AN ABSTRACT OF THE THESIS OF

HARVEY ALLEN HOLT for the Doctor of Philosophy
(Name) (Degree)

in Forest Management (Ecology) presented on August 19, 1970
(Major) (Date)

Title: INTERNAL MOISTURE RELATIONS OF STANDING DOUGLAS-FIR TREES INJECTED WITH ORGANIC ARSENICALS

Abstract approved: Signature redacted for privacy.
Dr. Michael Newton

Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) ranging from 9.6 to 14.3 inches diameter breast height were treated with the organic arsenicals, monosodium methanearsonate (MSMA) and cacodylic acid. Treatments were applied at monthly intervals from February, 1967 to October, 1968, to ten to 25 trees each month. Treated trees were sampled in September, 1967 and September, 1968. The time lapse from treatment to harvest ranged from five to 19 months, during which time the trees were left standing in the forest to air-dry. Untreated control trees were cut in February, 1967 and at both of the September cutting dates. Treatments consisted of boring holes, one for each three inches of diameter at breast height and pouring ten to 20 milliliters of the herbicide in each hole.

Wafer samples were cut from the ends of each log at the time the trees were cut. The respective diameters and moisture contents of the bark, sapwood and heartwood were recorded. Tree and log measurements were taken in the field. Individual logs were weighed after skidding to the landing for each harvest made in September.

A model tree was constructed mathematically, based on measurements from the samples and field data, for a standard comparison of the moisture profiles of each treatment. The moisture profiles were determined by multiple linear stepwise regression analysis of the moisture contents of the sample components (bark, sapwood and heartwood) and data characterizing each sample. Weights of these components and the total tree for each treatment were determined by integration of the moisture profiles over the model tree.

Percentage weight reductions range from negative values to values greater than 20 percent. Weight losses were a result of drying in the bark and sapwood and loss of bark. MSMA treated trees were consistently drier than trees treated with cacodylic acid. The moisture content of the heartwood was unaffected by the treatments. Bark loss was more apparent and breakage tended to occur more frequently with long drying periods. The data suggest that treating in mid-summer after the major insect flights created trees unattractive to certain insects during the second year.

The summer of 1967 was abnormally hot and dry and the summer of 1968 was abnormally wet. Thus, weather had an important bearing on results, particularly in reducing the drying exposure of trees treated in September and October, 1967.

The economic implications and potentials of the results are discussed for various aspects of the forest industry and forest practices. Visual observations made of the treated trees being cut into lumber and veneer indicated that utilization processes were not adversely affected. Drying times longer than those tested appear to be possible without degrade. The drier wood enables more uniform kiln drying and reduces the time required for air drying by nearly 25 percent. This feature should be applicable to all types of drying of various products. This is especially important for products requiring very long drying periods such as poles and pilings. Benefits of field drying carry through logging, shipping, manufacturing, and handling. Drying was adequate to permit faster drying of sapwood veneer. At the moisture contents obtained there was no effect on the veneer process nor on pulping quality. The loss of weight was adequate for an appreciable increase of the volume per truck load for hauling, and for an increase in the efficiency of present logging equipment while making less expensive equipment more practical.

This type of treatment permits more intensive management of timber stands, enabling the land manager to accomplish many objectives at one time and has the potential of reducing the diameter of the marginal tree. Storage of the wood fiber on the stump by continuous thinnings is a logical outgrowth of the above findings. This practice would keep the stand at optimum stocking for maximum growth while maintaining the killed trees in salvagable condition. The combined silvicultural benefits of insect and disease control, along with slash reduction and reduction of operating costs in logging and manufacturing, provide a tool of broad utility to forest managers.

Internal Moisture Relations of Standing Douglas-fir Trees Injected with Organic Arsenicals

by

Harvey Allen Holt

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

June 1971

APPROVED:

Signature redacted for privacy.

Associate Professor of Forest Management
in charge of major

Signature redacted for privacy.

Chairman of Department of Forest Management

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented August 19, 1970

Typed by Opal Grossnicklaus for Harvey Allen Holt

ACKNOWLEDGMENTS

This study could not have progressed to this point without the invaluable assistance of many people often at considerable inconvenience to them. I am greatly indebted to Rowley and Parker Tree Farm Service, Philomath, Oregon for adapting their logging operations as needed to obtain the necessary wood samples and log weights. Thanks are also extended to Hollis Allen and Rod Stevens for their assistance in collecting samples and other needed field data. I would also thank Larson Lumber Company, Philomath, Oregon and Oregon Alder - Maple Company, Willamina, Oregon for processing experimental trees at times adapted to my schedule.

I would like to thank Dr. Scott Overton for his assistance with the data analysis, interpretation and presentation of the results. Thanks are also extended to Mr. Leif Espenas for assistance in interpreting the moisture results in terms of drying and their utility to forest products. The programming assistance of Jim Arney and Jonna Zipperer is gratefully acknowledged.

I would like to thank The Ansul Company, Marinette, Wisconsin for their financial support and for providing the necessary herbicides.

The indebtedness to my advisor, Dr. Michael Newton, cannot go without mention. His advisement, criticism and continued guidance throughout this project from its inception to this final report are greatly appreciated. I would also like to thank my wife, Barbara, for her understanding and encouragement, for the many hours spent working on the collected samples and as chief note-taker for many field observations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTERNAL MOISTURE RELATIONS OF STANDING DOUGLAS-FIR TREES INJECTED WITH ORGANIC ARSENICALS

INTRODUCTION

The gross weight of timber is economically important from the time it is cut until it is a finished product. Much weight is carried from the forest to the mill, and is removed only in the last steps of manufacturing. Two important components of this weight are water and bark.

The average moisture content of sapwood of green, coast type Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is 115 percent; interior Douglas-fir is even higher in moisture at 154 percent (Rasmussen, 1961). As a comparison, the moisture contents of flooring, sash and door millwork, lumber joists, studs, and sub-flooring in use generally range from six to eight percent. Thus 50 percent, or more, of the weight of the lumber products sawn from this sapwood must be removed before the product is ready for utilization. Similarly, heartwood material must be dried from an initial moisture content of about 40 percent; a weight reduction of some 20 percent.

Bark, which reportedly comprises about eight percent of the volume of a young-growth Douglas-fir log (Bollen, 1969; Institute of Forest Products, 1957), is transported to the mill only to be burned or otherwise disposed of, creating a serious disposal problem for wood-using industries (Hall, 1968).

Assuming that sapwood comprises about 50 percent of the solid wood of a small sawlog, a sum of the products of the percent volume and percent wasted weight of each log constituent indicates that about 50 percent of the weight of a log is discarded in process of debarking and drying. Energy or inventory requirements for kiln or air drying, transportation costs, sinker losses and other costs of utilizing high-moisture timber contribute substantially to costs in lumber operations from woods to the consumer.

This research project investigates one approach to weight reduction before cutting. The study describes the moisture contents of the bark, sapwood and heartwood of treated and untreated trees. Moisture contents of these components are considered as continuous functions of location along the merchantable length of the tree. Mathematical models based on these data are used to describe the results of the treatments and measure their effectiveness. This provides a basis for comparing the amount of moisture loss and place of loss. The ultimate utility of this information will be in prediction of treatment effects, hence strategies, for various logging, milling, and other timber conversion operations. Biological implications of these strategies are considered.

LITERATURE REVIEW

Chemical Debarking and Weight Reduction

In the late 1940's to the mid-1950's considerable research was conducted in the area of chemical debarking or "chemi-peeling." The concept generally worked very favorably, in principle at least. Contributing to its demise were the toxicity of the primary chemical used, sodium arsenite, and the treatment method, hand girdling and painting the arsenic solution around the girdled area. The installation of the efficient hydraulic debarker in western Canada made the treatment unnecessary and the labor related costs were shown to make the practice of marginal economic value (Christiansen and Fedkiw, 1959).

The concept of chemical debarking was applied almost entirely to pulpwood. The typically small pulpwood trees have a relatively high percentage of sapwood and thin bark. They appear to respond to treatment more rapidly than large trees, and with more uniformity. Responsive species lost an appreciable amount of weight if treated early in the spring and summer and harvested in the fall. For maximum rates of moisture loss, treating in the spring and early summer was better than the late summer. Greatest moisture reductions occurred in treatment-harvest intervals lasting for a year, or extending over two summers. Advantages include bark loosening, moisture reduction, increased buoyancy, insect protection (reportedly for bark beetles (Blossfeld, 1962)), and seasoning time reduction. Various stand improvement and silvicultural operations may be carried out concurrently (White, 1947; Hale and McIntosh, 1949; Sutherland, 1952; Wilcox *et al.*, 1956; Myles and Jarvis, 1957; Thompson, 1957; Woodfin, 1963).

Insects, breakage, and fungi have been noted as a problem only on large sawtimber and in southern studies (Sutherland, 1952; Berntsen, 1954; Thompson, 1957).

Many pertinent observations were recorded in eastern Canada by McIntosh (1953). Weight reductions of as much as 17 pounds per cubic foot (272 kilograms per cubic meter) were obtained with jack pine (*Pinus banksiana* Lamb.). Appreciable weight reductions also occurred in white spruce (*Picea glauca* (Moench) Voss) and balsam fir (*Abies balsamea* (L.) Mill.). Coniferous species generally responded favorably except for those with very thin sapwood. Broad-leaved trees were usually less responsive. Reductions in weight of nearly 25 percent for trees killed for about a year are also reported (Chemical debarking of green timber, 1958).

Wort (1954a, 1954b, 1954c) conducted an extensive study on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Douglas-fir. Trees were girdled, frilled, basal sprayed and poisoned. Chemicals used were primarily ammonium sulphamate and sodium arsenite; some 2, 4, 5-T was included. Trees were treated in early summer and cut in late fall of the same year and at times during the next year, giving time lapses from treatment to harvest of up to 18 months.

Hemlock could be debarked easily two months after the earlier treatments of arsenite and ammate. By the time the logs reached the debarker, over 66 percent of the bark had fallen off and 43 percent of the logs were bark free. Logs could be debarked at the mill at three times the usual speed. The lumber and chips from the treated logs were found to be free of stain and decay. Damage from ambrosia beetles was insignificant. Easy debarking of Douglas-fir did not occur until 15 to 16 months after treatment. Hemlock losses in wood weight ranged from 13 to 21 percent after about one year. Reductions of 20 percent were obtained with Douglas-fir trees treated in early summer of one year and tested the following summer.

Wood-rotting fungi were found on the surface of a few chemically killed Douglas-firs, but little or no rot had occurred. Blue stain, when finally evident, was associated with ambrosia beetles. The surface of the sapwood of treated trees of both species was usually stained yellow or brown. This color appeared to be the result of chemical action and did not penetrate into the wood but remained as an extremely thin surface layer.

A part of the above study was also devoted to examination of entrance and movement of arsenic through the tree. The arsenic was absorbed by the sapwood from a girdle treatment, and rose through the wood, from which it diffused into the bark. Histological examinations revealed that the living cells of the cambium and phloem were killed first, followed by death of the parenchyma cells of the wood rays. Radioautographs of radioactive arsenic treatment showed heavy concentrations of arsenic in the outer one-eighth-inch of wood and in the first one-sixteenth inch of bark adjacent to the sapwood. The amount of arsenic decreased with distance from the cambium, becoming almost zero toward the center of the tree. The vertical distribution of arsenic shows a very rapid decrease above the girdled application area. Values range from 17.3 parts per million at six inches above the girdle, to 6.4 parts per million at 20 feet to 1.75 parts per million at 100 feet above the girdle. Arsenic concentration in the bark was a little higher at the six inch level, about one-half at 20 feet and less than 0.1 parts per million at the 100 foot sample height. These results illustrate that only very small amounts of elemental arsenic were needed to bring about the death of the tree.

Samples from treated trees were made into pulp with no adverse effects demonstrable. Chemical analysis of the pulp fiber indicated less than 0.02 parts per million arsenic, while the arsenic content of the filtrate was less than 0.01 parts per million. The samples pulp-tested were cut from the outer two inches of the trunk and might be assumed to contain the bulk of the arsenic. Jahn (1953) also reported that pulps made from wood from arsenite-treated trees were of the same quality as pulp from untreated trees. The arsenic content of the pulps and papers made from treated wood are uniformly low, zero to two parts per million.

A recent study of chemically treating trees before harvest was reported by Holt and Newton (1967). Young growth Douglas-fir were treated with cacodylic acid, an organic arsenical, in November and the following May; the trees were cut in September of that same year. The maximum time lapse from treatment to harvest was ten months. Weight reductions of seven percent for the spring treatment and ten percent for the fall treatment were indicated. Substantial bark loss did not occur nor did breakage appear to increase.

The introductory section of this paper alludes to two types of weight loss: 1) loss resulting from air drying of standing trees, and 2) loss of bark in normal handling of the logs. Associated corollary phenomena include the effect of bark on soil, the relationship of wood strength and moisture content, the potential effect on wood strength by drying trees in this manner, and potential effect on the utilization of wood that is drier than normal. The following reports allude to losses of bark and related effects of treatment.

Effect of Bark on Soil

Bollen (1969) reports that about five million tons of bark were produced as waste in the Pacific Northwest in 1966. He also notes that its nutrient value is usually higher than sawdust, although both are very low. Any "toxicity" noted after addition of bark to soil is usually a result of nitrogen deficiency. Bollen suggests that it would be very desirable to leave bark in the woods where it could be a protective organic cover, and not a disposal problem.

Moisture Content and Wood Properties

Basically, moisture content has no effect on strength properties of wood at values higher than fiber saturation point. Therefore, for any given tree, if the moisture content is reduced without affecting its strength values then the tree is stronger per unit weight. Most of the strength properties of wood increase rapidly as it dries below the fiber saturation point. This increase is a result of 1) strengthening and stiffening of the cell walls as they dry out (principally) and 2) increase in the density of wood substance because of shrinkage (Wilson, 1930; Espenas, 1947; Rietz, 1957; Wood, Erickson and Dohr, 1960; Siimes, 1967; Gibson, 1968). These same authors point out, however, that other problems can be incurred in drying. Strength increases may be offset, especially in large timbers, by the influence of defects that develop in seasoning. Crushing strength and bending strength increase greatly as wood dries, but stiffness is only moderately improved, while shock resistance may even decline slightly. Drying also enhances the weakening effect of defects such as knots, shake and cross grain. Wood with non-uniform moisture distribution is generally weaker than wood with the same amount of moisture in a uniform distribution. A principal cause of stress and defects in drying is a steep moisture gradient between surface and interior. Internal drying stresses, part of them permanent, are produced and the prevailing total stress may increase greatly as drying progresses thereby reducing the resistance to rupture.

Moisture Content and Utilization

Utilization of a drier log or tree does not appear to be a problem. Moisture content has little effect on cross sawing (Pahlitzsch, 1967). McKenzie (1967) noted that, at normal speeds of wood cutting, the coefficient of friction will be lower for wet than for dry wood. At low speeds, the coefficient will be slightly higher for wet than dry wood. Pulp mills can apparently use drier wood, particularly in view of industrial support of much of the early chemical debarking work (Myles and Jarvis, 1957; Chemical debarking of green timber, 1958).

Moisture content plays a very important role in veneer manufacturing. The quality of southern pine rotary-cut veneer at room temperature with high compression by a roller bar is inversely related to the cutting velocity and moisture content. In general, high moisture content and high cutting speed result in high loads on the roller bar, damage to thin veneer, and veneer weak in tension perpendicular to the grain (Lutz, Pergen, and Panzer, 1967). Hoadley (1963) found that, in comparison to cutting of wood whose moisture content is slightly above the fiber saturation point, cutting of fully saturated wood involves greater energy consumption and strain recovery, and results in thinner veneer of lower tensile strength. These effects were attributed to hydrostatic bursting of cell structure during the cutting process.

In summary, there appears a tendency, from the above-noted works, to conclude that low-moisture wood can have important advantages, and that the advantages occur in many of the utilization steps.

METHODS AND PROCEDURES

Site Selection

The study area includes about 15 acres located in MacDonald Forest, property of the School of Forestry, just northwest of Corvallis. The area is topographically uniform and is low to middle site III for Douglas-fir (McArdle and Meyer, 1949). The slope is moderate and of westerly aspect (Figure 1).

Figure 1. Treatment area.

The 60-year-old stand, mostly Douglas-fir, was marked for commercial thinning by a private logging contractor.[1] The experimental trees were selected from among those marked; the trees were nearly all codominant, intermediate and suppressed in crown class.

Experimental Procedures

Experimental Design

Experimental trees ranged from 9.6 to 14.3 inches diameter breast high (DBH) with a mean of about 11.5 inches. This diameter range was arbitrarily chosen as a means of maintaining some degree of homogeneity within experimental material. Tree heights ranged from 45 to 112 feet with a mean of about 88 feet.

The original experimental design was a completely randomized analysis of variance, with main effects of month of treatment, and linear and quadratic effects of sample diameter as covariates. Two hundred trees were selected and randomized among eight monthly treatments, February, 1967 to September, 1967, with 25 trees to be treated each month.

Treatment

Treatments consisted of boring three-quarter inch holes, one

[1] Rowley and Parker Tree Farm Service, Philomath, Oregon.

hole per each three inches of DBH, and pouring approximately 10 to 20 milliliters of herbicide[2] into each hole. The holes generally penetrated through the sapwood, and were usually about three feet from the ground, exact height depending on convenience. The holes were made with portable, gasoline-powered drills.

Twenty-five trees were treated monthly with MSMA, as planned, for the first three treatments, February, March, and April, 1967. There were indications that protection from insect attacks was not as good as anticipated with MSMA. Beginning in June, 1967 the monthly treatments were divided into two groups of ten treatment trees and five that were left untreated. One group of ten was treated with MSMA and the other group with cacodylic acid. The five untreated trees were utilized as needed for supernumeraries to maintain homogeneity of experimental material. The gain in information from changing to the more protective herbicide was sought despite the potential disadvantage of changing design.

The May treatment series was omitted because mechanical failures caused the April treatment series to extend into mid-May before completion. All treatments were then moved back one month,

---

[2]Monosodium methanearsonate (MSMA) and hydroxydimethylarsine oxide (cacodylic acid), Ansul Chemical Company products L-2505 and Silvisar 510 respectively, were supplied by The Ansul Company, Marinette, Wisconsin. They contain 6.6 and 5.7 pounds of active herbicide per gallon, respectively.

so the final treatment occurred in October, 1967 rather than September.

