The logging contractor felt his truck scales were not as accurate as desired however and subject to much variation with temperature fluctuations. It was then decided to weigh a random sample of 25 logs from each treatment using a dynamometer. The trees were to be skidded, tree-length, and separated by treatment at the landing. Then as they were bucked each log would be weighed directly and measured for determination of cubic volume.

Felling began on September 6 and 7 and nearly one-half of the stand was cut on these two days. The feller was then put on another job and did not resume work until September 15 and 16. At this time the remainder of the designated trees were felled.

During the four days of felling, approximately one tree from each of the previously described groups was sampled by taking a pie-shape sample from the stump at the time of felling. This procedure included only the control trees and trees from the two chemical treatments, and involved 60 trees. On September 18 and 19, when it was apparent that the trees would be in the woods for an unknown additional length of time, these same 60 trees were sampled with disc samples cut from the tops, at the point of six-inches diameter or smaller, and at breaks, if present. The diameters of the samples and distances between the samples were measured for these trees. This sampling was done only after permission was received from the land owner.

Weighing the logs with a dynamometer was attempted on September 27 as a means of recording total tree weights. The logs were lifted off the ground by a winch and pulley, with the dynamometer connected to the cable between the pulley and the log. The weight of the log could be read directly from the dynamometer. After weighing six logs the dynamometer malfunctioned and other methods became necessary. At that time it was decided to cut representative samples from the tops of all trees, and one truckload of logs from each treatment was to be weighed, on the truck, at the State Highway Department weigh station for verification.

Samples were collected from the tops of all trees in all treatments from one-half of the study area, which was also the same half that was originally cut on September 6 and 7. From September 28 to

October 3 top samples were taken from the remaining trees, which were those felled on September 15 and 16.

The experimental trees were bucked and loaded between October 12 and 14. Length and end diameters were measured for each log loaded. The same truck was loaded with logs from one treatment at a time. The truck was weighed empty prior to the first load and empty after the last load. The difference in weight was attributed to fuel consumption and an equal amount deducted from the gross weight of each load.

No butt samples were taken from the sour-felled trees because of the need for cutting two to three feet off the butt log in order to obtain a representative sample away from dry ends. It was believed that segments of the butt log would be cut off some of the trees in the sour-felling treatments in the process of bucking logs, poles, and pilings. Butt samples for the sour-felling treatments were then cut from these end segments when they were long enough to permit such sampling. Several samples were collected in this manner, but in this chance sampling only one sample was collected for the fall sour-felling treatment.

RESULTS

Effect on Moisture Content

The moisture content here is expressed on the percent of ovendry weight, according to the following equation:

$$\left(\frac{\text{Green weight} - \text{Oven dry weight}}{\text{Oven dry weight}}\right) \times 100 = \%\ \text{moisture content}$$

Moisture content is expressed in these analyses as a function of the sample diameter and the treatment. The width of the sapwood band is roughly constant throughout the tree. Width may vary from tree to tree but is assumed to be compensated by the random designation of trees to the treatments. Differences in mean sapwood width among treatments is a chance effect and has been disregarded. Moreover, the assumption was made that all samples of the same diameter have a similar heartwood-sapwood ratio.

The moisture content of a sample is considered to be a function of the moisture content of the heartwood and sapwood and their ratio in the sample. This assumption disregards density and specific gravity, per se, but their influence is indirectly expressed in the moisture content. This effect is assumed to be the same among all treatments as a result of the randomization. Therefore, differences in the moisture content of samples of the same diameter are attributed to the treatments.

The data analysis was conducted with a step-wise regression program and an IBM 1620 computer. The moisture content was analyzed for the linear, quadratic, and cubic relationship of sample diameter. (See figure 2.)

The lack of samples from the basal portion of the sour-felled trees is clearly indicated. Poor correlations for these treatments indicates that the data is approaching a horizontal line, with little clear relation between sample diameter and moisture content within these treatments.

The equations for these lines are as follows:

1. Fall - Chemical

$$\widehat{Y} = 119.997 - 9.9530 D + 0.484 D^2 - 0.007 D^3$$

$$\bar{Y} = 75.98 \qquad R^2 = 0.2212$$

2. Spring - Chemical

$$\widehat{Y} = 164.557 - 16.291 D + 0.688 D^2 - 0.008 D^3$$

$$\bar{Y} = 90.50 \qquad R^2 = 0.4396$$

3. Control

$$\widehat{Y} = 126.806 - 2.766 D - 0.111 D^2 + 0.004 D^3$$

$$\bar{Y} = 103.23 \qquad R^2 = 0.2620$$

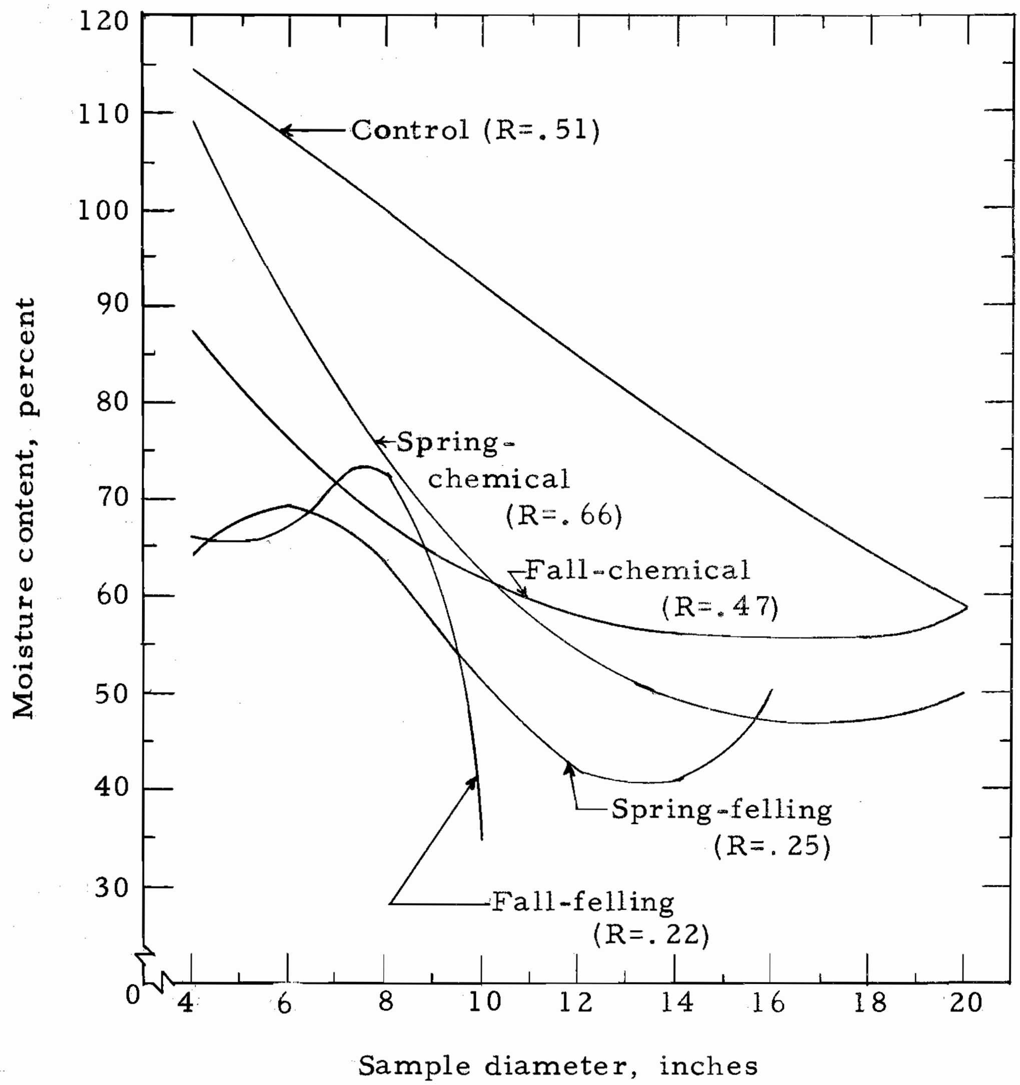

Fig. 2. Relation of moisture content and sample diameter for each treatment.

4. Fall - Felling

$$\hat{Y} = 266.296 - 107.468\ D + 18.297\ D^2 - 0.986\ D^3$$

$\bar{Y} = 63.78$ $\qquad R^2 = 0.0490$

5. Spring - Felling

$$\hat{Y} = -10.493 + 32.543\ D - 4.049\ D^2 + 0.142\ D^3$$

$\bar{Y} = 66.73$ $\qquad R^2 = 0.0629$

The calculated weight was compared to the net weight of the weighed truck loads to provide some indication of the accuracy of the fitted curves for the chemical treatments and the control trees. This was done by the following formula:

.45 × 62.4 × (1 + % moisture content) × V = total weight of log

when: .45 = specific gravity of coastal Douglas-fir (7, p.473)

62.4 = weight of a cubic foot of water at 4° C.

% moisture content = value read from fitted curve using the mean diameter of the log as the sample diameter

V = the calculated cubic volume of each log

$$V = 1/3\ (A_1 + A_2 + \sqrt{A_1 \times A_2})\ h$$

when: h = log length

A_1 and A_2 = area of log ends

The results are presented in Table 1.

Table 1. Comparison of predicted and actual weight.[1]

Treatment	Calculated weight (pounds)	Actual weight (pounds)	% Error
Fall-Chemical	45, 325	42, 260	7%
Spring-Chemical	46, 304	49, 765	7%
Control	52, 218	45, 305	15%

[1] To convert from pounds to kilograms multiply by 0.4539

The time lapse during which sampling was conducted, with unknown equilibration of wood moisture with atmospheric humidity, may have introduced some confounding into the moisture data, particularly that taken from truck weights. Impact of rain on the wood moisture responses to various treatments was impossible to estimate. Effects on responses to chemical treatments or sour-felling treatments would probably differ from those on the control trees, owing to different stages of dryness of each treatment. It is reported that a sharp drop in moisture content occurs during the first five days after felling (15). Since the trees were not bucked at the time of felling, and samples were collected from unbucked trees that had been lying in the woods from three to 25 days since felling, moisture data surely contains some bias, for control trees particularly.

Only those trees in the chemical treatments which were completely top-killed were included in the analysis. Substantial variance within this limitation is attributable to differing speed of response of individual trees to herbicide, hence difference in actual drying time after trees were totally defoliated. Moreover, defoliation was not necessarily associated with immediate degeneration of growing tissues.

The interrelationship of d.b.h. and tree position from which the sample was taken may also be confounding the data. A six inch diameter sample occupies an entirely different relative position in an eight inch tree than in a tree 20 inches d.b.h. A sample of the same size occurs in a lower relative position in the small trees and assumes a higher position as the tree diameter increases, due to the relation of diameter and height.

The influence of tree position and moisture content is shown for the ten to 12 inch diameter trees, (see Figure 3), in which each tree is considered to contain five equal segments. The graph is restricted to trees of this diameter due to the inherent bias of the sampling methods. Extension of this graph to include the larger trees would suggest comparison of the large trees with the smaller ones with substantially different heart-sapwood ratios. The designation of the samples by tree position was based on an average sample diameter at an average position of occurrence in the tree for each one-inch d.b.h. class. The division between positions was based on an average taper in the sampling area. Values used were obtained from the trees that were extensively sampled and measured, as described earlier.