Untreated standards consisted of five trees felled and sampled at the beginning of the study, 12 trees cut in September, 1967 and ten trees cut and sampled in September, 1968.

Figure 2 presents the essential treatment groups outlined in the preceding text. Time lapse is the time in months from treatment to harvest or the time the trees were left standing in the woods. Time lapse between treatment and visual symptoms varied, thus time lapse is not a measure of time the trees were dead or defoliated although there is a relationship.

The number of trees within each treatment series is the number of trees for which data are complete. The difference between the number of treated trees and the number of trees on record represents lost trees, or samples with incomplete data for other reasons. The number of samples listed in Figure 2 is the number of observations used for analysis.

Moisture Samples

Three separate cuttings were made in the stand. Five trees were cut in February, 1967, 27 trees were cut in September, 1967, and about 170 trees were in the final harvest in September, 1968. The first cutting was made by the author. The trees were bucked

Herbicide	Month treated	Time Lapse (Months)	Trees Sampled	Number of Samples
	(Treated in 1967 and sampled in September, 1967)			
MSMA	February	7	5	13
	March	6	5	11
	April	5	5	13
	(Treated in 1967 and sampled in September, 1968)			
MSMA	February	19	18	38
	March	18	16	38
	April	17	20	52
	June	15	10	23
	July	14	9	23
	August	13	5	14
	September	12	9	20
	October	11	9	22
Cacodylic acid	June	15	8	21
	July	14	9	24
	August	13	10	21
	September	12	10	22
	October	11	9	23
	When cut			
Control trees (Untreated)	February, 1967	--	5	22
	September, 1967	--	12	31
	September, 1968	--	10	24

Figure 2. Relevant features of study in terms of design and final numbers of trees and samples included in the analyses.

into logs 16.3 feet long and wafer samples were taken from the ends of all logs. The last two cuttings were made by the logging contractor. Each year the test trees were felled and bucked as in the normal routine. The wafer samples were then cut from the ends of each log; merchantability extending from the stump to a minimum top diameter of six inches diameter outside the bark (DOB). Log lengths were determined by the logger doing the felling.

The wafer samples were about one inch thick, and consisted of the total cross-section of the log end. Some fluctuated in size and shape around this criterion. Since the moisture content of the bark, sapwood and heartwood were determined separately, their occurrence in proper proportions was not highly important. Increment borings, while more easily collected and handled, do not account for moisture distribution around the stem, and have been shown to consistently underestimate the moisture content of timber above about 40 percent moisture content (Purslow, 1968).

The wafer discs were collected at the time of bucking, placed in polyethylene bags and brought to the lab. The data were recorded from all samples collected during the first two cuttings at the end of each day. Nearly all samples collected during the cutting of 1968 were frozen to maintain the moisture gradients within the samples during the following year of sample preparation after field collection.

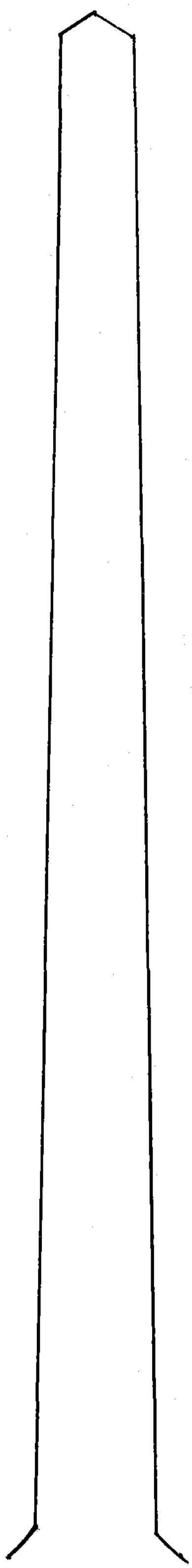
In the lab, the diameters of samples were measured outside the bark (DOB), inside the bark (DIB) and at the heartwood-sapwood transition. The respective measurements were recorded before and after the sample was debarked and after the sapwood was sawn from the heartwood. The samples were weighed while green and after drying at temperatures of 100 to 105 degrees Centigrade. Moisture content values as percentages of oven-dry weight were then calculated. A total of about 1400 observations were recorded in this way.

Field Data

Supportive field observations regarding the form and handling of each tree were collected at the time of cutting on the form in Figure 3. Log lengths, crown base, tree height, and heights and diameters of any other factors were represented diagrammatically on the form.

The logs of the individual trees were numbered in the woods in several places to facilitate identification of the logs after skidding and decking at the landing. Identifiable logs were then weighed individually with a dynamometer and tong arrangement as seen in Figure 4. Observations were also made at this time relating to bark loss, since this affected the recorded weight.

A small portion of the experimental trees cut in September, 1967 were observed being sawn into lumber with a band saw and gang saw at the Larson Lumber Company, Philomath, Oregon. Some of



Treatment ______ Tree No. ______
Species ______ Crown Class ______
D. B. H. ______ Kill Rating ______
Height ______ Age ______

OBSERVATIONS

Defect:

Insects:

Backflash:

Breakage:

Staining:

Bark Loss:

Other:

Figure 3. Field data form (primarily for heights and diameters).

the trees cut in September, 1968 were observed as they were converted to veneer core stock at Oregon Alder-Maple Company, Willamina, Oregon. In both instances only visual observations were made without reference to particular treatments. Personal observations and discussion with the involved mill personnel indicated that nothing unusual was apparent in utilizing the experimental trees by these two manufacturing processes.

Figure 4. Weighing individual logs at the landing.

RESULTS

Moisture contents of the samples, based on oven-dry weight, were calculated as follows:

$$\text{percent moisture content} = \left(\frac{\text{green weight - dry weight}}{\text{dry weight}}\right) \times 100 \qquad (1)$$

Because the weights and tare weights were not compiled for the samples of each harvest until all handling of the samples was completed suspected errors were usually impossible to correct. Some data were removed at this point where errors were obvious or highly suspected. This included several samples for which negative moisture contents resulted and five samples which had excessively high moisture contents.

The primary reason for collecting the moisture content and measurement data was to permit the reconstruction of the weights of the bark, sapwood and heartwood. The measure of the success of treatment was interpreted in terms of the relative differences between the weights of the treated versus control trees.

Moisture Content Regression Analysis

The purpose of regression was to merge the observed moisture contents of each treatment into one single moisture profile representative of the composite results of that treatment. This, in effect, blended all the trees of each treatment into one tree with moisture profiles of the bark, sapwood and heartwood as separate constituents. This was accomplished with multiple linear stepwise regression analysis. The moisture content of each sample constituent (bark, sapwood and heartwood) was considered the dependent variable and was regressed on its respective "independent" tree and sample variables. The analysis, in this respect, considered each sample to be unrelated to any other samples although up to three samples may have come from the same tree. The moisture content of each constituent was considered to be independent of the others, for example, the moisture content of the sapwood was explicitly modeled as a function excluding the moisture content of the bark and vice versa. This permitted a description of the moisture profile of one without belaboring the obvious interaction or relationship between the moisture contents of the two.

Each sample was described with respect to its own tree characteristics, which included DBH, total tree height, height to base of the crown and the proportion of the tree occupied by crown. Each sample also had its associated sample characteristics which included sample height, relative sample position in the total tree and relative position with respect to the base of the crown. Each constituent within samples had its associated variables which included its diameter, thickness, the percentage of the sample area comprised by the constituent, and, for the sapwood and heartwood, the percentage of the wood area comprised by each.

To understand the rationale behind the selection of these variables the reader should consider the moisture content of, say, the sapwood at single points on several different trees. The only restrictions placed on the trees are that they are the same species, received the same treatment, and are within five inches DBH of each other. The object is to mesh the moisture contents at the several points into a single profile in a way which reflects their actual relationship. The tree characteristics permit the expression of the influence of tree size, as measured by several variables, on moisture content. The sample variables permit the expression of the importance of height and relative position in the tree. Certain of these variables are interrelated. For example, diameter is correlated with height, and constituent thickness is related to percentage of area at that point.

The multiple stepwise analysis generated an equation, from the tree, sample and constituent variables that explained as much variation as possible hence provided the best description of the observed data. Each of the tree, sample and constituent variables had the possibility of entering into the analysis in the linear, quadratic and cubic form. This permitted each variable to be expressed in the form of best fit to the data.

Analysis on a treatment by treatment basis was considered the most informative procedure for several reasons. Since the objective was a best-fitting, descriptive equation, the use of many variables increased the likelihood of optimum fit. The resulting equation was a composite of all important variables describing the moisture content at any single point. Treatment by treatment analysis eliminated the factors of time or season and the complicated interactions resulting therefrom. The experimental material changed from month to month as the year progressed and the trees underwent changing and unknown physiological transitions. Responses to herbicides changed with season; the degree of exposure to drying changed in ways that were uncontrollable, hence impossible to assign numerical values.

Summary tables of the variables and their coefficients are found in Appendix A. Each descriptive model is formed by the algebraic summing of the product of each variable and its respective coefficient. Three equations, one each for bark, sapwood and heartwood, may be so constructed for each of 19 separate treatment-harvesting units or "complete treatments." Each equation is a complicated polynomial of several entangled variables. Interpretation of the equations with respect to causality is not possible. However, the equation is the equation of best fit generable at any particular point by supplying the proper values for the variables. These complex-appearing equations are a means to an end, and little emphasis is placed on what variables entered into the final equation, or on the change in coefficients from treatment to treatment.

Model Tree

An average or hypothetical tree was needed to permit treatment comparisons on a uniform basis to utilize the descriptive equations previously described. A model tree was generated from measurements made on the wafer samples and experimental trees. An arithmetic average of three tree characteristics for each wafer sample collected for all treatments gave the following tree values: 1) total height = 84.6 feet, 2) height to base of crown - 58.6 feet, 3) diameter breast height = 11.8 inches. One hundred and thirty-three wafer samples, representing 50 trees in the diameter range of 11.3 to 12.3 inches DBH, were used to generate the standard tree.

Diameter outside bark (DOB) was regressed on DBH, tree height, crown height, sample height and relative sample position in a manner exactly analagous to the method used to generate the previous moisture equations. The diameter inside bark (DIB) was regressed on the DOB, and the diameter of the heartwood was regressed on DOB and DIB. These regressions resulted in three equations with the diameter of the heartwood being expressed as a function of the diameter inside bark and diameter outside bark. Diameter inside bark is a function of diameter outside bark, and diameter outside bark is itself expressed as a function of several measured variables. These variables and their coefficients are presented in Appendix B, along with the computer program indicating the way in which the equations of the model tree were used to evaluate the moisture profiles.

As with the previous moisture equations, the model of the tree is difficult to visualize, but does in fact, describe the data very well. To enable one to visualize the model tree more clearly the equations have been evaluated in terms of sample height, see Figure 5. The model tree represents only the merchantable portion of the bole since this is the only area from which samples were taken.

Qualitative Moisture Content Results

The simultaneous solution of the polynomial equations of the moisture profiles and the model tree permitted plotting the moisture profiles as discrete functions. The simultaneous solution is necessary, since nearly all of the variables involved in the expression of the functional relationship of moisture content are themselves continuous functions of placement within the model tree. The model tree provided a consistent and uniform basis for evaluating these variables. Solutions of all equations at this point were given in terms of sample height, although any variable of interest could have been used. Sample height is easily visualized, easily illustrated and more useful in future steps. Graphic presentations of the computed moisture profiles of bark, sapwood and heartwood for each treatment over

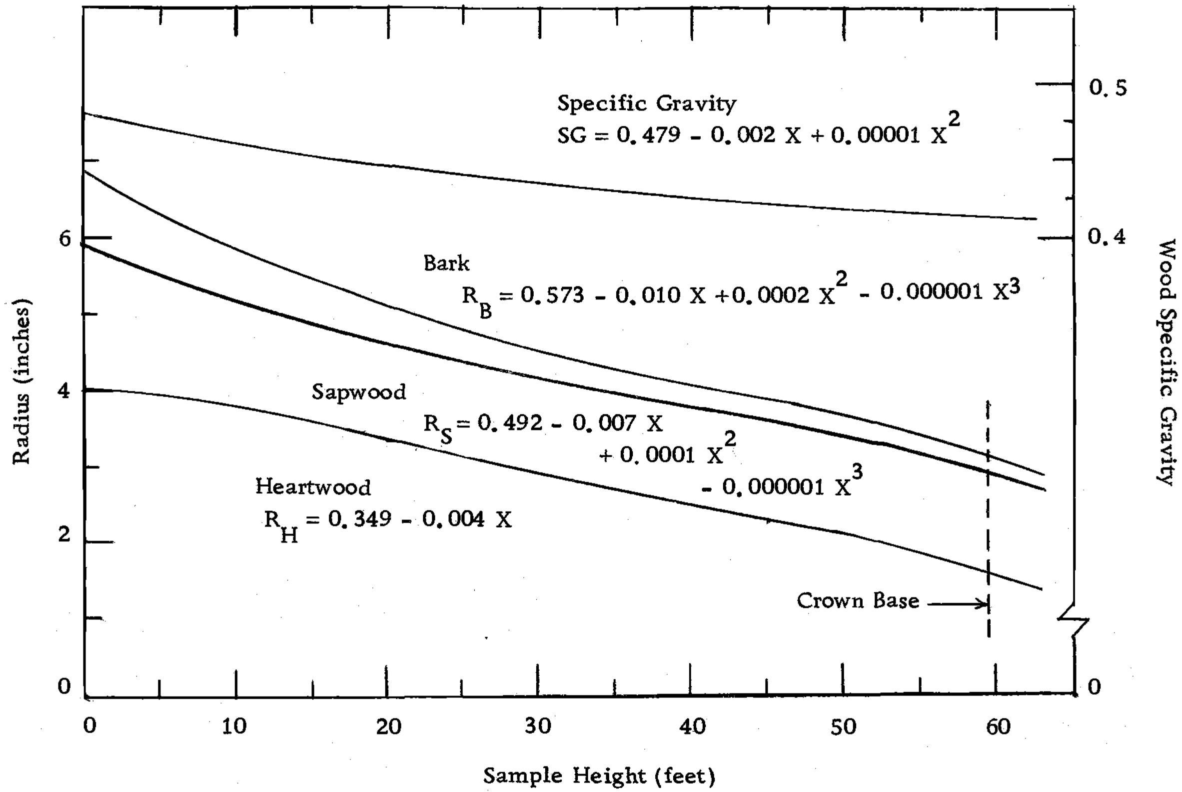


Figure 5. Radii of bark, sapwood and heartwood, and specific gravity of sapwood and heartwood, of model tree as related to sample height (SG = specific gravity, R_B = radius of bark, R_S = radius of sapwood, R_H = radius of heartwood, and X = sample height).

the merchantable portion of the model tree are given in Appendix C; a brief summary by component follows.

Bark

The untreated trees cut in February, 1967 had the highest moisture values, up to 180 percent in the tops. The control trees cut in September, 1967 and 1968 had very similar moisture profiles, when compared to the February control trees, although differing in degree; the bark was considerably drier. In view of the extremes of climate in 1967 compared to 1968 the similarity of the moisture profiles of the two September control samplings was somewhat unexpected. The summer of 1967 was characterized by a very long dry period of record setting length; the summer of 1968 was atypical in the amount of rain occurring and the very short dry season.

The bark of the treated trees sampled in September, 1967 was generally drier than the bark of their respective control trees although tending to contain more moisture at the basal region. The bark of the February and April treated trees was considerably drier in 1968 than in 1967; in March the reverse relation was noted. The February trees treated with MSMA had approached a very constant moisture content after 19 months

Trees treated with MSMA tended to have bark drier than their control trees by 1968. This was particularly notable above about 20 feet in height, bark tending to be more moist on the butts of the trees. Bark of the cacodylic treated trees cut in 1968 failed to decrease in moisture content rather uniformly, when compared to the control trees, with June being the driest to October as the wettest. The bark of cacodylic trees was consistently wetter than the bark of the MSMA treated trees regardless of month treated.

Sapwood

The moisture profiles of the sapwood of the control trees were very unexpected, particularly in that the control trees cut in 1968 were appreciably drier than those cut at the end of the previous summer. By September, 1968 the trees treated with MSMA in February, March, April, June, July and August had very similar moisture profiles. They showed a very pronounced trend in decreasing moisture content with sample height and were generally similar in moisture content values. The September and October MSMA treatments were appreciably wetter than the others. While the June and July cacodylic acid-treated trees had moisture profiles similar to their MSMA treated counterparts, trees treated during the rest of the months showed an increase in moisture content. As with the bark, the trees treated with cacodylic acid tended to have wetter sapwood than the corresponding MSMA treatment.

Heartwood

The heartwood moisture content of the control trees and all treatments tended to remain unchanged. The most consistent pattern was the 35 to 40 percent range of moisture values at the stump, a slight decrease occurring from ten to 30 feet up and constant for the remaining length of the tree. The final moisture content in the top generally ranged from 30 to 35 percent.

Computed Weights from Descriptive Models

The following discussion describes the functional relationship of factors influencing the weight of wood and the steps involved in this analysis for estimation of these factors. The weight of wood is determined by its volume, specific gravity and moisture content. These variables change with change in position in any tree. The next few pages present the way in which these variables were estimated so that total weight could be determined by integrating directly over a definite interval.

The weight of any piece of wood can be determined from the functional relationship as follows (Espenas, 1967, personal communication):

$$W = (62.4)(SG)(1 + MC)(dV) \tag{2}$$

where W = weight of wood of any volume

SG = specific gravity of wood based on green volume and oven-dry weight

62.4 = weight of one cubic foot of water at 4° Centigrade

MC = moisture content based on oven-dry weight with moisture content expressed as a decimal rather than as a percentage

dV = volume in cubic feet

The variables of specific gravity, moisture content and volume change throughout the length of a tree. From the calculus, volume can be computed by adding successive infinitely thin discs by the process of integration. Volume of a single disc is:

$$dV = \pi [R(x)]^2 dx \tag{3}$$

where dV = infinitesimal volume

π = 3.1416

R(x) = equation expressing radius as a function of sample height

dx = infinitesimal thickness of disc

Integration of this equation gives the total volume of a section of the tree.[3] If one considers a single disc of thickness "dx" then, by

---

[3]

$$V_{a,b} = \pi \int_{x=a}^{b} [R(x)]^2 dx \tag{4}$$

definition, the weight of that disc is expressed as equation (2). The total weight of the tree or any section of it is in the sum of the weights of all discs in the tree or section of the tree. Therefore, the total weight of any length of the model tree is the integral of equation (2), as follows:

$$W_{a,b} = (62.4) \int_{x=a}^{b} (SG_x)(1+MC_x)\, dV_x \qquad (5)$$

Construction of Equations

Radius. The model tree in Figure 5 is described in terms of radius for the calculation of volume as just illustrated. The radii were reanalyzed by the same stepwise multiple regression program used to model the tree from measurement data. In this second analysis the respective computed points of radii of bark, sapwood and heartwood were regressed on sample height, sample height squared, and sample height cubed. The result is a model which fits the evaluated points almost exactly and expresses radius in terms of sample height alone. The equations of radii are expressed in feet rather than in inches, hence they are applicable to cubic foot computations.