Some interesting aspects presented in Figure 3 include the general grouping of the two types of treatments used, the similarity in the shape of the lines, and the distinct linearity of the chemical treatments. The response to all treatments was relatively uniform and differed largely in degree.

It is interesting to compare the means of the core samples, extracted at the time of spring treatment application, and the means of the butt samples, drawn from Figure 3. See Table 2.

Table 2. Comparison of samples from the basal portion of the tree, collected at a five month interval.

Treatment	Spring sampling % moisture content	Harvest sampling % moisture content
1. Fall-Chemical	51.97	52.50
2. Fall-Felling	44.99	37.23
3. Control	50.63	65.24

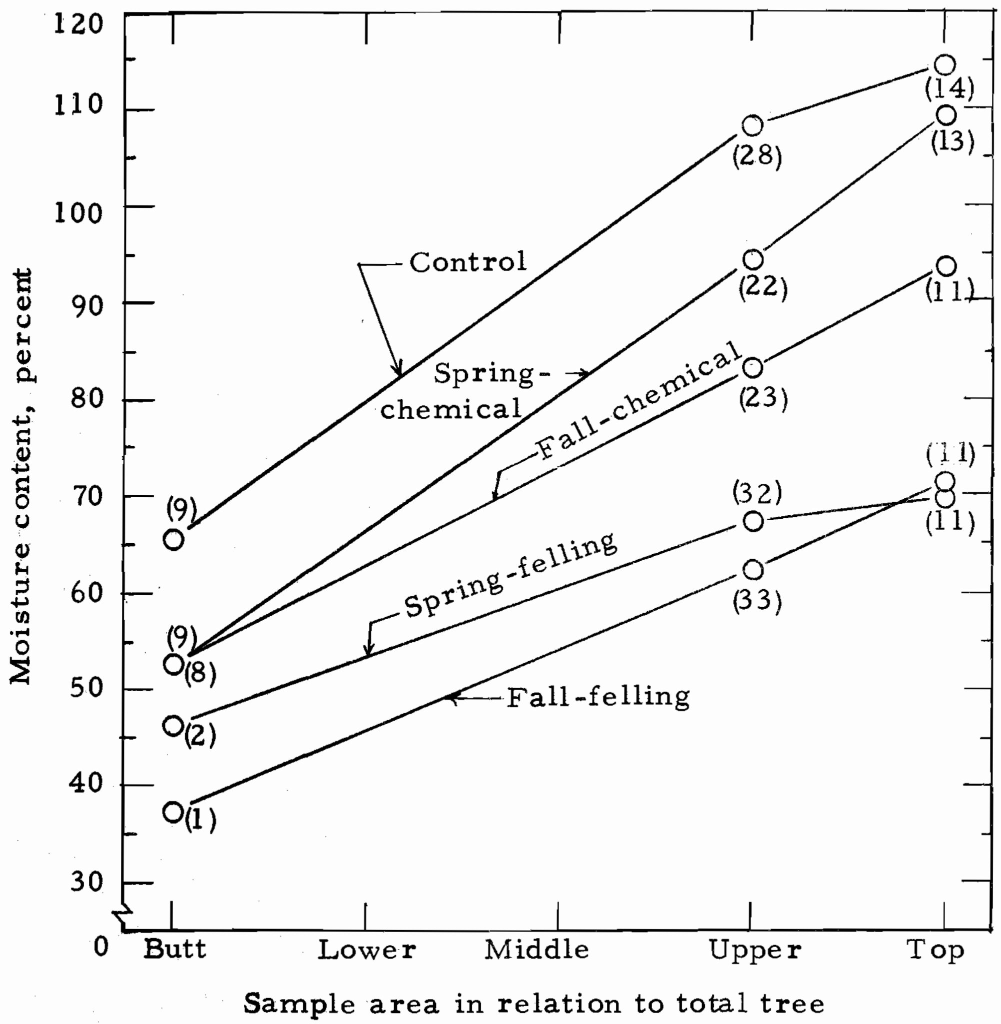

Fig. 3. Comparison of the moisture distribution, in trees 10 to 12 inches d. b. h., for each treatment.[1]

[1]Numbers in parentheses indicate sample size.

The basal portion of the fall-chemical treated trees did not change during the sampling interval of five months. It is speculated that the difference in the fall sour-felled trees would not be as great had there been a larger sampling at harvest time. The control trees increased considerably. The differences in the means of the core samples are not statistically significiant.

Morphological Response

Chemical treatments. Trees treated chemically in November were beginning to show the influence of treatment within two months. They appeared to have thin tops, or tops noticeably less dense than normal trees. One tree was completely defoliated within eight weeks. It was a suppressed tree, 8.3 inches d.b.h. and apparently was in poor vigor when treated. A check of the cambial area indicated recent defoliation by the presence of green cambium; presumably the tree was not dead when treated. This was the driest tree measured at the end of the experiment and was the only tree to check as a result of drying. The bark was very loose when it was cut.

By the third month after treatment the trees were in various stages of dying. Edge trees demonstrated a very interesting response. Necrosis was in the 1965 foliage, as on all trees, but was obviously present more on the exposed side of the crown than on the sheltered side. Trees within the stand appeared to be dying from the tops downward and from the tips of the branches inward.

By the end of the fourth month some indication of backflash was apparent. A very limited amount of insect activity was found in April. The ambrosia beetle, Trypodendron, was the only insect found at this time. Attack was very limited and occurred, with few exceptions, in the stump area of the trees. Occurrence was essentially below or between the axe marks. It was also noted that the phloem of treated trees did not have a healthy resinous odor, but tended to smell somewhat like cacodylic acid, which has a peculiar and obnoxious odor.

The spring chemical treatment was especially effective in producing immediate results, as was expected. The treatment was applied in May and within a month all trees had various degrees of reddish-brown crowns. With the exception of the more rapid crown discoloration by the spring application, field observations indicated no different developments between the two chemical treatments in kind but some differences in degree.