Specific gravity. The inclusion or even the construction of an equation for specific gravity may be somewhat questionable since this value was not measured on the wafer samples. Specific gravity changes with height in a tree (McKimmy, 1959). An equation that expresses this change can account for the proportionality of changes occurring in a tree. The construction of this equation was derived from data published by McKimmy (1959). He presented data of average specific gravity of young-growth Douglas-fir for different height levels and decades for sites II, III and IV. Average specific gravity of weighted averages were determined at six height levels, from five to 93 feet. Specific gravity was then regressed over sample height exactly as described for equations of radii, see Figure 5.

The specific gravity equation applies only to the heartwood and sapwood; no model of bark specific gravity could be so constructed. An average of 0.422 was assumed from Smith and Kurucz (1969). This is an average bole bark specific gravity determined from measures on 42 Douglas-fir with an average age of 65 years, about the same age as trees in this study.

Moisture content. Equations were fitted to the computed moisture contents of the bark, sapwood and heartwood of each treatment in a manner exactly identical to that used to define the model tree components. These results are the equations given for each moisture profile in Appendix C. The moisture contents were converted from percentages to proportions and the variable of sample height to the fourth degree was included to permit more accurate fitting of certain equations to the data points. The inclusion of the fourth degree term is not construed as having significance in terms of biological meaning. The original equations of several variables determine the shape of the moisture profile.

Equations have now been derived that express radius, specific gravity and moisture content as a function of sample height for each component by treatment (Figure 6). This figure summarizes all variables influencing the weight of the heartwood of the model tree combined with the moisture results of the control trees cut in September, 1967. The total weight of the heartwood is the integral of the product of the three equations times the constant 62.4π; see equation (5).

Weights of the sapwood and bark for all treatments are computed in the same manner with a minor revision. The sapwood volume is the total volume of the solid of revolution with a radius of the sapwood minus the volume of the heartwood. Therefore the adjusted equation for computing the volume of the sapwood is the square of the equation for the radius of the sapwood minus the square of the equation for the radius of the heartwood, which is then handled in the same way as the equation for heartwood. Similarly, the adjusted bark equation is obtained by subtracting the squared equation of sapwood radius from the squared equation of bark radius. The weights of each component can be calculated for any desired length or position by multiplying the appropriate equations and integrating the resulting equation over the desired interval. See Appendix D for a more detailed presentation of the equations, the computing algorithm, flow chart and computer program.

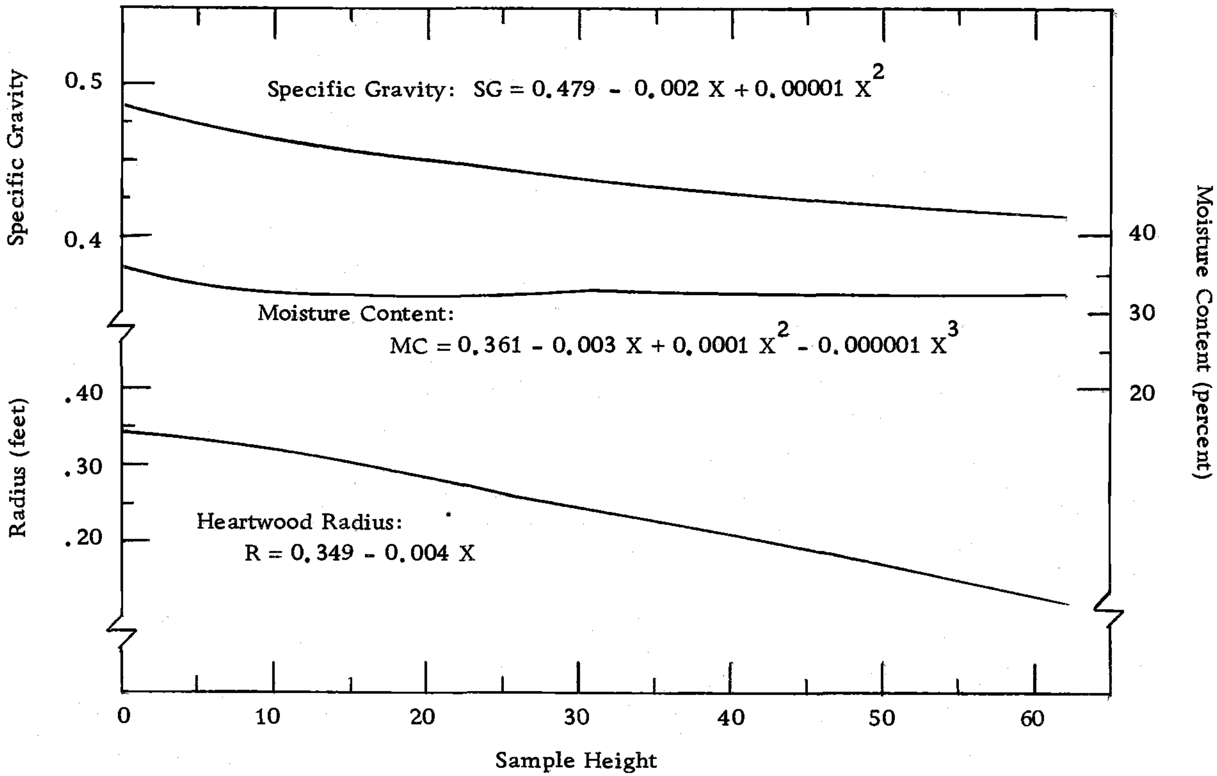


Figure 6. Variables influencing heartwood weight of controls cut 9/67.

Weights for bark, sapwood, heartwood, total tree, and solid wood were computed by this type of integration. These weights were also divided by their respective volumes to give densities. The total model tree was divided into three 20 foot logs and the same values were computed by integration of intervals from one to 21 feet, 21 to 41 feet, and 41 to 61 feet. These logs were designated as butt, middle, and top log, respectively. Density of each part of each log was calculated from weights and volumes. The respective percent weight reductions of each component by treatment and log may be computed by ratios. These manipulations of data appear in Appendix E.

Comparison of Predicted and Actual Weights

An indicator of the correctness of the predicted weights, and the equations from which they are derived, provide the proper framework for their interpretation. Actual log weights are those which were recorded at the landing by weighing individual logs. The log lengths were measured when the trees were bucked into logs, and end diameters were measurements made on the wafer samples collected from each end of the logs. The volume of each log was computed on the assumption that all were shaped as frustrums of right circular cones or conoids. The calculation of volume was as follows (Forbes, 1961):

$$V = 1/3\ (A_1 + A_2 + \sqrt{A_1 \times A_2})\ L \qquad (6)$$

where V = volume of log

A_1 and A_2 = areas of log ends in square feet

L = log length in feet

The weights and volumes of the logs from each treatment were summed and their totals converted to weight per cubic foot. Logs with computed weights of less than 25 pounds per cubic foot and greater than 78 pounds per cubic foot were not included in the totals of actual weights and volumes as a means of eliminating log weights which were mismatched with log sizes. Assuming a specific gravity of 0.45 (Rasmussen, 1961), oven-dry Douglas-fir must weigh 28.1 pounds per cubic foot. The same wood at the lowest air-dried moisture content possible (about ten percent) weighs about 31 pounds per cubic foot. The acutal log weights were of logs with various degrees of bark loss, however, even though the volumes are computed for diameters outside the bark. This results in an underestimation of the weight per cubic foot of any log with loss of bark. The lower limit of 25 pounds allowed for this error in weight per cubic foot computation and was a means of eliminating unrealistic values without a non-random elimination of logs from treatments incurring considerable bark loss. The upper limit, 155 percent or 72 pounds per cubic foot, is based on a maximum moisture content attainable by wood of this specific gravity (Espenas, 1947). These weight per cubic foot values were computed from equation (2) with volume held constant and the appropriate moisture contents substituted.

Table 1 presents a comparison of the predicted and actual weights by treatment. The predicted weights are those weights computed using the model tree while the actual weights are based on the logs weighed in the field. This fact invalidates a direct comparison of the two values as a check on the accuracy of the fitted equations. Had the derived equations been used to predict the weight of the individual logs that were weighed then this type of comparison would be valid. The equations for the component radii of the model tree were derived from measurements made on samples taken from trees ranging from 11.3 to 12.3 inches DBH or within one-half inch of the indicated average tree DBH. These equations may or may not adequately fit trees of larger or smaller diameter classes which were included in the study. This assumes that there was a random and equal diameter distribution among treatments. In addition, the objective of using the model tree was to provide a means of comparing individual treatment effects on a uniform basis. The predicted and actual results are presented together to indicate the degree to which the derived results follow the actual results.

A more indicative comparison of the utility of the derived equations lies in the ratio of actual and predicted results. This ratio is consistently less than one indicating that, while the actual numbers

Table 1. Comparison of predicted and actual weights of merchantable portion of tree, ratio of predicted to actual, and their respective weight reductions.

Treatment	Tree weight per cubic foot			% Weight reduction	
	Model tree	Actual	A/P	Predicted	Actual
Control - Cut 2/67	50.4	41.5	.82	--	--
Control - Cut 9/67	47.6	42.6	.89	--	--
Feb - MSMA - Cut 9/67	46.7	35.2	.75	--	17
March " " "	46.1	35.2	.76	3	17
April " " "	43.2	34.6	.80	9	19
Control - Cut 9/68	46.1	40.2	.87	--	--
Feb - MSMA - Cut 9/68	41.8	35.1	.84	9	13
March " " "	43.2	33.8	.78	6	16
April " " "	42.6	35.2	.83	8	12
June " " "	42.5	31.9	.75	8	21
July " " "	42.4	33.2	.78	8	17
Aug. " " "	41.4	36.8	.89	10	8
Sept. " " "	45.5	39.2	.86	1	2
Oct. " " "	47.3	40.8	.86	-3	-1
June - CACO - Cut 9/68	43.0	35.7	.83	7	11
July " " "	43.5	36.7	.84	6	9
Aug " " "	44.6	37.3	.83	3	7
Sept " " "	48.2	38.3	.79	-5	5
Oct " " "	49.7	37.6	.76	-8	6

differ, the derived equations do exhibit a consistent trend in their estimation. After multiplying the predicted weights by a correction factor of 0.82, the ratio mean, the predicted weights of all treatments are within nine percent of their respective actual weights.

Several factors are probably influencing the difference between the estimated treatment effect, in terms of weight per cubic foot, as measured by the two computational methods. There is a greater probability of the larger logs reaching the landing in recognizable condition for the weighing operation. The average DBH of all trees included in the study is 11.5 inches whereas the average DBH of trees represented in the logs weighed is 11.9 inches. For a given tree the butt log is generally the largest and is more likely to reach the landing without being mangled or broken in skidding or decking. This is also true for logs from larger diameter trees. The larger logs have a greater proportion of heartwood which, because of its very low moisture content, tends to reduce the weight per unit volume of the logs when compared to smaller diameter trees or upper logs.

The butt logs further confound the computations by being the section of the tree which is least accurately characterized by a conoid or frustrum of a cone, the equation used for volume computation. Because of the butt swell and the fact that the diameters at each end of the log are used in equation (6), the log volume is over-estimated. This volume is then divided into a weight which is already suspected of being low by virtue of the log size. This interaction further contributes to the lower weights per cubic foot of the actual values.

The specific gravity equations for the model tree are only estimates. The bark specific gravity is an extrapolation from trees measured in British Columbia; this is a single value and there is no reason to assume that bark specific gravity does not change with height. The inclusion of specific gravity for sapwood and heartwood in the form used was to provide a more realistic change of weight per unit volume with changing height in the tree. This gives a more realistic weighting factor for comparison of relative weights of the butt compared to the top of the tree.

The model tree also suffers from the lack of samples collected from the lower region of the trees. The tree is probably well characterized at the one foot level and at points above the minimal first log, 16 to 20 feet. As a result the equations describing the model tree, while being constructed from measurements made from trees averaging 11.8 inches DBH, yield a tree with a diameter breast height of 12.8 inches. This suggests that the bark and wood thickness should decrease more rapidly in the basal region than they do in the model tree but there is a lack of data for this region. The over-estimated volume in the predicted values results in over-estimated weights.

The percent weight reductions for the actual and predicted results are computed separately for each set of weights by comparing the weights of each treatment to its respective control group as follows:

$$\text{percent weight reduction} = \left(\frac{\text{control weight} - \text{treatment weight}}{\text{control weight}}\right) \times 100 \quad (7)$$

Figure 7 is a graphic illustration of the predicted and actual densities and further illustrates the agreement in the trends of the results. The degree to which the actual weights can be estimated from the previously described sampling procedure may be of some practical utility. Weighing of individual logs at the landing is very time consuming, dangerous and costly. The sampling procedure was easily accomplished with a minimum of interference with the regular felling and bucking operation. The ability to determine the actual weights from samples would facilitate future studies of this nature and help establish guidelines for woods operations. Figure 8 illustrates the steps and procedures which were developed and used for the analysis of data in this study.

Bark Loss

Estimates of bark loss were very subjective at best. Estimates were made with particular emphasis on logs with a substantial degree of debarking. Treatments with a consistently small amount of loss would not tend to be noted. This could have been a factor in the June treatment of MSMA which had a very low weight per cubic foot value

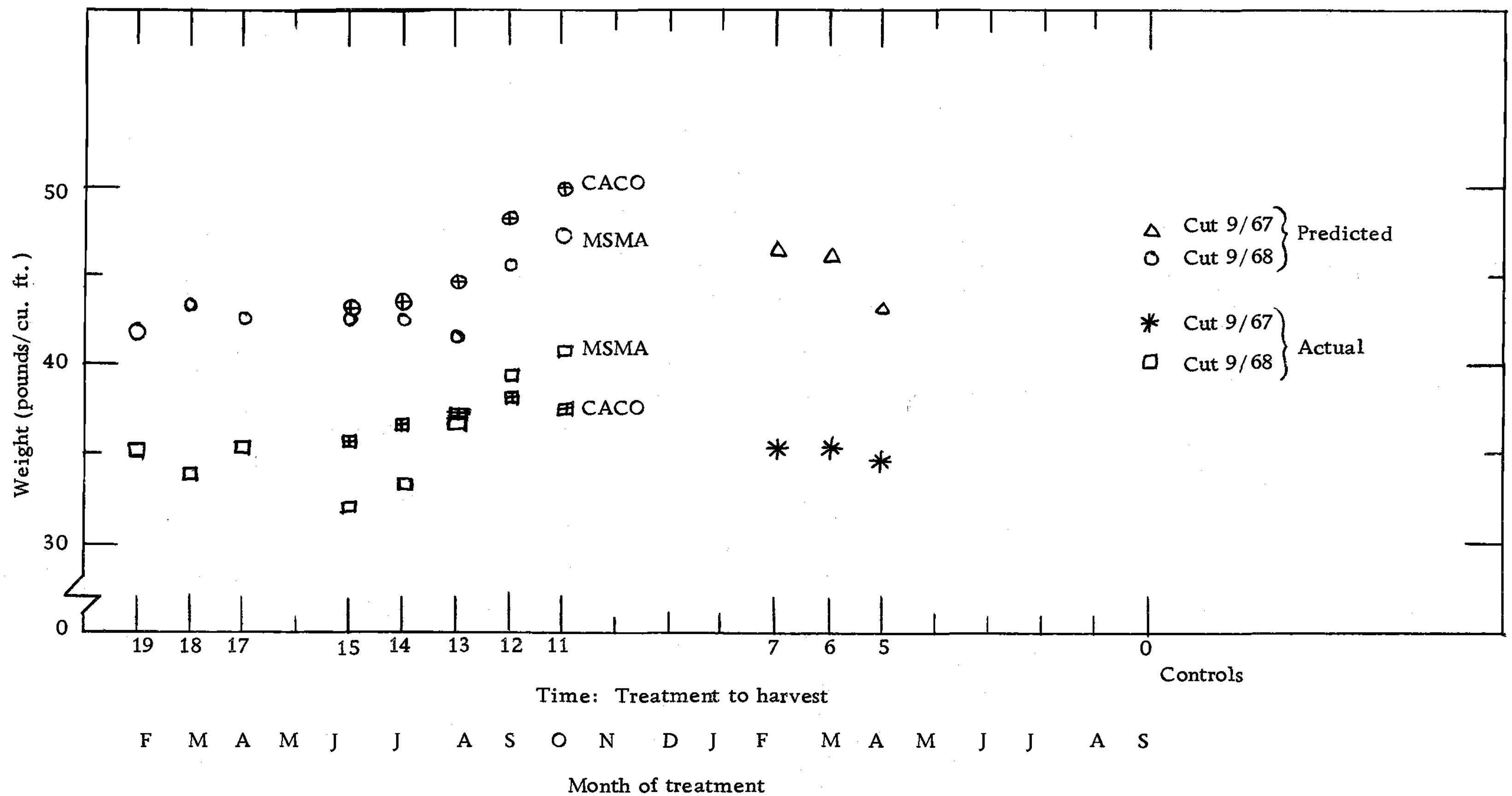


Figure 7. Comparison of predicted and actual tree densities by treatment.

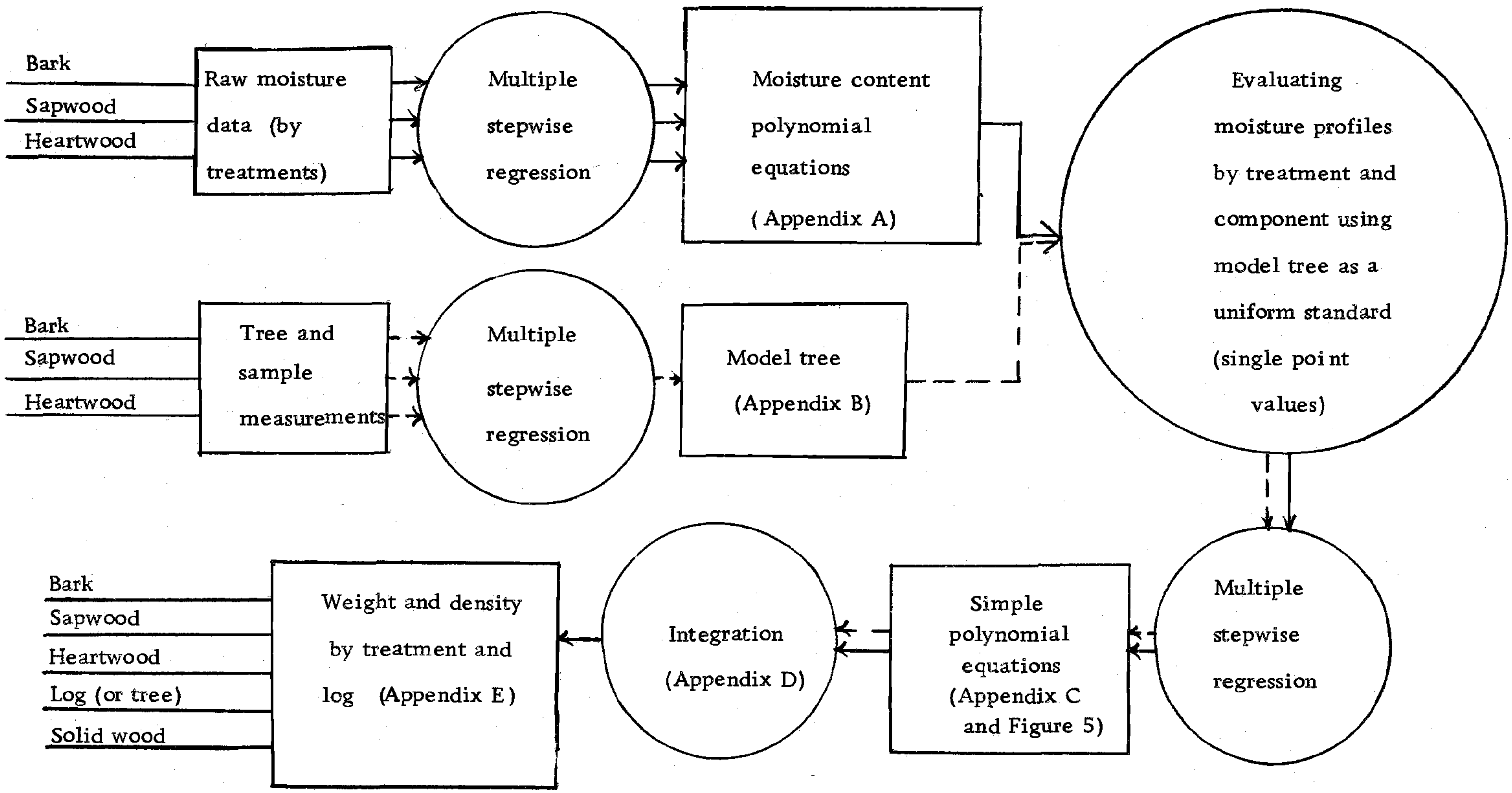


Figure 8. Flow chart of steps involved in analysis of data.

but almost no indication of loss of bark. Considerable loss was noted in trees treated with MSMA in February, March, April, and July of 1967 and cut in September, 1968. The bark loss for these treatments averaged 32 percent for February, 41 percent for March, 20 percent for April, and 22 percent for July. These averages were obtained by adding up the losses noted, and dividing by the total number of logs weighed for each treatment. Time lapse from treatment to harvest for these treatments range from 14 months for July to 19 months for February. This is very similar to findings of Wort (1954a) as noted in the literature review. The nature of debarking is indicated in Figure 9.

Breakage

The occurrence of breakage at diameters greater than four inches DOB was noted in the field at the time of cutting. Figure 10 summarizes the average DOB of the first break greater than four inches DOB and the percentage of measured treated trees in which breaks occurred at diameters greater than six inches DOB. Since the minimum merchantable diameter was six inches, only breaks at larger diameters were considered of economic importance. The values for control trees are for all control trees cut in September, 1967 and 1968. The average diameter of the first break tended to increase with time from treatment to harvest, as did the percentage

Figure 9. Typical bark condition of logs at the landing.

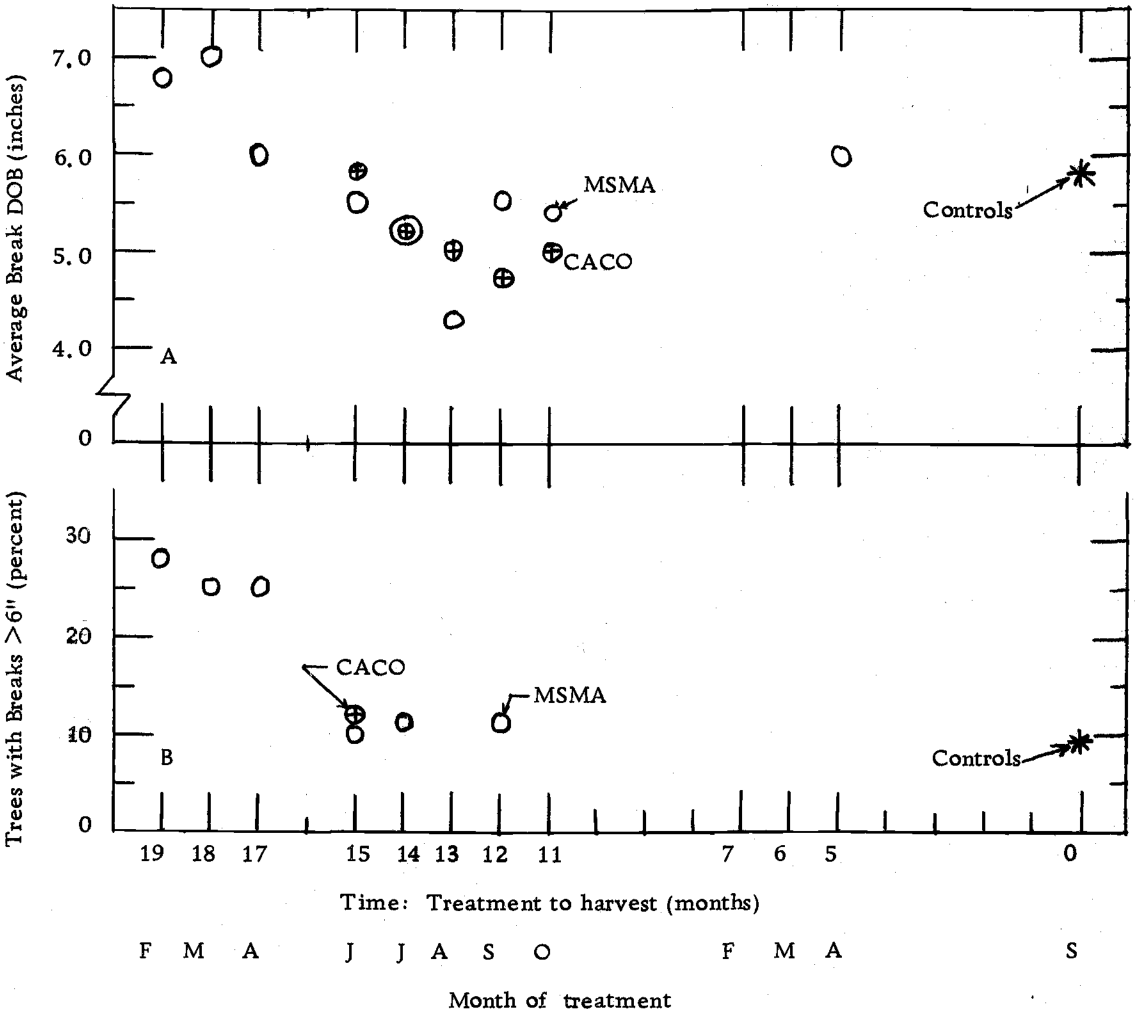


Figure 10. Comparison of breakage by treatment.
A) Average DOB of first break greater than four inches

B) Percentage of treated trees with breaks at diameters greater than six inches DOB incidence of merchantable breakages.

These data indicate that treated trees can be left standing for 15 months before breakage by either measure becomes substantially more than that occurring in untreated control trees. This tends to substantiate a previous report of limited breakage in trees left drying for ten months (Holt, 1967).

It seems possible that there may be some sort of age-dryness-herbicide interaction since there is not an obvious reason for this 15-17 month threshold value.

Insects

The incidence of insects, as recorded from the wafer samples, provided an index of insect activity as influenced by treatment and season. The insects of principal concern were the Douglas-fir bark beetle, Dendroctonus pseudotsugae Hopk., ambrosia beetles, and large and small wood borers. The distinction between large and small wood borers was primarily based on the degree to which they contributed to reduction of lumber grade. The large borers made galleries in the outer sapwood and in some instances entered the merchantable wood. The small borers appeared to be scavengers of sorts and essentially confined their galleries to the bark with only minor wood engraving.

Figure 11 summarizes the principal patterns of occurrence in

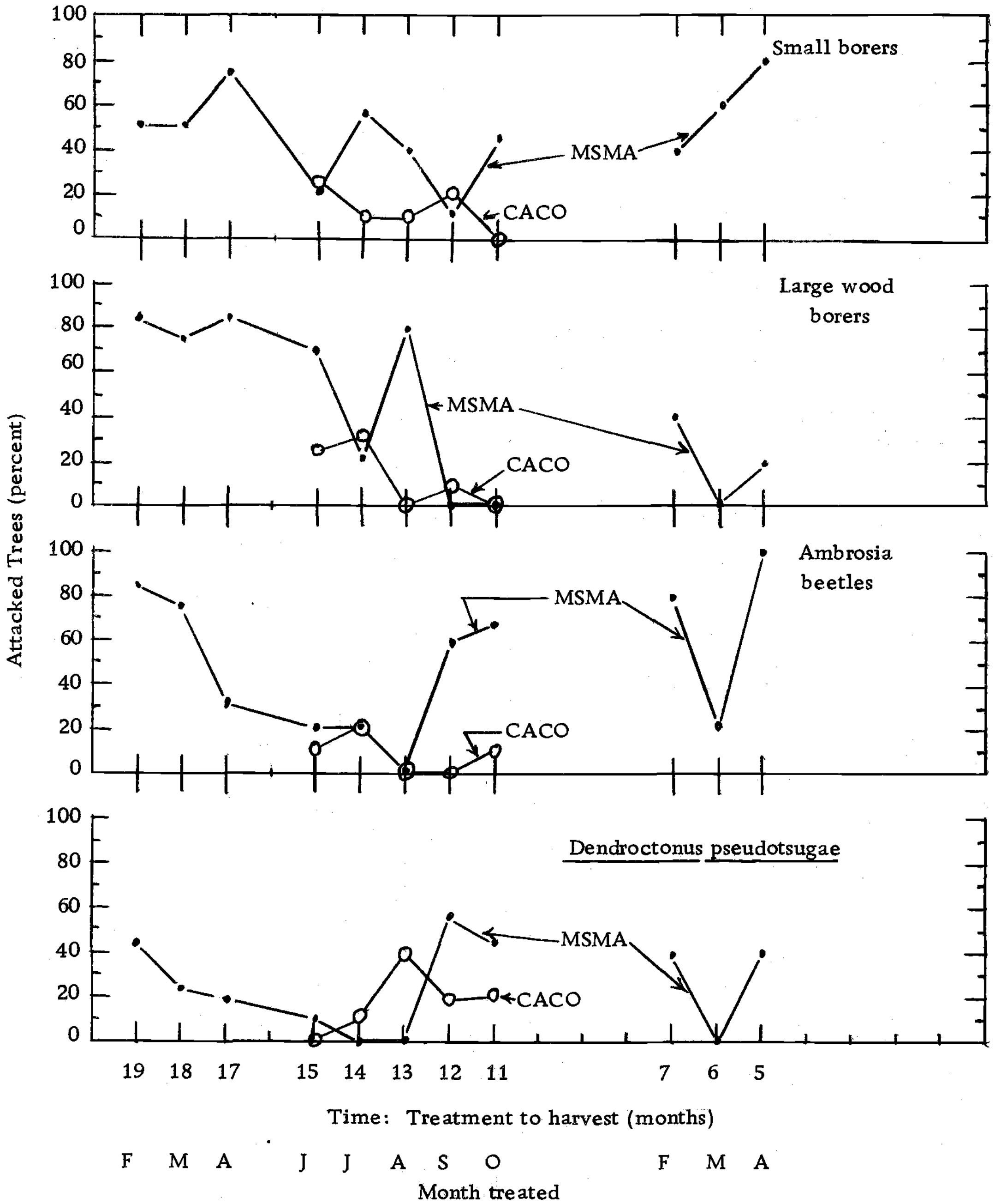


Figure 11. Summary of insect activity by insect group and herbicide.

treated trees. The incidence of insect attack is expressed in terms of the percent of treated trees in which at least one sign of the particular insect was found in a sample. Consequently, the percentages of attacked trees is not indicative of the extent or degree of attack.

Bark beetles seem to respond to the success of moisture reduction. The trees treated in February and April of 1967, and cut in September of the same year, were attacked but no larval mines were found on the wafer samples. That the trees were not attacked the second year of exposure is indicated by the lack of additional infestations in the trees cut in September, 1968. Nearly 80 percent of the recorded larval mines were found in the trees treated in September and October. The mines tended to be abnormally short and narrow, often ending with dead larvae. Without exception, no signs of successful emergence of Douglas-fir bark beetles were found. These facts suggest that trees could be treated in mid-summer after the main flights and be unattractive to the insects the following year. Laboratory studies show that host material with a moisture content of less than about 90 percent moisture content is unattractive to this insect (Johnson, 1963).

For the months in which both herbicides were used, cacodylic acid was generally associated with equal or lesser percentages of attacked trees than MSMA, except in the case of D. pseudotsugae. It also appears that the MSMA-treated trees were attacked by ambrosia beetles in the spring and early summer; trees treated in September and October were probably not attacked until the next season. As with the bark beetles, it appears that these insects are responding, at least in part, to the dryness of wood of the summer treatments since the trees were not attacked during 1968.

Cacodylic acid appeared to inhibit wood borers, compared to MSMA, but this may be confounded with the increased moisture in cacodylic treated trees and the lack of complete cambial kill. This response has also been found in wood borers associated with ponderosa pine treated with the two herbicides (Newton and Holt, 1970).

Wood Deterioration

One of the most interesting observations made on the study was purely accidental. Sections from the butts of treated and untreated trees were brought to the laboratory for pulping and preservative treatments. All sections were piled on the north side of the warehouse to be debarked in September, 1968. The reference to position is to indicate a cool environment and damp moisture conditions. In February, 1970 the sections were removed for disposal. The original plans had been abandoned because of the time delay in debarking the sections.

After noticing marked degrees of sapwood deterioration, the sections were segregated by chemical treatment and control trees.

The contrast is illustrated in Figure 12. The untreated trees have fungi fruiting bodies protruding from the ends of the sections. The sapwood is extensively stained and decayed. The treated trees do not have the advanced decay found in the control trees. The sapwood is somewhat stained but the wood is still sound and is consistently without sporophores. The control trees have been cut almost a year and one-half and the treated trees have a time lapse of at least two and one-half years from treatment to February, 1970. The maximum time lapse in the tested series of treatments was 19 months. This small sample suggests that logs so treated have an induced durability that justifies further examination.

Backflash

The incidence of backflash or apparent translocation of herbicide from a treated to an untreated tree was consistently higher with cacodylic acid than with MSMA. Its occurrence was greatest in the trees of codominant crown class with both herbicides. Thirteen percent of the trees treated with MSMA were implicated in backflash while twice this, or 27 percent, of trees treated with cacodylic acid are thus involved. These percentages are based only on the trees treated during the months when both chemicals were used. If the trees treated with MSMA in February, March and April are considered, the percentage of MSMA-treated trees decreases to only seven

A

B

C

Figure 12. Comparison of wood deterioration of control trees (A), trees treated with cacodylic acid and MSMA (B), and the trees together (C), after one and one-half years of storage, hence at least two and one-half years after treating for the treated trees.

percent. There is also more of a tendency for backflash with cacodylic acid, when occurring, to be fatal to the untreated tree than with MSMA.

DISCUSSION

Trends Supported by Actual and Predicted Weights

In view of the data manipulation that has been performed to obtain the predicted results, the support offered by the actual results to certain trends is most gratifying (Figure 7). Trees treated with cacodylic acid tend to be heavier than trees comparably treated with MSMA. Trees treated in late winter, spring and early summer are drier than those treated in late summer and early fall. Moisture was lost during the first summer from the early treatments but was not lost during the summer of the following year from the late treatments. The control trees cut in 1968 were consistently lighter or drier than those cut the previous year.

Climatic Patterns

Some of the trends just mentioned point to a discrepancy of results between the summer of 1967 and 1968. Since several points hinge on this comparison, a discussion of the summers of each year is warranted. The previous section alluded to opposite extremes of climate for this area during the summers of 1967 and 1968.