It was apparent during both seasons that the phloem was dying in strips proceeding up the tree in line with the point of injection. (See Figure 4.) The chemical strips varied in pattern among treatments and among trees in the same treatment. In some instances they were visible 60 to 70 feet up the tree, and in others they disappeared after only a few feet. The chemical strips tended to exhibit a slowly spiraling, left-turning ascent. This is similar to the movement of dye in Douglas-fir reported by Rudinsky and Vité (32).

Fig. 4. Chemical strip indicating little tangential movement of the cacodylic acid.

Trees not completely killed formed adventitious buds. The buds on the tips of twigs aborted completely, this condition usually persisting throughout on small twigs. On the branch itself, however, buds had formed with the appearance of viability. It may be possible for trees not extensively defoliated to recover by such a mechanism.

Sour-felling treatments. Needles began to loosen after eight weeks on the trees that were felled during November. The crowns were still dark green and the trees generally looked as though they were only recently cut. Fall-felled trees were attacked readily by insects in April, five months after cutting. At the end of seven months, the fall sour-felled trees still had green cambium, although generally restricted to the unexposed sides. Some of the trees burst buds, put on new shoot growth, and developed strobili.

The spring sour-felled trees were attacked by insects within a week of felling. At the time of harvest the crowns of spring-felled trees were completely brown, but dead needles were still clinging. Crowns of the fall sour-felled trees were bare.

Logging. Breakage did not increase as the result of killing. This observation conflicts with some reports (4, 38), but appears well substantiated in this timber type. Some breakage occurred in all treatments but was not a serious problem with the chemically treated trees. The trees would fall faster, with seemingly less hang-up, but would land with less impact than control trees. Seasoned lumber is known to be stronger per unit weight than unseasoned wood. It seems logical that this same relationship would hold for partially seasoned trees with no decay or insect damage.

Chemical treatment did not affect felling of the trees adversely. The trees were dead, but were not weakened as might be insect-killed snags. Sawing properties were not abnormal and it was possible to control the direction of the dead trees just as well as the live trees.

Fire hazard. It appears that the chemical treatment would have a favorable effect on fire hazard. At the time of felling the crowns are essentially bare and much of the finer fuel breaks off on impact. Most of the flash-type fuel is on the ground and incorporated with the duff. It should be noted that the trees in this study were small, so slash was not heavy in any event.

Bark loss. Loss of bark occurred chiefly in the sour-felling treatments. This may have been a result of drying and loosening of the bark or the drying accompanied by the extensive undermining by bark beetles. Many of the sour-felled trees were semi-debarked by the time they reached the landing. There was an occasional problem with chokers slipping but this was avoided easily by setting the choker farther back on the log initially. Bark on chemically-treated trees was unaffected except that it was loosened to some extent over the dead phloem strips. In the tops, where drying was most obvious, the bark seemed to shrink around the tree and was not easily peeled.

The only staining found in chemical treatments was in the dead phloem-cambial strip. This did not appear to penetrate into the xylem. Considerable staining was found in the sour-felled trees, much of which is associated with occurrence of insect vectors.

<u>Backflash</u>. Trees in the fall chemical treatment exhibited a higher rate of apparent backflash than the spring chemical treatments. Twenty-one percent of the fall chemical trees, as opposed to about 13 percent of the spring chemical trees, had some influence on their neighbors. Among all the chemical treatments, 17 percent of the trees showed some indication of backflash. Importance of the seasonal difference is not known.

The incidence of backflash in the spring chemical treatment does not seem to follow a definite pattern by d. b. h. or by degree of kill. Fall chemical treatment shows a much stronger tendency for backflash to occur in the smaller diameters. (See Figure 5.) This may be a result of over-treatment, or tendency for suppressed trees to be dependent on dominants through root grafts.

Backflash, per se, is not necessarily considered indicative of a root graft but it does make a strong case for such an occurrence. A study of Douglas-fir root systems recorded several cases of grafting of small trees to the main laterals of larger trees. Perhaps more important than actual grafts is the considerable amount of intermingling of root systems (28). While backflash has not been a problem in chemical thinnings of Douglas-fir (31), the different methods of application must be noted. The thinnings have been conducted with a chemical injecting hatchet with chemical placement at breast height. Only one-half to one cubic centimeter of chemical is