Figure 13 is a graphic illustraton of the Burning Index for the Salem, Oregon weather station. The Burning Index was computed by

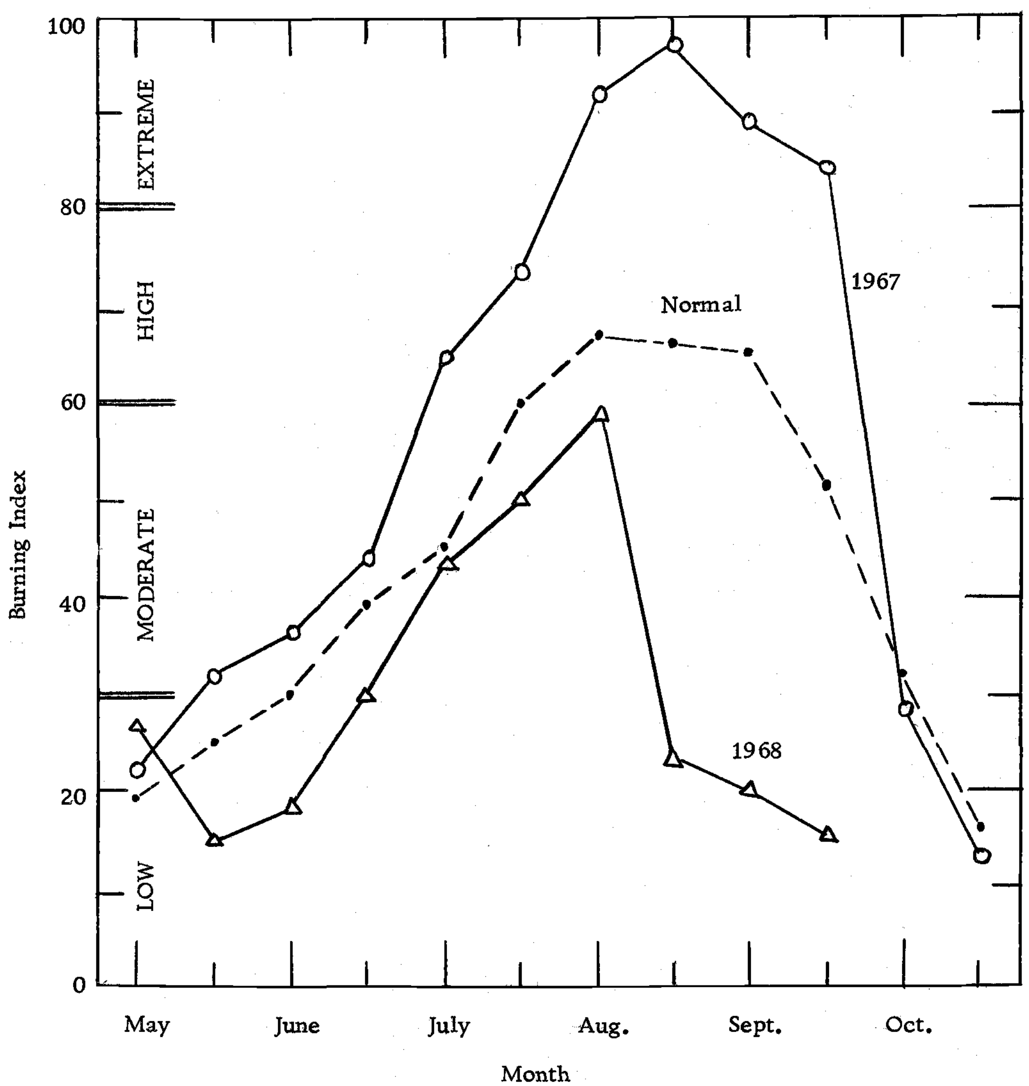


Figure 13. Burning index at Salem, Oregon for 1967, 1968, and 10-year average (normal).

the Oregon State Department of Forestry at Salem. This index is an integration of the drying influences of temperature, relative humidity and lack of precipitation for both the heavy and fine fuels (Schroeder, 1969). These data are for the fire seasons of the two years in question and a ten year average. If one can equate Burning Index with length and severity of drying condition or drying capacity in a very relative manner, the summer of 1968 had much less drying potential than normal and the summer of 1967 had a great deal more. The summer of 1968 is characterized by about one-half or less of the "drying capacity" of the summer of 1967. Rain in late May effectively set 1968 back one month in terms of Burning Index build-up, and rain in mid-August eliminated the last month and one-half of what is usually a period of active drying, so that the time of favorable drying weather was reduced by about 50 percent in 1968. The highest average index value attained in 1968, for a two week period, was reached and greatly exceeded for three months in 1967. Fire danger was extreme for two months in 1967. It is felt that the relationship of the length and severity of the two summers is very influential in the difference in measured drying between the two years.

Weights of Control Trees

Untreated trees cut in 1968 weighed less than similar trees cut in September, 1967; both predicted and actual weights indicate this relationship. In view of the previous discussion of the two years, this appears contradictory. The reason for this anomally is outside the scope of this study, but the fact of its existence is obviously important. The finding that the control trees cut in 1968 were drier than 1967 controls tends to offset the weight reductions from the treatments. These were compared to the weights of the control trees cut in each respective year. While some of the treatments were followed by loss of weight during 1968, the weight lost by the control trees tended to obscure the treatment results.

Weight Reductions, 1967

Some of the trees treated in February, March, and April, 1967 were cut in September of the same year. The time lapse from treatment to harvest ranged from five to seven months. In this short time, substantial weight reductions were observed. The predictive results indicate a general trend of substantial reductions in top logs, decreasing in the low logs, particularly for April, although it has the shortest time lapse (Appendix E). The April reduction is also greatest in the actual weights by a substantial margin. This suggests that the trees are at a lower moisture content in April than during earlier months.

Weight Reductions, 1968

All remaining trees from all treatments were cut and sampled in September, 1968. These include trees treated with MSMA, cacodylic acid and control trees. As in 1967, the largest losses, or smallest gains, are in the tops of the trees for both bark and sapwood. Trees treated with MSMA have a very sharp break in results between August and September. The treatments up through August are uniformly dry while the September and October treatments are substantially wetter. This pattern is found in both predicted and actual weights. One may speculate that trees did not respond to the late treatments until the following year. Consequently trees treated during September and October did not dry during 1967, and were not exposed to severe drying during 1968. It is likely that the treated trees absorbed water in much the same way as untreated trees. The treated trees were probably very inactive in terms of water movement at the time of treatment so the effects of the herbicide did not occur until after the tree responded to the stimulus of available water. Both treated and untreated trees were taking up water in like manner until the next year when the treated trees were finally killed by the herbicide. At this point the two trees were very likely to have contained nearly the same quantity of water. The control trees presumably lost water during the summer of 1968 by transpiration, whereas the dead trees would have lost water only by diffusion through bark, which, presumably was very small during that summer.

Douglas-fir is more responsive to MSMA than to cacodylic acid. The initial decision to use MSMA was based on its demonstrated action of more complete cambial kill, i.e., better lateral translocation. Strip killing by cacodylic acid can defoliate the tree without killing a major portion of the cambium. The trees treated late in the season took longer to be defoliated when treated with cacodylic acid, therefore they were exposed to a shorter, if any, drying period in 1967; with live roots trees were able to take up water during the winter before the 1968 drying season. Thus the trees treated with cacodylic acid were generally wetter than those treated with MSMA. The moisture of undefoliated trees treated with cacodylic acid probably approached the moisture content of the untreated trees cut in February, 1967 before being defoliated in the spring of 1968.

Model Tree

The model tree appears to be a very unique and useful way of illustrating tree characteristics and relationships. The bark thickness changes relatively little after the first few feet and the sapwood thickness is almost constant after about ten feet. Contrary to the citations mentioned in the introduction of this paper, the bark comprises almost 20 percent of the volume of the tree rather than eight percent. This suggests that the bark disposal problem may be greater than generally acknowledged. Smith and Kozak (1967) noted that percentage double bark thickness increases as diameter outside bark decreases. Hankin and Rowe (1969) report that weight of bark per board foot of gross log volume increases curvelinearly with decreasing diameter class. In management of small second-growth, therefore, the special incentive for leaving bark in the woods is well illustrated.

The tree also illustrates the prominence of sapwood in young-growth trees. Sapwood makes up more than 40 percent of the total tree volume and greater than 50 percent of the merchantable wood volume (Table 2).

Table 2. Volume percentages of bark, sapwood and heartwood of model tree

Total tree	Tree (percent)	Butt log (percent)	Mid. log (percent)	Top log (percent)
Bark	19	22	16	15
Sapwood	42	37	43	54
Heartwood	39	41	41	31
Solid Wood				
Sapwood	52	47	51	64
Heartwood	48	53	49	36

Although the model tree has certain problems, as previously described, it has served well in the capacity for which it was created. The tree provided a standard basis for defining the moisture profiles of the constituents for each treatment. The descriptions of the moisture profiles would be severely restricted without a reference tree to provide values for the many variables at any height. The model tree has provided a consistent reference for volume determinations. The common reference enables qualitative comparisons of treatment effects for the moisture profiles and, when combined with the common volume reference, quantitative comparisons of treatment results are possible. The discussed fallacies relating to the equations of the model tree do not effect the comparisons between the treatments.

Hypothesized Drying Sequence

The following discussion is proffered as a possible explanation of the events leading to the degrees of drying measured in the predicted weights. The first trees were treated in February, 1967. Trees treated during February and March were probably at very nearly their highest moisture contents (Parker, 1954; Johnson, 1964). While the trees are not immediately defoliated by these treatments, the amount of water lost through transpiration is probably reduced at a fairly early point, since defoliation is the first manifestation of effects. In effect, this creates a tree that must lose all the water through air-drying, when drying is started from the tree's wettest condition. The net result is only a very small weight reduction by the end of the summer. The control trees to which the treatments are compared can lose water through the transpiration process, which is shown by their lower weight in September.

The trees treated in April may have the advantage of starting at a lower moisture content than the earlier treatments (Parker, 1954; Johnson, 1964). It should be recalled that the April treatment, because of mechanical problems, lapsed into May by a considerable extent. This period generally covered the time of new growth initiation inherent in bud burst and shoot elongation. It is felt that these factors may have reduced considerably the total moisture supply or reserve in the tree. The April-May treated trees started at a lower moisture content, and responded much faster to the herbicide than during previous months so were exposed to the same amount of favorable drying conditions as the two previous months. This may have accounted for the large weight reductions indicated for April by both predicted and actual weights.

The treatments applied during June and July, and August - MSMA, provided rapid mortality at times of continuously decreasing moisture reserves. The later treatments applied in September and October, and August - cacodylic, apparently do not kill cambium completely until the rainy season begins to replenish the moisture lost during the summer. That MSMA is more effective than cacodylic acid was indicated in the inability of the tree to take up excessive water before the herbicide takes effect. These treatments, therefore, have consistently wet butt logs while the top logs were drier; dryness throughout decreased from August to October, and drying was less pronounced with cacodylic acid than with MSMA.

Little drying probably occurred during the first summer. The weight reduction measured in the April-May treatment was something of an artifact resulting from arresting the trees at a lower moisture content, but was also confounded by the extreme drying conditions occurring during the summer of 1967. Bark is known to be a very good insulator and one of its functions is to prevent desiccation of the inner tissue. The trees treated with MSMA in October and with cacodylic acid in September and October did not respond until the following year. After defoliation early in the spring and summer of 1968, the drying conditions were not severe enough to cause major diffusion through the protective shield of the bark. Thus trees of these treatments had consistently wet sapwood and were heavier than their respective control trees. Their weights, in fact, were comparable to the weight of the control trees cut in February, 1967. This was the approximate moisture content which the trees had when defoliated, and they simply did not dry despite one year or one season of drying exposure, and, as previously indicated, an unfavorable summer for drying.

The optimum drying rate did not occur until the second season after treating. This was a result of cracking and loosening of the bark and the associated death and deterioration of the cambial layer. The moisture movement is not necessarily through the bark after these events. The wood itself is more "exposed" to the drying forces. Although the summer of 1968 was not an indicative summer for drying conditions, with one exception, the bark and sapwood of the treatments sampled in September, 1967 were drier in September, 1968 than during the previous year. The incidence of bark drying during the second summer stems from the ability of the inside portion of the bark to dry in a more direct way, just as the wood is more directly exposed to the drying environment.

Economic Potential

It is believed that some very important benefits can be obtained from these treatments. Some estimates of how these benefits can accrue to the industry will follow:

Lumber Drying

Dry sapwood permits shorter periods of drying, and promotes uniformity of moisture content in the dried product. A relative measure of savings in this operation can be computed by simulation of drying lumber cut from sapwood of selected treatments (Army-Navy-Civil Committee, 1946; Espenas, 1970, personal communication). In Douglas-fir, the marked difference between the heartwood and sapwood moisture contents enables the heartwood to reach the desired moisture content before the sapwood, even though it is more difficult to dry because of extractives and pit aspiration. Sapwood is the factor which most affects drying times and drying schedules.

An average moisture content for the sapwood of successful treatments was obtained by dividing the sapwood density by 28.08 (specific gravity times weight of a cubic foot of water--0.45 × 62.4). This uses equation (2) to solve for moisture content when other values are given. For this example a board one inch thick and ten inches wide is dried at 120 degrees Fahrenheit under conditions yielding a ten percent equilibrium moisture content. The final desired moisture content is 19 percent. Under these conditions, wood with an initial moisture content of 103 percent requires 8.9 days to reach 19 percent moisture content, while wood at 54 percent only takes 5.8 days, a time reduction of 35 percent. While this is a comparison of the wettest and driest treatments measured in this study, even greater sapwood moisture contents for Douglas-fir are reported as standards (Rasmussen, 1961). Comparison of drying time reductions due to treatments compared with their respective control trees are given in Table 3. Treatments during several of the months reduced the

Table 3. Comparison of simulated drying times[1] based on average sapwood moisture contents of the respective treatments.

Treatment	Sapwood density	Average MC (%)	Drying time (days)	Drying time reduction (%)
Control - Cut 2/67	57.0	103	8.91	--
Control - Cut 9/67	55.5	98	8.71	--
Feb. - MSMA - Cut 9/67	48.6	73	7.29	16
March " " "	52.9	88	8.19	6
April " " "	46.3	65	6.62	24
Control - Cut 9/68	51.6	84	7.94	--
Feb. - MSMA - Cut 9/68	43.3	54	5.78	27
March " " "	44.7	59	6.17	22
April " " "	44.1	57	6.01	24
June " " "	43.8	56	5.93	25
July " " "	44.5	58	6.09	23
Aug " " "	43.7	56	5.93	25
Sept " " "	51.6	84		
Oct " " "	53.8	92		
June - CACO - Cut 9/68	44.4	58	6.09	23
July " " "	45.3	61	6.39	19
Aug " " "	47.1	68	6.91	13
Sept " " "	55.2	97		
Oct " " "	58.3	108		

[1] 1 x 10 inch board @ 120°F with 10% EMC conditions dried to 19% moisture content

potential drying time by nearly 25 percent.

Uniformity of the sapwood and heartwood moisture contents at the end of the drying period has the potential of being a major benefit of pre-harvest drying. In terms of the new lumber standards, this can aid in meeting the uniformity requirements. This can also aid in improving the flow of materials through the manufacturing processes, since drying is often a bottleneck.

Similar remarks are also applicable to air-drying. Time savings and/or uniformity should apply in proportionate ratios regardless of drying method or schedule. When the expected time of drying ranges from weeks to months, a 25 percent time reduction can be substantial in reducing capital investment in drying lumber.

Shipping "Green"

A substantial volume of lumber from the Pacific Northwest is shipped as undried lumber. About 50 percent of shipments from western Oregon are green (Espenas, 1970, personal communication); this is also true for much of the lumber of western Canada (Duhamel, 1967). Railroad freight charges for lumber are based on weight directly (Schmidt, 1967). Weight differentials in lumber or other products cut from treated trees would save in freight costs proportional to the amount of weight reduction. As indicated in Appendix E, several treatments permit a savings in freight costs of about ten percent. This savings could be applied to wood shipped immediately after being sawn, without the time and expense of drying.

The following example indicates the potential magnitude of savings on transportation. Schmidt (1967) indicated that Oregon shipped almost twice as much tonnage of lumber to Texas as to any other area east of the Continental Divide in 1963. The zone freight rate for much of Texas is $1.32 per hundredweight; a seven cent reduction per hundredweight is possible if the carload meets minimum requirements. A boxcar 40 feet long has a minimum weight requirement of 70,000 pounds; this same car has a capacity of 3,763 cubic feet, and a maximum net weight on the order of 120,000 pounds. By equation (2), 120,000 pounds of lumber at 66 percent moisture content (average of wood of the control trees cut September, 1967) and a specific gravity of 0.45 would only be 2,574 cubic feet. This weight is well above the minimum weight requirement and the volume is substantially below the full capacity. This carload of "green" lumber going to Texas would have a freight rate of $1,500.00. A ten percent weight reduction would still qualify for the same freight rate, but would mean a savings of $150.00 or ten percent extra volume for each car. If 111 trees were needed to yield this volume, as in the model tree, the savings realized from this one step would indicate that about $1.40 could be spent on treating each tree. It is easily recognized that this savings increases directly with weight increase and would be enhanced when considered in terms of larger cars; a 40 foot box car is one of the smaller sizes.

Poles and Pilings

Poles and pilings must be dried, either by air drying or Boulton drying, before treating with preservative. Since the response to Boulton drying is very similar to effects of kiln drying (Graham and Womack, 1961) the same proportional time savings, whether in retort time or time in air drying, will be possible. For these products, where air drying can take from several months to a year or more, a 25 percent time reduction should be very important.

Pulp

Since the concept of chemical debarking was originated by the pulp industry, it might be assumed that drier material does not present a physical deterent to pulp and pulping processes. This contention is supported by personal communications with persons in the pulp industry. Of course, the same transportation benefits still accrue.

If the trend apparent in wood deterioration is valid, a very important benefit for pulp mills involves the reduction of wood fiber lost to decomposition in bulk chip piles.

Veneer

Veneer is usually dried by moving it through an oven with set drying conditions. The time of drying for veneer, is regulated by the speed at which it moves. Field-dried sapwood veneer could be processed faster than green wood, and would be similar to the heartwood in moisture content.

Considerable emphasis has been placed on the moisture content of the sapwood. This, in part, stems from the fact that, in the model tree, over one-half of the merchantable volume was sapwood. While sapwood is not a major constituent in old-growth trees, it accounts for a large portion of the volume of second-growth trees and will be increasingly important under exclusively second-growth management.

Log Hauling by Truck

Logs weighed show weight reductions on the order of 20 percent for several treatments. Predicted weight reductions were about one-half this, or ten percent. When allowances are made for the estimated percentages of bark loss for those treatments mentioned, weight reductions for the predicted values approach 15 percent. If one compared the drier treatments corrected for bark loss, with the control trees cut in February, 1967, the weight differentials exceed 20 percent. During the winter the control trees return to the higher moisture contents while the treated trees do not gain in moisture. This suggests that percentage weight differentials are greatest during other than the driest time of year, which was the time of recording.

The weight reductions of ten to 20 percent can be interpreted as an extra margin of safety in meeting legal highway weight limits or can mean additional volume per load. To take full advantage of the volume bonus, it may be necessary to add to the uprights on the truck bunks or haul longer logs. This would permit easier loading and enable forming squarer loads than are possible with present bunks in trees of this size. Extension of uprights is already used in areas in the South and would appear to be a natural development as management intensifies in the Northwest and the forest industry becomes more dependent on volumes obtained in commercial thinnings. Reducing the weight of these smaller trees, thereby increasing load volumes, would be a very realistic way of improving the economics of utilization. This is particularly important because economically marginal trees are the most responsive to pre-harvest killing and drying treatments.

The physical absence of bark is an important means of increasing the wood volume per load. Bark comprises nearly 20 percent of the volume of the model tree so a 40 percent loss of bark increases the merchantable volume on the load by almost eight percent. This benefit would be optimized with long periods of drying, with concommitant loss of bark.

Yarding and Skidding

The importance of weight is easily seen in the newer logging systems such as balloon and helicopter logging. The total weight of cables, rigging and logs determine the lifting ability. Pre-harvest drying treatments might increase the utility of these newer logging methods.

The handling of lighter trees makes possible the use of smaller equipment with lower operating costs. Present machinery should be able to operate more efficiently and with less down time because of the reduced weight.

Water Driving and Storage

The moisture lost in drying before harvest will increase buoyancy and reduce sinker losses, particularly for a species like western hemlock, during water driving. About 121,000 logs, valued at four million dollars, sank from booms in coastal waters of British Columbia during 1967 (Western Timber Industry, 1968). Water transport may tend to reduce benefits in terms of reduced drying time but the treatments would increase the time the logs could be in the water without sustaining losses.

It should be evident that dry land storage would be best for optimizing the results obtained from the drying period. Water storage would tend to limit benefits to those operations occurring between the woods and the mill. It is suggested that the dried logs would be more easily stored on land than untreated trees. Present practices require sprinkling systems to keep the logs wet to reduce end checking, insect and fungal attack. The dried trees would be less susceptible to attacks by insects and fungi, thus extensive sprinkling systems may be unnecessary for those products where end checking is not a problem. In fact, it may be optimal to segregate treated from untreated logs in the yard inventory so untreated material can be utilized first since the treated material can apparently be stored for longer periods, without degrade, than "green" logs.

Waste Disposal

Dried waste products, bark and sawdust, will be lighter to haul away or will burn easier and, more importantly, will burn cleaner with less smoke. The resulting bark loss induced by the treatments means less to be disposed of at the mill which also tends to reduce the pollution problems since there is less to burn.

Waste disposal is a chronic problem of wood-using industries. High moisture contents contributes to smoke emission in combustion disposal units, and to high costs of transportation and utilization when manufactured into saleable products. Pre-dried wastes offer substantial economic incentives in either case.

Increased Harvest

The first commercial thinning of any stand is beset by problems of high operating cost and low return. Application of the concepts developed in this thesis could aid in development of silvicultural practices that minimize these.

The practice of killing the trees before harvest offers a mean of increasing the volume cut at the time of actual cutting without unduly reducing the growing stock. The stand could be marked as is normally done except that the trees would be killed instead of painted. The trees killed would allow the stand to maintain optimum growth for an additional two, and possibly more, growing seasons. The treated trees would be stored in the field for that time. The residual trees are allowed the additional time for growth. When the stand is entered for cutting, after a two to three year period, the contractor can remove those trees previously treated, and those now ready for removal. This allows him to remove more volume than would be possible if only making one harvest in the stand, without seriously depleting the growing stock. Increased volume increases profit for the logging contractor, since he need only move equipment into the stand one time and is able to harvest more volume with that operation.

The nature of the above concept should provide a means of increased management of all sites. This practice would probably work best on the higher sites, however, in terms of the amount of volume increase which could be harvested. Low sites, on the other hand, have slower growth, with lower volumes harvested at longer intervals. Treating with herbicides can maintain maximum growth on these very sites which need the most help in producing maximum crops but are most uneconomic for justifying large silvicultural expenses such as fertilization.

Application to Other Species

Coniferous species are generally characterized by having sapwood moisture contents at least twice, and up to five times higher than the moisture content of heartwood. Hemlock, sugar pine, white and grand fir have heartwood moisture contents of about 90 percent or greater. The species in this test, coast type Douglas-fir, has almost the driest sapwoof of all the coniferous species (Rasmussen, 1961). In general, the higher the wood moisture content, the faster it dries (Mathewson, 1930). This suggests that the concept of pre-harvest treating may be applied, with even greater moisture loss, to nearly all other conifers.

Western hemlock trees treated with MSMA in December, 1967 and cut the following September were 30 percent drier in the tops and about ten percent drier in the butts than untreated trees (Laird, 1970, unpublished data). These trees were left standing for only nine months and during the wet summer of 1968, previously discussed. Presumably even larger losses would be possible. The control trees were cut in September, 1968, so, again, the control trees are probably at their lowest moisture content and these differences would doubtless have been increased had the trees been cut later in the year or early in 1969.

Treating Methods and Prospects

Young-growth trees have the common characteristic of having relatively thin bark at points above the stump area. The treatments in this study were applied by drilling holes in the trees and pouring in the herbicide. It seems very logical that the same results could be obtained by injections of the herbicides by the various commercial tools for just this purpose. Injectors would facilitate the speed and ease of treating while not impairing the commercial qualities of the log. In the same area, Douglas-fir from 7.0 to 9.5 inches DBH and grand fir up to 16 inches DBH were easily treated with one such injector, the Hypo-Hatchet. Injecting tools would also permit placing herbicide more uniformly around the tree, thereby giving more uniform response and better distribution of the chemical used. This should further enhance the reduction of insects by modifying their environments more uniformly.

While only compounds classed as herbicides were used in these treatments, it seems probable that systemic insecticides and fungicides could be added and the whole mixture applied in one treatment. This would offer a means of storing timber in the field for almost indefinite periods thereby further increasing the drying effect while keeping the stand at optimum density for maximum production.

The herbicides used in this research, MSMA and cacodylic acid, have been shown to have important side effects which tend to enhance their use for pre-harvest treatments. The apparent inhibition or retardation of insects has been demonstrated on ponderosa pine (Newton and Holt, 1970). Two important species of the family Scolytidae, Ips pini Hopk. and Dendroctonus ponderosae Hopk., have been unable to raise successful broods in the chemically thinned trees. MSMA has been demonstrated to be inhibitory to Fomes annosus (Fr.) Cke. attack in western hemlock (P. Laird, 1970, unpublished data). Hemlock trees of commercial size were treated at several seasons and were not even susceptible to artificial inoculation.

In addition, chemical treatments enable the land manager to pre-harvest treat commercial trees and at the same time conduct pre-commercial thinnings, remove undesired species, improve spacing, kill cull trees, and other stand improvement practices.

Consequently, several objectives can be realized with only one trip through the stand.

Residues

Earlier work (Holt, 1967) has indicated considerable variation in arsenic concentration in foliage of the treated trees. At the moment there is a lack of information concerning the biological importance of concentration deviation from the normal background levels. The impact on the environmental arsenic level from chemical silvicultural techniques and its importance is receiving further study by numerous agencies.

It is believed that the small amount of elemental arsenic added to the total biomass will be proven to be an insignificant contribution to the total environmental arsenic level. There is increasing evidence that the organic arsenical herbicides are subject to microbial degradation (Newton and Holt, 1970, unpublished data). The evolved volatile compound contributes to an absolute arsenic reduction in the treated area. Since arsenic is not synthesized in the usual sense of organic compounds the treatments do not contribute to a universal environmental build-up of the element, but only constitute a shifting of the element from one area to another. It should be pointed out, however, that this redistribution does involve possible system consequences.

CONCLUSIONS

Important changes in the moisture contents of small Douglas-fir sawtimber trees are possible through pre-harvest killing. Reduction in moisture to the extent practicable has very important implications in all facets of the forest industry and forest operations. Not only can the inherent weight reduction be demonstrated consistently for several treatments but these are possible without adversely affecting the utilization of the merchantable wood.

Season has a strong influence on the degree of effect as do climatic patterns. Treating too late in the year does not enable the full herbicide response to develop until the following year. This is an undesirable time loss and may even retard the drying process. Treating in mid-summer kills the trees at a lower moisture content than earlier treatments and may be used to reduce the time needed to leave the trees in the woods.

The nature of the herbicide used and the type of response it initiates are also important factors. MSMA is more responsive to warm temperatures and is more uniform in the degree of cambial kill than cacodylic acid. This is felt to be a necessary prerequisite for a successful treatment. Trees treated with MSMA are defoliated faster, particularly if treated later in the season, and the herbicide has a much greater degree of lateral movement than does cacodylic acid.

Summer treated trees are less attractive to insects. These trees, when treated after the primary insect flights in the spring, are unattractive to insects the following year. This suggests that if a treated tree can exist through the first drying season without insect attack, it may be safe from attacks for the duration of exposure. This hypothesis would need further testing to evaluate fully the activities of wood boring insects. The cacodylic-treated trees in these tests are generally attacked to a lesser degree than those treated with MSMA, particularly in terms of percentage of trees attacked. This could indicate that a mixture of the two may be more advantageous. The MSMA would give the initial killing action while the cacodylic acid may be better able to provide the insect protection desired. It appears that Douglas-fir bark beetles are responsive to the degree of drying; the percentage of attacked trees is very low for both herbicides during the months giving the most complete drying. This also appears true for ambrosia beetles.

The summer treatments with little insect activity also have very low incidence of breakage. Although the degree of insect activity may be a factor influencing breakage, the drying conditions to which these treatments were exposed must be important. The summer treatments were exposed to less severe drying conditions, in terms of total drying, because they were not dead and drying until late summer.

The impact of weight reduction or moisture reduction has a great deal of potential for all aspects of the forest industry. Lighter, less expensive equipment could be used for handling the logs, and more volume can be hauled per truck load. Reduction in drying requirement would reduce inventory and degrade and more volume per car load is possible at any point in shipping for operators without kilns.

The concept of pre-harvest killing of commercial or marginal timber has the silvicultural advantages of a thinning while improving the economics of logging the smaller trees. It appears quite possible that trees may be stored successfully on the stump for longer periods than the year and one-half storage of the trees in this study. Storage of timber for three or four growing seasons would greatly enhance the condition of the stand and increase the volume harvested at each cutting. Moreover, the herbicides used have been demonstrated to be inhibitory to Fomes annosus and certain insect species.

Many species appear to have the potential for successful application of this silvicultural concept.

In retrospect, two salient features of the concept should be emphasized. First, the weight reductions reported in this study are compared to control trees which were cut at their lowest moisture content, hence lowest weights. It is easily demonstrated that the percent weight reductions would be greatly enhanced by cutting treated trees at times when untreated trees would be at their maximum moisture contents. This implies that the reported reductions are very conservative estimates of the actual potential of the concept. Secondly, the reduced moisture and weight have very real advantages for all aspects of the forest industry and utilization, not just one single phase or operation. In this respect, the concept imparts benefits to each operation from felling to marketing the finished product.

BIBLIOGRAPHY

Army-Navy-Civil Committee. 1946. Kiln certification. ANC Bulletin 21. Issued by the Army-Navy-Civil Committee on aircraft design criteria under the supervision of the Aeronautical Board. 157 p., U. S. War Department.

Berntsen, Carl M. 1954. Some results of chemical debarking on Sitka spruce, western hemlock, and red alder. (U. S. Department of Agriculture, Forest Service) Pacific Northwest Forest and Range Experiment Station. Research Note 104. 7 p.

Blossfeld, O. 1962. (Desirable and Undesirable Effects of Chemical Debarking.) Deut. Akad. den Landwirtwiss. Iagungsber. 54: 103-107. (G.e.).

Bollen, W. B. 1969. Properties of tree barks in relation to their agricultural utilization. (United States Department of Agriculture, Forest Service) Pacific Northwest Forest and Range Experiment Station. Research Paper PNW-77. 36 p.

Chemical debarking of green timber. 1958. The Lumberman 85(10): 60.

Christiansen, N. B. and J. Fedkiw. 1959. Chemical debarking - is it economically advantageous? State University College of Forestry at Syracuse University, Syracuse, New York. (Cited in Panshin, A. J., et al. 1962. Forest Products, their sources, production and utilization. 2d ed. New York, McGraw-Hill Book Company. 538 p.

Duhamel, Roger. 1967. Program review 1965 and 1966. Forest Products Laboratory, Vancouver, British Columbia. Department of Forestry and Rural Development, Forestry branch, Ottawa. 56 p.

Espenas, L. D. 1947. Some wood-moisture relations. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison. No. R1648. 9 p.

Forbes, R. D. (Editor). 1961. Forestry Handbook. New York, Ronald Press Company.

Gibson, E. J. 1968. An appraisal of some aspects of timber research and their application. Journal of The Institute of Wood Science 20:3-18.

Graham, R. D. and R. J. Womack. 1961. A preliminary study of kiln drying sections of Douglas-fir transmission poles. (Unpublished data, Forest Research Laboratory, Oregon State University, Corvallis, Oregon).

Hale, J. D. and D. C. McIntosh. 1949. Treatment of pulp trees with toxic chemicals to facilitate bark removal and reduce weight. British Columbia Lumberman 33(10):61-62, 82.

Hall, Albert G. 1968. What's Happening in Forestry 19(15):3.

Harkin, J. M. and J. W. Rowe. 1969. Bark and its possible uses. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison. Research Note FPL-091.

Hoadley, R. B. 1963. Influence of certain variables on veneer cutting behavior. Forest Products Journal 13(12):538-348.

Holt, Harvey A. 1967. Pre-harvest measures to reduce the weight of second-growth Douglas-fir. Master's thesis. Corvallis, Oregon State University. 54 numb. leaves.

_______________ and M. Newton. 1967. Preharvest killing of commercial timber. In: Herbicides and Vegetation Management Symposium Proceedings. Oregon State University, Corvallis. p. 167-185.

Institute of Forest Products. 1957. Conversion factors for Pacific Northwest forest products. University of Washington, Seattle. 28 pp.

Jahn, E. C. 1953. Chemical debarking of trees. Southern Lumberman 187(2336):41-2.

Johnson, N. C. 1963. Factors influencing the "second attack" of the Douglas-fir beetle - progress 1960-1962. Weyerhaeuser Company, Centralia, Washington. Forest Research Note No. 53.

Johnson, N. C. 1964. Effects of different drying rates and two insecticides on beetle attacks in felled Douglas-fir and western hemlock. Weyerhaueser Company, Centralia, Washington. Forest Research Note No. 58. 16 p.

Lutz, J. F., Alfred Pergen, and Harry Panzer. 1967. Effect of moisture content and speed of cut on quality of rotary-cut veneer. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison. Research Note FPL-0176.

Mathewson, J. S. 1930. The air seasoning of wood. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison. Technical Bulletin No. 174. 65 numb. leaves.

McArdle, R. E. and W. H. Meyer. 1949. The yield of Douglas-fir in the Pacific Northwest. Washington, D. C., 75 p. (United States Department of Agriculture. Technical bulletin No. 201.)

McIntosh, D. C. 1953. Effects of chemical treatment of pulpwood trees. Tappi 36(8):150A-160A.

McKenzie, W. M. 1967. Friction in wood cutting. Forest Products Journal 17(11):38-43.

McKimmy, M. D. 1959. Factors related to variation of specific gravity in young-growth Douglas-fir. Corvallis, Oregon. 52 p. (Forest Products Research Center, Oregon State University, School of Forestry. Bulletin No. 8.)

Myles, D. V. and B. E. Jarvis. 1957. Chemical treatment of trees. A report of practical applications. Pulp and Paper Magazine of Canada 58(6):177 . . . . 195.

Newton, Michael and Harvey A. Holt. 1970. Scolytids and buprestids in ponderosa pine injected with organic arsenicals. (Manuscript in preparation.)

Pahlitzsch, G. 1967. Aspects of chain saw cutting. In: Wood Machining Seminar, University of California, Richmond. Edited by William A. Dost. October 10-11. p. 38-45.

Parker, J. 1954. Available water in stems of some Rocky Mountain conifers. Botanical Gazette 115:380-385.

Purslow, D. F. 1968. Errors in moisture determination made on unseasoned timber by increment boring. Wood 33(7):29-30.

Rasmussen, Edmund F. 1961. Dry kiln operators manual. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison. Agriculture Handbook No. 188. 197 p.

Rietz, R. C. 1957. Importance of seasoning. Southern Lumberman 195(2441):97-99.

Schmidt, David R. 1967. Some factors affecting rail distribution of Northwest lumber. Master of Forestry thesis, Oregon State University, Corvallis, Oregon. 58 numb. leaves.

Schroeder, J. E. 1969. Oregon fire-danger rating system handbook. State of Oregon Department of Forestry. Fire Control Division. 15 numb. leaves.

Siimes, F. E. 1967. The effect of specific gravity, moisture content, temperature and heating time on the tension and compression strength and elasticity properties perpendicular to the grain of Finnish pine, spruce and birch wood and the significance of these factors on the checking of timber at kiln drying. Valtion Teknillinen Tukimuslaitos Statens Tekniska Forskningsanstalt (The State Institute for Technical Research, Helsinki). Publication 84. 86 p.

Smith, J. H. G. and A. Kozak. 1967. Thickness and percentage of bark of the commercial trees of British Columbia. University of British Columbia, Faculty of Forestry Mimeo. 33 p.

_______________ and John Kurucz. 1969. Amounts of park potentially available from some commercial trees of British Columbia. Paper presented at Northwest Scientific Association, Cheney, Washington. March 21-22.

Sutherland, Charles F. 1952. Debarking and moisture loss in grand fir, western red cedar and western larch. Potlatch Forests Inc. 32 p. (Unpublished).

Thompson, W. S. 1957. Chemical debarking of southern trees. Journal of Forestry 55(1):33-34.

Western Timber Industry. 1968. 19(8):19.

White, Alexander. 1947. Chemical treatment of live trees. Pulp and Paper Magazine of Canada 48(2):67-71.

Wilcox, H., et al. 1956. Chemical debarking of some pulpwood species. Technical Publication 77, College of Forestry, State University, Syracuse, New York. 34 p.