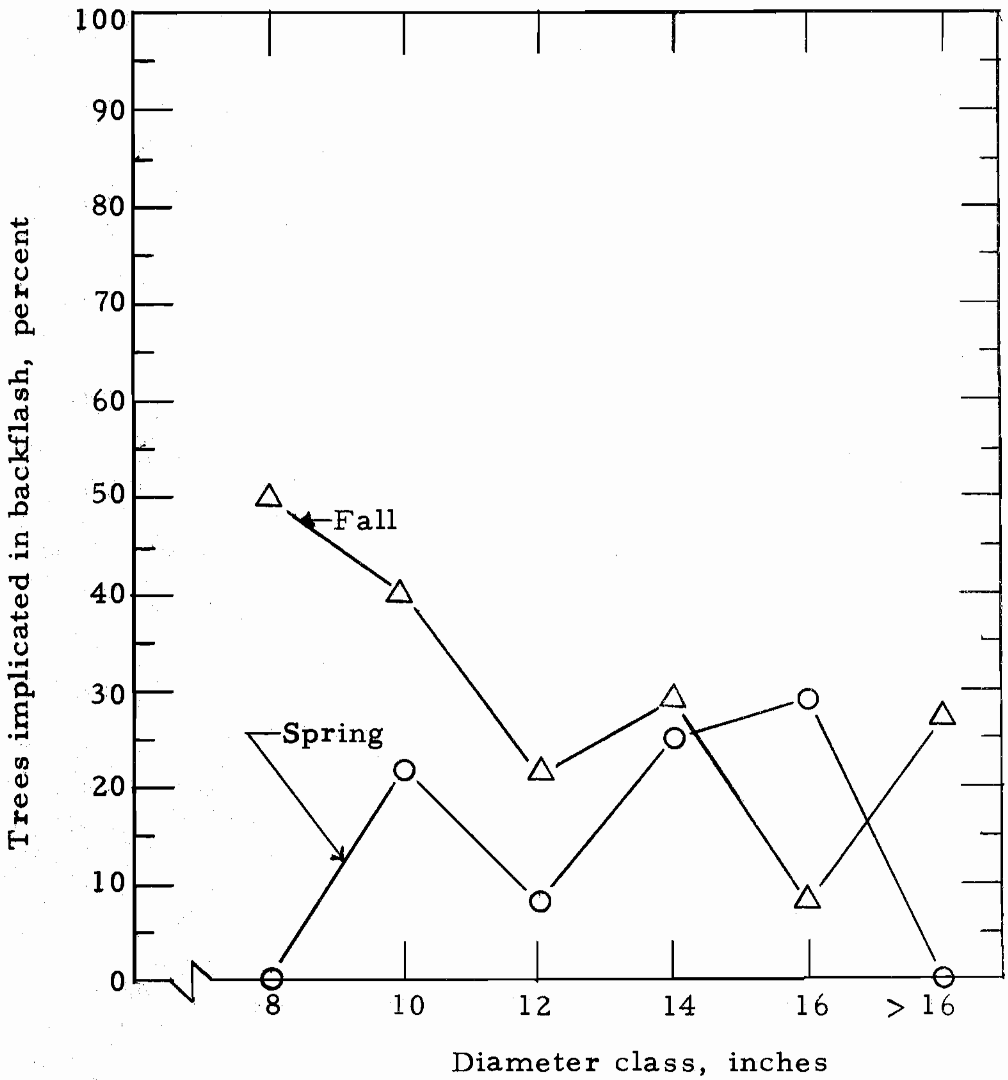

Fig. 5. Trees implicated in backflash in each chemical treatment by two-inch diameter classes.

injected per cut and it is placed well into the xylem tissue at breast height. The axe frill exposed a larger proportion of phloem tissue, and the frill was filled to overflowing with chemical. Consequently, considerable chemical was placed close to major roots, and could be translocated downward by the phloem. The incidence of downward movement seemed to be enhanced if the chemical were applied over a main lateral root. (See Figure 6.)

Fig. 6. Downward translocation of chemical by a lateral root to adjacent tree.

Insects. The major insects found on the study area were the Douglas-fir bark beetle, Dendroctonus pseudotsuga Hopk., ambrosia beetles, Trypodendron sp., and Cleridae species. Sour-felled trees in particular, were readily and heavily attacked. Brood success was still rather limited due to a variety of possible factors. There was a high rate of mortality due to predation by the Cleridae species. A second limiting factor appeared to be the increased crowding. As the infestation increased the egg galleries became shorter and fewer eggs were noted. This effect has also been noted elsewhere (29). A third factor is quite logically the influence of drying. Johnson (21) reports that when the moisture content of the sapwood reaches about 90 percent oven-dry weight the adult beetles will leave their galleries to seek fresh material. The sour-felled trees were well below this level when sampled.

The chemically treated trees, in general, had an extremely mild insect attack. As the summer progressed, a few did develop heavier infestations. Only 22 percent of the fall-chemical treated trees, and only eight percent of the spring chemical trees had signs of insect activity. Less than 16 percent of all the trees chemically treated showed some appearance of insect attack.

The degree of insect attack could possibly reflect the influence of the chemical on the trees, making them unattractive, or to the decreased moisture content. The infestation in this case is compounded by the presence of the felled trees in the woods. In many instances heavily infested sour-felled trees were adjacent to chemically treated trees which were free from attack .

Insect attack was noted on only seven trees in the spring chemical treatment. Of these, four were rated as moderate attacks and three as light attacks. There is no apparent pattern in insect selection of trees in this treatment. Fall chemically treated trees do show rather definite patterns of attack. When attacked trees are expressed as a percentage of total trees in that diameter class the larger trees are strongly preferred. (See Figure 7.) Furniss (14), in examining fire injured Douglas-fir, notes that the incidence of attack of Douglas-fir beetles increased with tree size and severity of fire injury to crown and cambium. Attacks decreased sharply with outright fire-kill. When the trees were completely defoliated, the beetles showed a preference for the large trees, possibly due to retention of phloem moisture by thick bark. It is also interesting to note that all the attacked trees over 22 inches d.b.h. were rated as a heavy attack; none of the smaller trees were attacked heavily. Approximately 75 percent of the trees up to the 16 inch diameter class were rated as lightly attacked and 75 percent of the trees from 16 to 20 inches d.b.h. were rated as moderate among those trees where insects were present.

Evidence of unsuccessful attack by the Douglas-fir engraver beetle, Scolytus unispinosus Lec., was found when the chemically treated trees were cut. They were not noted in the sour-felled trees. Their unsuccessful attacks or absence appears to be due to dryness of the tops of treated trees. Chararus (10), reports that scolytids are attracted to unhealthy trees while the sap is still

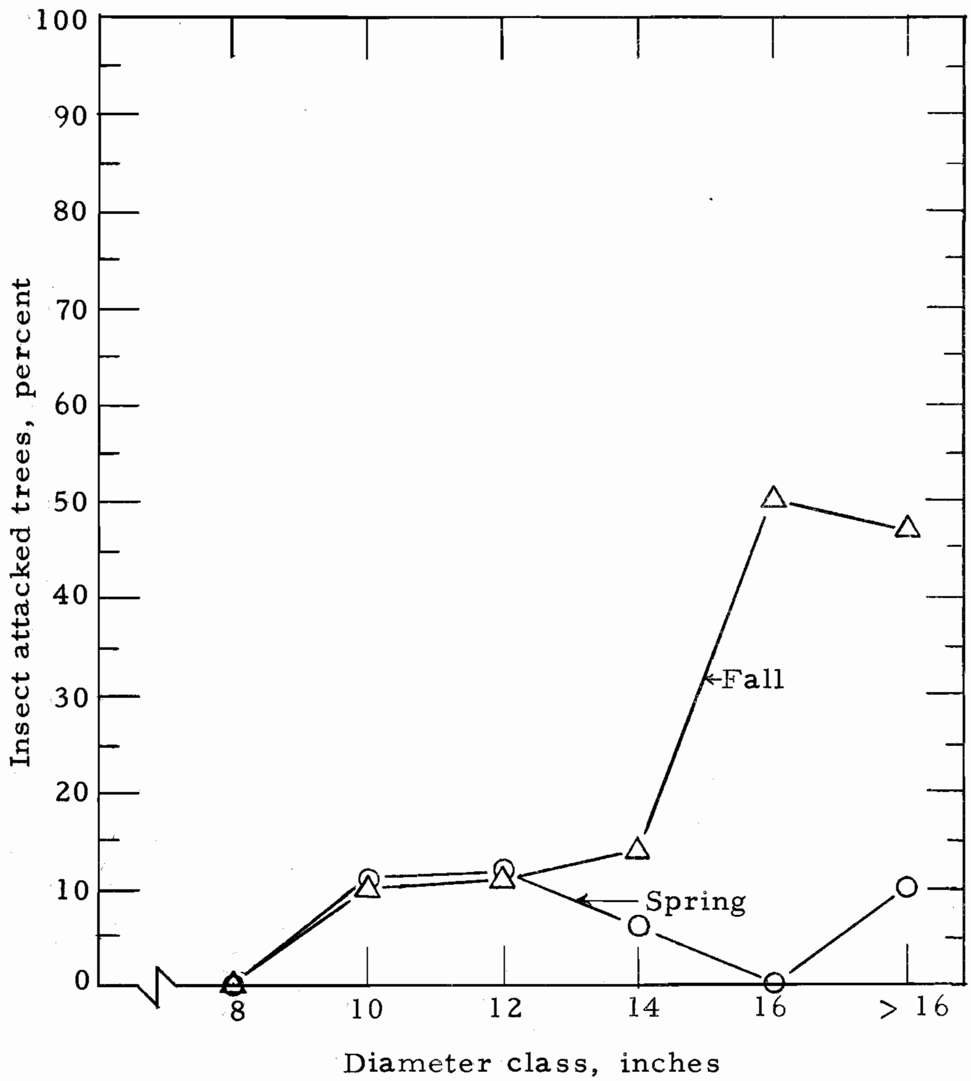

Fig. 7. Insect attacked trees in each chemical treatment by two-inch diameter classes.

moving and the bark is moist. Dry trees never attract scolytids, and standing trees generally are attacked more than felled ones. Among the 59 trees in the chemical treatments which were found to have insects or were implicated in backflash only one tree was in both categories.

Degree of kill. The effectiveness of the chemical is strongly and inversely correlated with tree size. The trees were rated on the degree of kill, as evidenced by crown appearance, prior to final harvest. There was a time lapse between injection and evaluation of ten months for the fall treatment and five months for the spring treatment. At harvest time there was a highly significant difference in the degree of kill by each treatment. A larger percentage of the fall-treated trees were rated as dead, with fewer trees in the dying stages than in the spring-treated group. (See Figure 8.) This difference is further exemplified when the dead trees are compared to all the trees of that treatment as a percentage based on d. b. h. (See Figure 9.). It is believed that, given additional time, the trends will merge and will approach 100 percent kill in all diameter classes. The relationship of percentage killed to diameter was nearly linear, particularly in the spring treatment.