Wilson, T. R. C. 1930. Moisture in wood and its relation to strength. American Lumberman 2879:58-59.

Wood, Lyman W., E. C. O. Erickson, and A. W. Dohr. 1960. Strength and related properties of wood poles. (United States Department of Agriculture, Forest Service) Forest Products Laboratory, Madison, 83 numb. leaves.

Woodfin, R. O. 1963. Treating and harvesting interval for debarking ponderosa pine pulpwood with sodium arsenite. Tappi 46(2): 73-75.

Wort, D. J. 1954 a. Chemical debarking of western hemlock and Douglas-fir (Part I). Canadian Pulp and Paper Industry 7(6): 10-26.

____________ 1954 b. Chemical barking of western hemlock and Douglas-fir (Part 2). Canadian Pulp and Paper Industry 7(7): 8-18.

____________ 1954 c. The chemical barking of western species. Paper Industry 36(5):488-489.

Yerkes, V. P. 1967. Effect of seasonal stem moisture variation and log storage on weight of Black Hills ponderosa pine. (United States Department of Agriculture, Forest Service) Rocky Mountain Forest and Range Experimental Station Note RM-96. 8 p.

APPENDICES

APPENDIX A. Emperical equations for moisture profiles derived by multiple regression analysis.

Each regression model is the algebraic sums of the product of variable and its coefficient. As an illustration, the model for the bark of control trees cut in February, 1967 is as follows:

$$\text{Percent moisture content} = 33.8237 + 102.0005\ \text{CRITR} + 0.0052\ \text{SMPHT2} + 276.1441\ \text{SMITR2} - 61.2299\ \text{SMICR2} + 13.5009\ \text{THKB3}$$

Other equations are constructed in like fashion. This equation describes the bark moisture content at any point in the tree for trees of this treatment, controls.

The following notations or symbols for particular variables are used:

Variable	Meaning
APCB	Bark percentage of gross sample area: $\frac{DOB^2 - DIB^2}{DOB^2}$
APCB2	$(APCB)^2$
APCB3	$(APCB)^3$
APCH	Heartwood percentage of gross sample area: $\frac{DIAM^2}{DOB^2}$
APCH2	$(APCH)^2$
APCH3	$(APCH)^3$
APCS	Sapwood percentage of gross sample area: $\frac{DIB^2 - DIAM^2}{DOB^2}$
APCS2	$(APCS)^2$
APCS3	$(APCS)^3$
Constant	Intercept value when all other variables are zero.
CRWHT	Height to base of crown
CRWHT2	$(CRWHT)^2$
CRITR	CRWHT÷TRHT - Proportion of tree that is crown
CRITR2	$(CRITR)^2$
DBH	Diameter breast high
DBH2	$(DBH)^2$
DIAM	Diameter of heartwood of sample
DIAM2	$(DIAM)^2$
DIAM3	$(DIAM)^3$
DIB	Sample diameter inside bark
DIB2	$(DIB)^2$
DIB3	$(DIB)^3$
DOB	Sample diameter outside bark
DOB2	$(DOB)^2$
DOB3	$(DOB)^3$

Variable	Meaning
PCHSW	Heartwood percentage of solid wood area: $\frac{DIAM^2}{DIB^2}$
PCHSW2	$(PCHSW)^2$
PCHSW3	$(PCHSW)^3$
PCSSW	Sapwood percentage of solid wood area: $\frac{DIB^2 - DIAM^2}{DIB^2}$
PCSSW2	$(PCSSW)^2$
PCSSW3	$(PCSSW)^3$
SMPHT	Sample height
SMPHT2	$(SMPHT)^2$
SMPHT3	$(SMPHT)^3$
SM1CR	SMPHT÷CRWHT - Relative position with respect to crown base
SM1CR2	$(SM1CR)^2$
SM1CR3	$(SM1CR)^3$
SM1TR	SMPHT÷TRHT - Relative position in tree
SM1TR2	$(SM1TR)^2$
SM1TR3	$(SM1TR)^3$
THKB	Bark thickness of the sample
THKB2	$(THKB)^2$
THKB3	$(THKB)^3$
THKH	Thickness of heartwood of sample
THKH2	$(THKH)^2$
THKH3	$(THKH)^3$
THKS	Thickness of sapwood of the sample
THKS2	$(THKS)^2$
THKS3	$(THKS)^3$
TRHT	Total tree height
TRHT	Total tree height
TRHT2	$(TRHT)^2$

Table 4. - Multiple regression moisture models: their variables and coefficients by treatment and tree constituent.

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Control - Cut 2/67	Bark	Constant	33.8237		16	.95
		CR1TR2	102.0005	4.225**		
		SMPHT2	0.0052	1.225		
		SM1TR2	276.1441	5.284**		
		SM1CR2	-61.2299	-5.145**		
		THKB3	13.5009	2.502*		
	Sapwood	Constant	−108.9983		17	.87
		TRHT	1.7322	6.955**		
		THKS2	-3.0996	-2.111*		
		APCS	179.0225	3.578**		
		APCS3	-49.6457	-0.760		
	Heartwood	Constant	40.7315		19	.57
		DIAM3	0.0315	4.887**		
		THKH	-5.5289	-4.168**		
Control - Cut 9/67	Bark	Constant	115.7218		24	.85
		SMPHT3	0.0002	3.181**		
		DOB3	-0.0098	-2.842**		
		SM1TR	-98.3879	-2.991**		
		SM1CR	33.9355	3.963**		
		THKB3	13.1810	3.704**		
		APCB	-211.9805	-2.502*		
	Sapwood	Constant	67.7678		27	.65
		SM1CR	22.9136	5.872**		
		THKS	17.6966	2.820**		
		THKS3	-0.9925	-3.237**		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Control - Cut 9/67	Heartwood	Constant	32.3570		26	.81
		CRWHT	0.1073	4.384**		
		SMPHT	-0.1560	-5.774**		
		SM1CR	4.0967	2.933**		
		APCH3	-49.1437	-7.768**		
Control - Cut 9/68	Bark	Constant	49.0822		22	.64
		SM1CR2	47.6818	6.263**		
	Sapwood	Constant	134.0565		19	.77
		CR1TR2	-73.1087	-4.271**		
		SM1TR	-27.9150	-2.237*		
		APCS3	890.3491	5.136**		
		PCSSW3	-545.1151	-4.658**		
	Heartwood	Constant	111.7427		17	.73
		DBH	-2.5735	-2.782*		
		CRWH	-0.2319	-2.276*		
		SM1CR	26.1955	2.260*		
		SM1CR3	-24.2424	-2.485*		
		APCH	-114.2687	-3.439**		
		PCHSW3	76.6297	2.629*		
Feb. - MSMA - Cut 9/67	Bark	Constant	105.2715		6	.96
		TRHT	0.8601	3.250*		
		CR1TR	-173.3277	-6.499**		
		SMPHT	-3.0848	-4.832**		
		DOB3	0.0006	0.322		
		SM1TR	210.7064	5.404**		
		SM1CR2	52.5441	3.420*		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Control - Feb.-MSMA - Cut 9/67	Sapwood	Constant	249.5278		8	.82
		DBH2	-0.8526	-2.280		
		CRWHT	2.6883	1.648		
		CR1TR2	-438.1257	-2.762*		
		DIB3	0.0179	5.170**		
	Heartwood	Constant	31.9125		11	.72
		THKH3	0.0475	5.305**		
March - MSMA - Cut 9/67	Bark	Constant	44.4090		8	.60
		SM1TR3	298.7482	2.707*		
		SM1CR2	-74.9528	-1.893		
	Sapwood	Constant	-124.6584		5	.97
		DBH	14.6924	7.638**		
		TRHT2	0.0072	5.573**		
		CRWH-	-0.0700	-0.172		
		SMPHT	-1.7248	-3.043*		
		SM1CR	101.6981	2.896*		
	Heartwood	Constant	39.4659		7	.76
		SM1TR	-170.6770	-3.238*		
		SM1TR2	574.4481	2.914*		
		SM1TR3	-500.6675	-2.693*		
April - MSMA - Cut 9/67	Bark	Constant	-94.4889		8	.87
		DBH2	-0.2699	-2.180		
		TRHT	2.0741	4.098**		
		SM1TR3	49.6252	2.304		
		THKB3	23.7307	6.250**		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
April - MSMA - Cut 9/67	Sapwood	Constant	39.1906		10	.60
		SM1CR3	5.3994	2.141		
		THKS	14.2920	3.634**		
	Heartwood	Constant	26.6086		10	.35
		SM1CR2	5.2908	1.241		
		PCHSW3	58.0520	2.335*		
Feb. - MSMA - Cut 9/68	Bark	Constant	1028.4980		30	.60
		DBH	-162.2192	-5.384**		
		DBH2	6.8251	5.290**		
		TRHT2	-0.0002	-0.195		
		SM1CR2	-1.8933	-0.360		
		THKB2	39.5921	1.779		
		THKB3	-16.0045	-1.886		
		APCB	-176.3668	-2.062*		
	Sapwood	Constant	26.0586		33	.67
		TRHT2	0.0023	2.299*		
		DIB	3.0693	1.988		
		SM1CR	-19.0105	-2.387*		
		PCSSW3	-39.5458	-3.079**		
	Heartwood	Constant	37.7416		33	.54
		SMPHT3	0.00005	3.538**		
		SM1TR	-7.7886	-2.215*		
		SM1TR3	-33.3304	-2.319*		
		SM1CR2	2.0291	1.792		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
March - MSMA - Cut 9/68	Bark	Constant	60.0525		35	.32
		CRWHT	-0.0030	-2.149*		
		DOB2	0.0779	3.501**		
	Sapwood	Constant	72.4040		36	.35
		SM1TR	-39.9569	-4.399**		
	Heartwood	Constant	51.5926		31	.68
		TRHT2	0.0035	3.405**		
		CRWHT	-1.1221	-4.374**		
		CR1TR2	60.4880	3.941**		
		SMPHT	0.3501	2.522*		
		SM1TR	-41.4677	-3.313**		
		PCHSW3	-14.8089	-2.159*		
April - MSMA - Cut 9/68	Bark	Constant	-49.1606		47	.65
		TRHT	1.2771	3.009**		
		CRWHT2	-0.0083	-2.334*		
		CR1TR2	12.9044	0.477		
		APCB2	368.1041	7.350**		
	Sapwood	Constant	139.9568		45	.64
		CR1TR	-176.3500	-5.494**		
		DIB3	0.0153	3.432**		
		SM1TR	181.6904	3.193**		
		SM1CR	-152.0743	-3.639**		
		APCS	131.5972	2.259*		
		APCS3	-184.9547	-2.062*		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
April - MSMA - Cut 9/68	Heartwood	Constant	37.8329		47	.63
		DBH2	0.0259	2.141*		
		CR1TR2	-6.5162	-2.356*		
		SM1TR	-19.9864	-5.128**		
		SM1TR2	15.1470	2.772**		
June - MSMA - Cut 9/68	Bark	Constant	9.8253		20	.64
		CRWHT	0.4789	3.078**		
		DOB3	0.0093	4.823**		
	Sapwood	Constant	-61.2153		18	.70
		CR1TR	366.3387	2.779*		
		CR1TR2	-246.6503	-2.541*		
		SMPHT	-0.7001	-1.989		
		SM1CR	2.0467	0.113		
	Heartwood	Constant	29.4936		21	.56
		DIAM2	0.1464	5.135**		
July - MSMA - Cut 9/68	Bark	Constant	-748.0764		15	.67
		TRHT2	0.0615	2.999**		
		CRWHT2	-0.0990	-2.890*		
		CR1TR	993.8112	2.523*		
		SMPHT3	0.00004	0.689		
		DOB	-1.7317	-0.536		
		THKB2	122.4695	2.460*		
		THKB3	-76.7023	-2.666*		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d.f.	R^2
July - MSMA - Cut 9/68	Sapwood	Constant	-73.0957		16	.74
		TRHT	0.8453	3.089**		
		DIB3	-0.0037	-0.768		
		SM1TR	-80.5643	-5.373**		
		THKS3	-4.9776	-2.802*		
		PCSSW	288.9340	3.074**		
		PCSSW2	-180.9213	-2.201*		
	Heartwood	Constant	22.1064		18	.57
		CR1TR	28.5600	2.204*		
		DIAM3	0.0043	2.633*		
		SM1TR	-4.3267	-1.579		
		PCHSW	-18.1211	-3.343**		
Aug. - MSMA - Cut 9/68	Bark	Constant	-1.4888		10	.69
		SMPHT	1.5734	3.096*		
		SM1TR3	-148.6175	-2.249*		
		THKB3	37.9057	4.496**		
	Sapwood	Constant	19.7378		9	.85
		SMPHT	0.7202	3.101*		
		DIB3	0.0175	1.905		
		THKS3	10.4230	2.703*		
		APCS3	-229.5573	-3.068*		
	Heartwood	Constant	25.8644		9	.80
		DIAM	0.1150	0.155		
		SM1CR	4.2371	1.648		
		APCH2	-100.0420	-3.313**		
		PCHSW2	83.6752	2.812*		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d.f.	R^2
September - MSMA - Cut 9/68	Bark	Constant	49.5884		12	.59
		SMPHT2	0.0295	1.321		
		SMPHT3	-0.0003	-1.383		
		DOB3	0.0061	1.546		
		SM1TR2	-59.2169	-0.369		
		SM1CR	-120.1700	-2.146		
		SM1CR2	240.8822	2.827*		
		SM1CR3	-108.9282	-2.936*		
	Sapwood	Constant	-72.2865		15	.83
		CR1TR	120.7457	6.621**		
		SMPHT2	-0.0135	-4.824**		
		DIB	6.4697	5.220**		
		PCSSW	197.5299	6.047**		
	Heartwood	Constant	138.9402		13	.92
		DBH	-4.4169	-5.821**		
		TRHT	-1.6433	-2.483*		
		TRHT2	0.0118	2.661*		
		DIAM	-2.9041	-0.423		
		THKH	13.1521	0.971		
		PCHSW	-48.6182	-6.457**		
Oct.-MSMA - Cut 9/68	Bark	Constant	147.2105		17	.68
		DBH2	-0.2150	-2.162*		
		TRHT	0.7711	3.196**		
		APCB	-1237.0237	-3.896**		
		APCB2	2981.9646	3.430**		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Oct.- MSMA - Cut 9/68	Sapwood	Constant	-108.3925		15	.76
		CRWHT2	-0.0095	-2.517*		
		CR1TR	122.6699	2.855*		
		THKS	134.8598	4.127**		
		THKS3	-14.4463	-2.861*		
		APCS2	280.5221	2.982**		
		PCSSW3	-319.2625	-3.560**		
	Heartwood	Constant	33.3526		18	.78
		SM1TR	-6.7313	-3.161**		
		APCH3	-125.6519	-3.299**		
		PCHSW2	54.3577	3.053**		
June - CACO - Cut 9/68	Bark	Constant	205.6138		13	.85
		TRHT	-5.5015	-3.603**		
		TRHT2	0.0360	4.057**		
		SMPHT2	0.0347	2.773*		
		SMPHT3	-0.0004	-3.688**		
		SM1TR3	-40.4693	-0.582		
		THKB	88.7336	3.279**		
		THKB3	-27.8820	-2.971*		
	Sapwood	Constant	26.2807		19	.74
		DIB2	0.4135	7.283**		
	Heartwood	Constant	53.8344		15	.88
		CR1TR	-16.6342	-3.143**		
		SMPHT	-0.2711	-2.787*		
		SM1TR	29.6383	2.165*		
		SM1CR	-11.3785	-2.000		
		PCHSw3	-23.2581	-4.672**		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
July - CACO - Cut 9/68	Bark	Constant	112.6262		20	.60
		DBH	-11.0394	-3.665**		
		TRHT	0.9581	4.195**		
		SM1CR3	-16.0511	-1.661		
	Sapwood	Constant	47.2456		20	.78
		TRHT	0.7383	3.193**		
		SM1TR	-66.5314	-4.650**		
		APCS	-62.6259	-2.039		
	Heartwood	Constant	185.0577		18	.74
		DBH	-24.6270	-1.831		
		DBH2	1.0321	1.766		
		DIAM3	-0.1074	-2.757*		
		SM1TR	-12.5348	-2.874*		
		THKH3	0.8304	2.658*		
Aug.-CACO - Cut 9/68	Bark	Constant	-426.4755		11	.92
		DBH2	-1.1128	-5.233**		
		CRWHT	-1.0089	-4.116**		
		SMPHT2	0.0781	5.568**		
		DOB	84.1142	7.193**		
		DOB2	-2.4136	-6.929**		
		SM1TR3	-351.6539	-2.532*		
		SM1CR	403.9277	4.746**		
		SM1CR2	-566.6932	-3.991**		
		SM1CR3	279.9434	4.338**		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Aug. - CACO - Cut 9/68	Sapwood	Constant	92.7742		18	.43
		SMPHT	-1.5774	-2.240*		
		SM1TR2	124.5126	1.270		
	Heartwood	Constant	106.9298		15	.80
		CR1TR	-239.8288	-4.902**		
		CR1TR2	219.8943	5.323**		
		SMPHT	-0.4834	-4.308**		
		SM1TR2	38.1141	2.559*		
		THKH	-1.9267	-2.093		
Sept. - CACO - Cut 9/68	Bark	Constant	0.2514		19	.65
		TRHT	0.7972	5.796**		
		SM1CR2	4.0286	3.029**		
	Sapwood	Constant	-1135.4891		11	.78
		DBH	203.6514	4.133**		
		DBH2	-7.8542	-3.887**		
		TRHT2	0.0075	1.024		
		CRWHT	-3.8108	-2.363*		
		CR1TR2	312.0682	2.715*		
		DIB	-7.9098	-1.435		
		SM1TR2	-410.6383	-1.858		
		SM1TR3	591.3993	2.366*		
		APCS2	474.8077	1.620		
		APCS3	-720.5691	-1.963		

Table 4. (Continued)

Treatment	Constituent	Variable	Coefficient	T-value	d. f.	R^2
Sept. - CACO - Cut 9/68	Heartwood	Constant	31.3843		14	.83
		TRHT	0.0263	0.529		
		CRWHT2	-0.0003	-0.662		
		SM1TR	31.7113	2.856*		
		SM1CR	-28.7827	-3.747**		
		SM1CR3	3.8790	4.023**		
		THKH2	1.3562	2.645*		
		THKH3	-0.2561	-2.975*		
Oct. - CACO - Cut 9/68	Bark	Constant	-180.1637		18	.66
		CRWHT2	-0.0056	-1.808		
		CR1TR	777.5644	3.302**		
		CR1TR2	-559.5190	-3.501**		
		SM1CR2	21.8245	3.457**		
	Sapwood	Constant	-171.8694		12	.72
		CR1TR	837.9060	3.197**		
		CR1TR2	-634.5649	-3.326**		
		SMPHT	-0.3159	-0.588		
		SM1CR	-240.7520	-2.344*		
		SM1CR2	567.3333	2.723*		
		SM1CR3	-281.8259	-2.340*		
		THKS2	-14.1224	-1.882		
		APCS	108.4831	0.957		
		APCS3	-1336.5949	-2.499*		
		PCSSW3	747.2340	2.013		
	Heartwood	Constant	30.9048		21	.60
		THKH2	0.3128	5.571**		

*significant at 5% level
**significant at 1% level

APPENDIX B: Model tree : emperical equations derived by multiple regression.