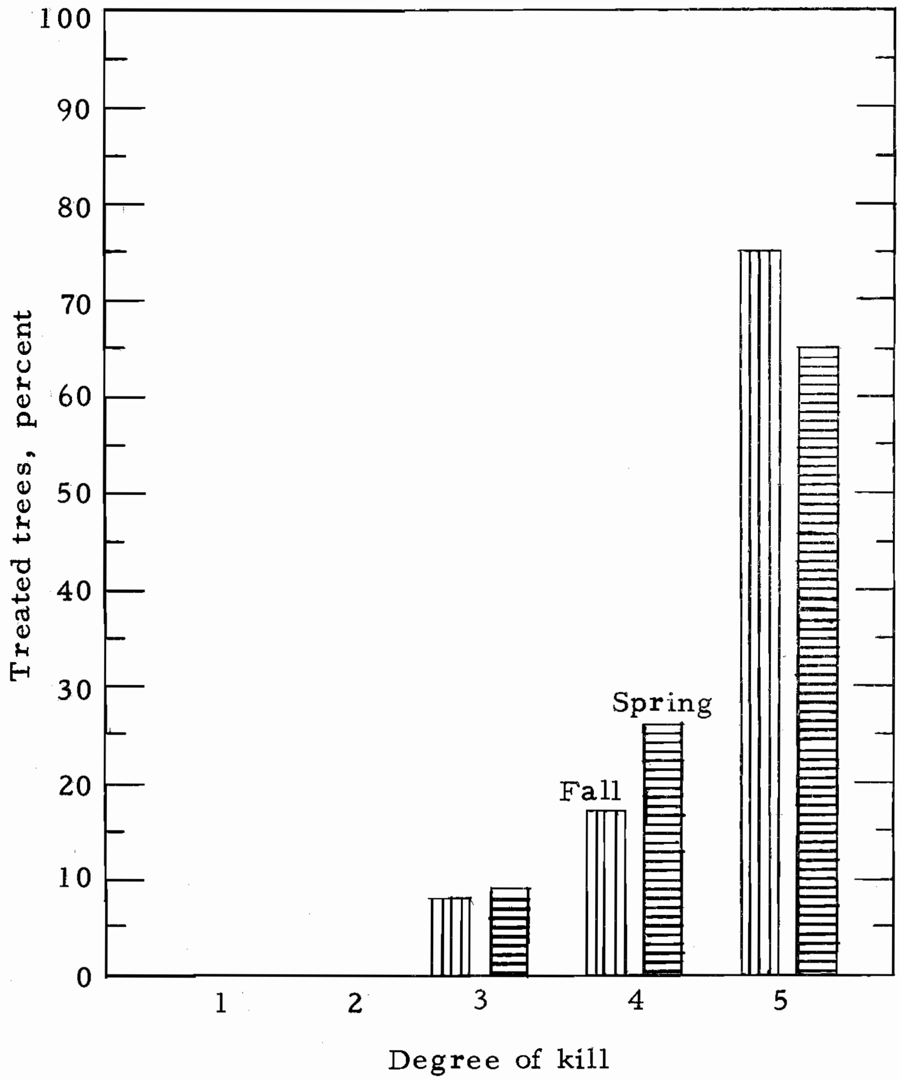

Fig. 8. Response of trees in each chemical treatment to cacodylic acid.

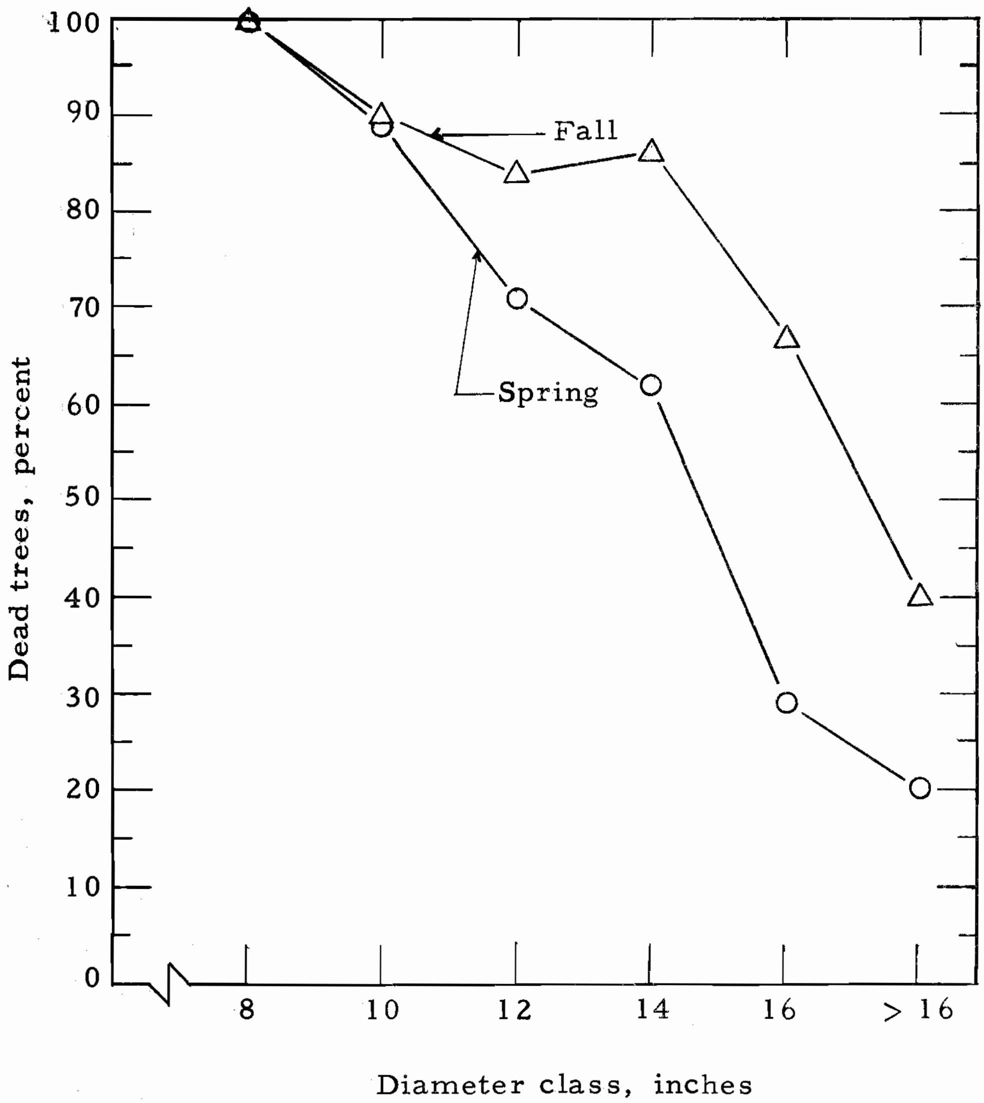

Fig. 9. Dead trees in each chemical treatment by two-inch diameter classes.

CONCLUSION AND DISCUSSION

Losses of weight occurred in all treatments varying with treatment in differing degrees. It is felt that the results indicate some very real economic advantages over present logging procedures. The relationships presented in Figure 3, for the ten and 12 inch trees only, are expanded in Tables 3 and 4. This diameter range is in the marginal range with respect to profitable harvesting, and is the primary area toward which this study is directed. Table 3 ranks the moisture contents and weights for each treatment. This ranking is based on the moisture content taken from Figure 3 at a point midway between the butt and upper samples. This point is assumed to be an indication of actual moisture content of the merchantable portion of the trees.

Table 3. Listing of moisture contents and weight per unit volume for each treatment.

Treatment	% Moisture content	Weight	
		Weight/ cubic foot[1]	Kilograms/ cubic meter[2]
Control	86.5	52.4	839.34
Spring-Chemical	73.0	48.6	778.47
Fall-Chemical	67.5	47.0	752.85
Spring-Felling	56.5	44.0	704.79
Fall-Felling	49.5	42.0	672.76

[1] Calculated weight from the previously mentioned equation: $.45 \times 62.4 \times (1+\%\text{moisture content}) = \text{Weight per cubic foot}$.

[2] Weight per cubic foot $\times$ 16.018.

Table 4 presents the relations of moisture content reduction and weight reduction as percentages for comparison among any two treatments.

Table 4. Comparison of percent moisture and weight reduction among treatments on a dry weight basis.

	Treatment	Percent moisture content reduction				
		Control	Spr.-chem	Fall-chem	Spr.-fell	Fall-fell
% Weight reduction	Control	--	16	22	35	43
	Spr.-chem	7	--	8	23	32
	Fall-chem	10	3	--	16	27
	Spr.-fell	16	9	6	--	12
	Fall-fell	20	14	11	5	--

This indicates that trees in the spring-chemical treatment are 16 percent drier than the control trees, reading on the upper and right side of the table. In terms of weight, shown on the lower and left side of the table, the trees in the spring-chemical treatment are seven percent lighter. Trees in the fall-chemical treatment are 22 precent drier or ten percent lighter than the control trees.

Comparison of percent weight reduction of the fall and spring applications of each treatment indicates little difference. The additional time of drying for fall sour-felled trees may be offset by water absorption during the winter. It may be probable that the crown is essentially dying during the winter, a time of low transpiration, and is rapidly dried out during the summer when it should be most efficient. Conversely, the crowns of the spring-felled trees are in condition to actively transpire when cut.

There is an even smaller weight reduction between the fall and spring chemical treatments. This is probably due to the general lack of response to the fall application of herbicide until the early spring. The major difference in response was expressed in the larger sizes and relative completeness of defoliation. Both seasons produced similar defoliation response in this ten to 12 inch range.

The relative difference between the control trees and the other treatments is believed to be considerably greater than indicated in the table. Table 4 is based on samples collected up to three weeks after felling. Table 5 indicates the weight relationships among the treatments based on actual weight divided by the computed volume.

Table 5. Comparison of weight per unit volume (actual weight divided by computed volume).

Treatment	Weight/cu. ft.	kilograms/cu. m.
Spring-chemical	47.8	765.7
Control	44.6	714.4
Spring-felling	43.1	690.4
Fall-chemical	42.3	677.6
Fall-felling	41.7	668.0

The particular interest here is in the difference between the spring-chemical treatment and the control trees, and the relative closeness of the control trees and the remainder of the treatments. Figures 2 and 3 indicate that the control trees contained more moisture at the time of sampling. Weight per unit volume from the actual weighed loads indicate the control trees to be considerably drier than trees in the spring chemical treatment. It must be noted that the truck loads were not weighed until mid-October, at which time the control trees had been cut but unbucked for up to five weeks. It is concluded that there was a significant amount of drying over this time lapse. This is given added weight if it is assumed that the fitted curves for the chemical treatments in Figure 2 are some indication of existing conditions due to the closeness with which they predict the actual weight of the truck loads, as presented in Table 1.

The rapid drying associated with the control trees indicates a potential for sour-felling. Felling the trees in August or September should alleviate the insect problem associated with the earlier felling treatments. There is some problem in bucking sour-felled trees after they have fallen over one another but this could be reduced with bucking done concurrently with skidding.

All treatments have decreased the moisture content of the trees, but the chemical treatments seem to afford some degree of protection from insects and staining. This protection is not present in the sour-felling treatments in this study.

The economic potential of such treatments can extend from the stump to the mill. Reduction of weight per unit volume would permit the use of smaller logging equipment, with the benefit of less capital investment. Moreover, it would permit the skidding of more volume per turn, improving utilization of the present equipment. Dry timber would also enable the hauling of more volume per truck load. Should it be possible to remove bark in the woods, it would not be necessary to dispose of this by-product at the mill and would constitute additional loss of weight. Utilization of timber that is drier than normal should also extend to the amount of seasoning required after conversion into lumber or the desired product. This could result in less yard space tied up by air drying, or shorter kiln schedules, or also in the possibility of shipping directly after conversion without the necessary drying period. The drier timbers should take preservative treatments better, thus producing more desirable products.

It appears that the chemical-treated trees would be drier if allowed to remain in the woods for an additional length of time beyond those observed in this study. They do not appear to be greatly attractive to insects, and perhaps for the additional season left in the woods they would dry until they are completely unattractive to the usual degrading insects.

Staining was not apparent in the chemical-treated trees whereas it was existent in the sour-felled trees. A certain amount of this stain was induced by the insect attack.

Logging operations are not adversely affected by either of the methods studied. Bark loss may be important in the sour-felling treatments.

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APPENDIX

Table 6. Results of arsenic analysis.[1]

Treatment - Tree no.	Date collected	Arsenic (PPM)
Fall - 186	April 27, 1966	60.00
Fall - 186	June 13, 1966	12.40
Fall - 186	August 30, 1966	34.40
Fall - 272	April 5, 1966	82.00
Fall - 272	April 27, 1966	82.00
Fall - 272	June 13, 1966	102.00
Fall - 272	August 30, 1966	66.00
Spring - 127[2]	April 27, 1966	68.00
Spring - 127	June 13, 1966	171.00
Spring - 127	August 30, 1966	130.00
Control - 396	April 27, 1966	2.15
Control - 396	June 13, 1966	1.88
Control - 396	August 30, 1966	1.53
Grafted tree from 186	September 11, 1966	106.00
Ants killed at 127	June 13, 1966	2.60
Ants (control sample)	September 15, 1966	340.00

[1]Methods: A.O.A.C., 358(24.016) (1965) 10th ed.

[2]Tree was untreated at this time.