Equation formation and variable notation follow Appendix A.

Table 5. Model tree : radius equations of bark, sapwood and heartwood.

Radius	Variable	Coefficient	T value	d.f.	R^2
Bark	Constant	10.1579		122	.94
	DBH3	0.0015	3.164**		
	TRHT	0.0939	3.841**		
	CRWHT	-0.1025	-2.899**		
	CRITR	-8.8821	-1.667		
	CRITR2	11.1349	3.165**		
	SMPHT	-0.0498	-2.427*		
	SMITR	-14.1629	-4.449**		
	SMITR2	28.2803	2.970**		
	SMITR3	-19.3407	-2.208*		
	SMICR	-1.8904	-2.939**		
Sapwood	Constant	-1.0919		129	.98
	DOB	1.3058	-4.207**		
	DOB2	-0.0364	-1.232		
	DOB3	0.0007	0.808		
Heartwood	Constant	0.8186		128	.87
	DOB2	0.0938	3.436**		
	DOB3	-0.0060	-4.507**		
	DIB	-0.3688	-0.654		
	DIB2	0.0699	2.631**		

* - significant at 5% level

** - significant at 1% level

The computer program illustrates the interrelationship of the model tree equations and the descriptive equations of the moisture profiles. The percent bark, sapwood and heartwood moisture content (PCBMC, PCSMC and PCHMC, respectively) are computed after the values of all variables have been established. This procedure is repeated for each desired increment of height. The moisture profile equations are given in Appendix A for each treatment. The program, as presented, computes the moisture content at one foot increments from zero to 62 feet for the trees treated with MSMA in March, 1967 and cut in September, 1967. The evaluated moisture profiles for other treatments are determined by replacing the percent moisture content equations by the appropriate ones for the desired treatment.

The computed points resulting from this program are plotted in Appendix C for each component of the tree for each treatment. These evaluated moisture content points and their associated sample heights are used to determine the equations given for each line in the figures in Appendix C.

```
      PROGRAM PATTERN
C COMPUTES MOISTURE PATTERNS WITHIN TREE
C USES EQUATIONS FROM MULTIPLE LINEAR STEPWISE REGRESSION
C PROVIDE TREE MEASURES: DBH, TREE HEIGHT, CROWN HEIGHT
C SET BEGINNING SAMPLE HEIGHT AT ONE UNIT LESS THAN TRUE HEIGHT
      DBH=11.8
      TRHT=84.6
      CRWHT=58.6
      SMPHT=-1.0
      DBH2=DBH**2
      DBH3=DBH**3
      TRHT2=TRHT**2
      CRWHT2=CRWHT**2
      CR1TR=CRWHT/TRHT
      CR1TR2=CR1TR**2
    3 SMPHT=SMPHT+1.0
      SMPHT2=SMPHT**2
      SMPHT3=SMPHT**3
      SM1TR=SMPHT/TRHT
      SM1TR2=SM1TR**2
      SM1TR3=SM1TR**3
      SM1CR=SMPHT/CRWHT
      SM1CR2=SM1CR**2
      SM1CR3=SM1CR**3
      DOB=10.1579+0.0015*DBH3+0.0939*TRHT-0.1025*CRWHT-0.0498*SM
     1PHT-14.1629*SM1TR+28.2803*SM1TR2-19.3407*SM1TR3-1.9904*SM
     21CR-8.8821*CR1TR+11.1349*CR1TR2
      DOB2=DOB**2
      DOB3=DOB**3
      DIB=-1.0919+1.3058*DOB-0.0364*DOB2+0.0007*DOB3
      DIB2=DIB**2
      DIB3=DIB**3
      THKB=(DOB-DIB)/2.
      THKB2=THKB**2
      THKB3=THKB**3
      APCB=(DOB2-DIB2)/DOB2
      APCB2=APCB**2
      APCB3=APCB**3
      DIAM=-1.148+1.7795*DOB-0.0225*DOB2-0.0036*DOB3-1.5772*DIB
     1+0.1227*DIB2
      DIAM2=DIAM**2
      DIAM3=DIAM**3
      THKS=(DIB-DIAM)/2.
      THKS2=THKS**2
      THKS3=THKS**3
      THKH=DIAM/2.
      THKH2=THKH**2
      THKH3=THKH**3
      APCS=(DIB2-DIAM2)/DOB2
      APCS2=APCS**2
      APCS3=APCS**3
      APCH=DIAM2/DOB2
      APCH2=APCH**2
      APCH3=APCH**3
      PCSSW=(DIB2-DIAM2)/DIB2
      PCSSW2=PCSSW**2
      PCSSW3=PCSSW**3
      PCHSW=DIAM2/DIB2
      PCHSW2=PCHSW**2
      PCHSW3=PCHSW**3
      PCBMC=44.409+298.7482*SM1TR3-74.9528*SM1CR2
      PCSMC=-124.6584+14.6924*DBH+0.0072*TRHT2-0.07*CRWHT-1.7248
     1*SMPHT+101.6981*SM1CR
      PCHMC=39.4659-170.677*SM1TR+574.4481*SM1TR2-500.6675*SM1TR3
      BRKMC=PCBMC/100.
      SPWMC=PCSMC/100.
      HRTMC=PCHMC/100.
      WRITE(29,20)SMPHT,SM1TR,BRKMC,SPWMC,HRTMC
   20 FORMAT(1X,F4.0,F5.3,3F7.4)
      IF(62.0-SMPHT)30,30,3
   30 CALL EXIT
      END
```

APPENDIX C. Graphic illustrations of moisture profiles of consituents by treatment.

The following notation is used in this Appendix section (Figures 14 to 32):

X	Sample height
BMC	Bark moisture content
HMC	Heartwood moisture content
SMC	Sapwood moisture content

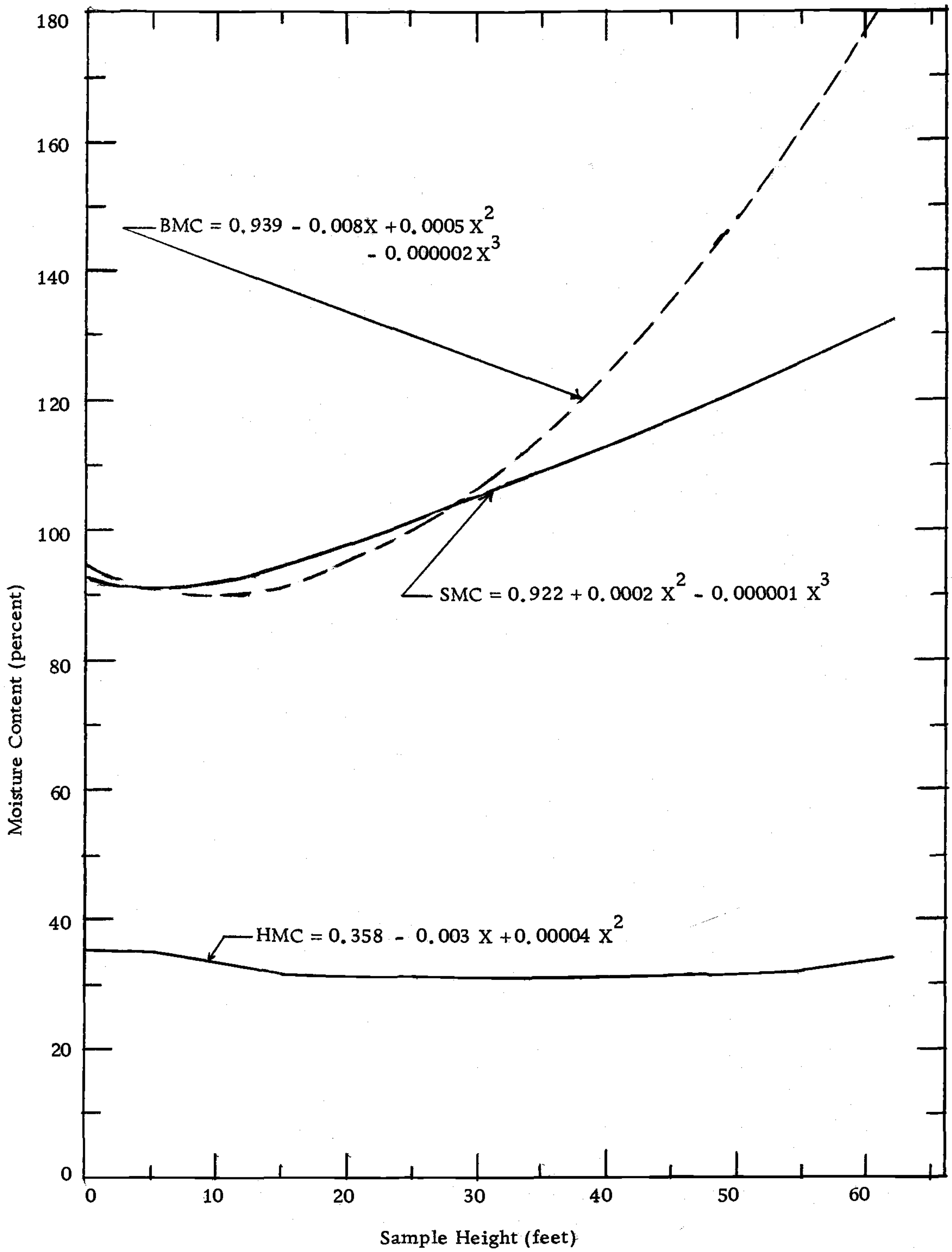


Figure 14. Moisture profiles of components of control trees cut February, 1967.

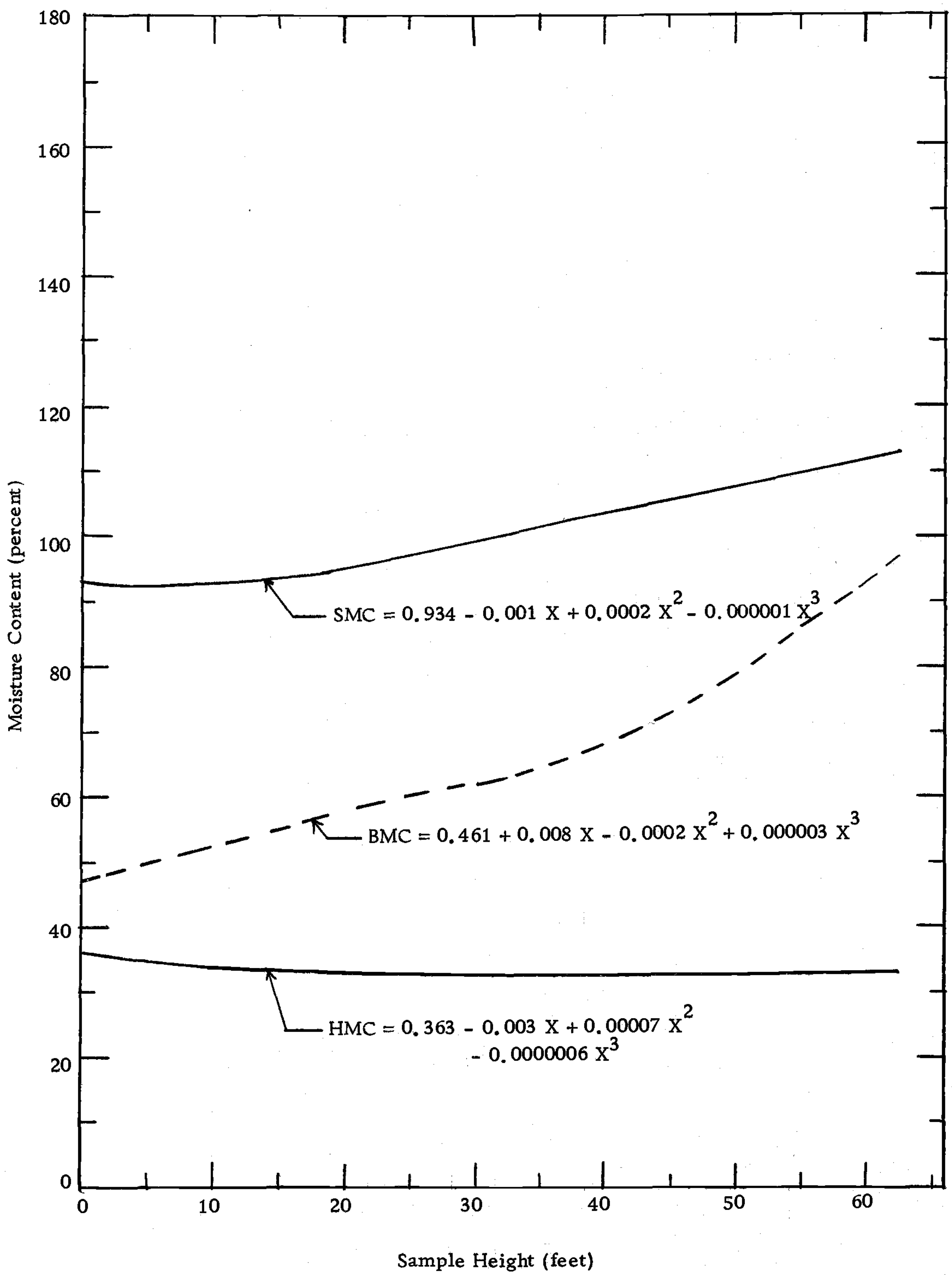


Figure 15. Moisture profiles of components of control trees cut September, 1967.

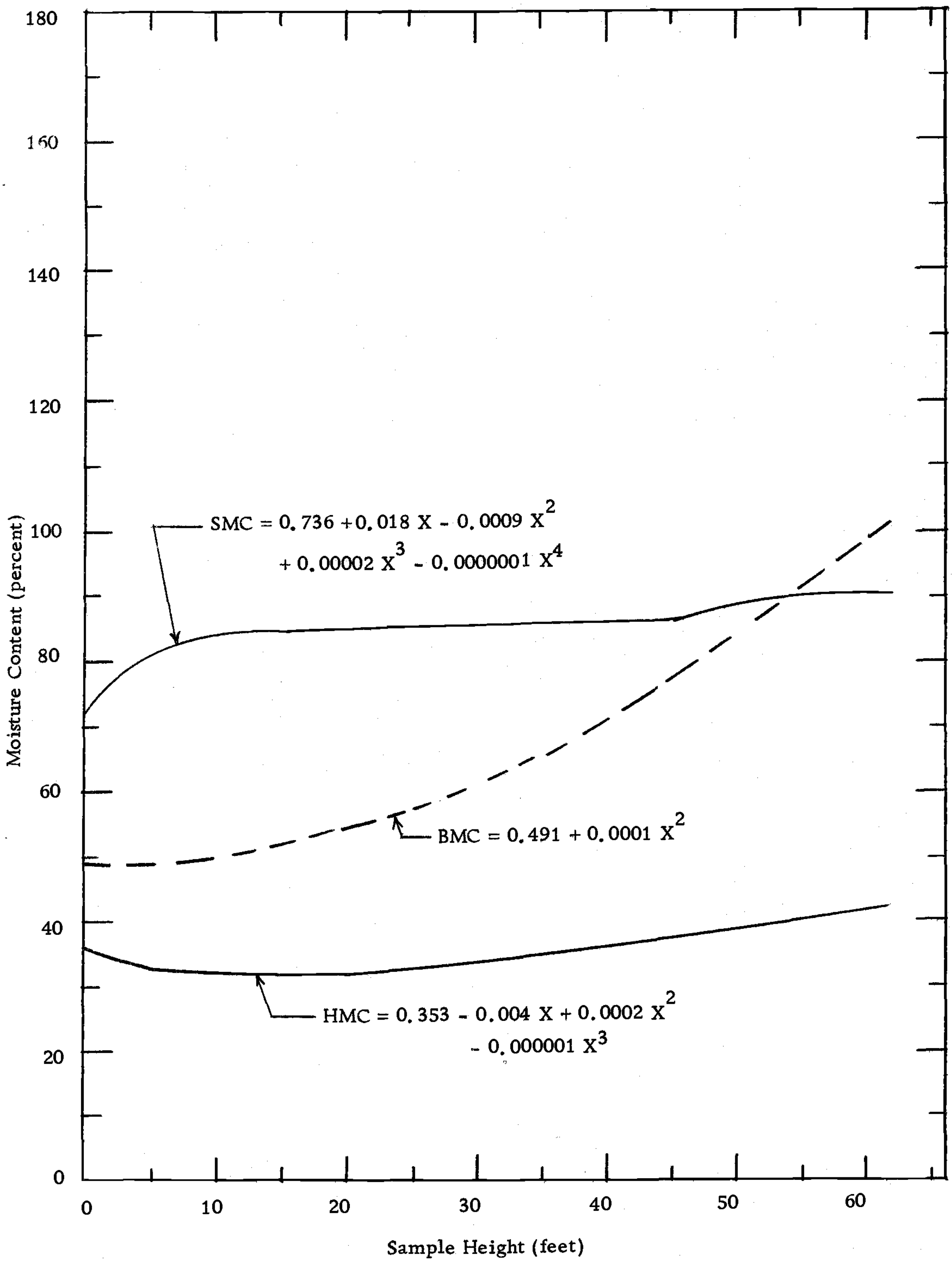


Figure 16. Moisture profiles of components of control trees cut September, 1968.

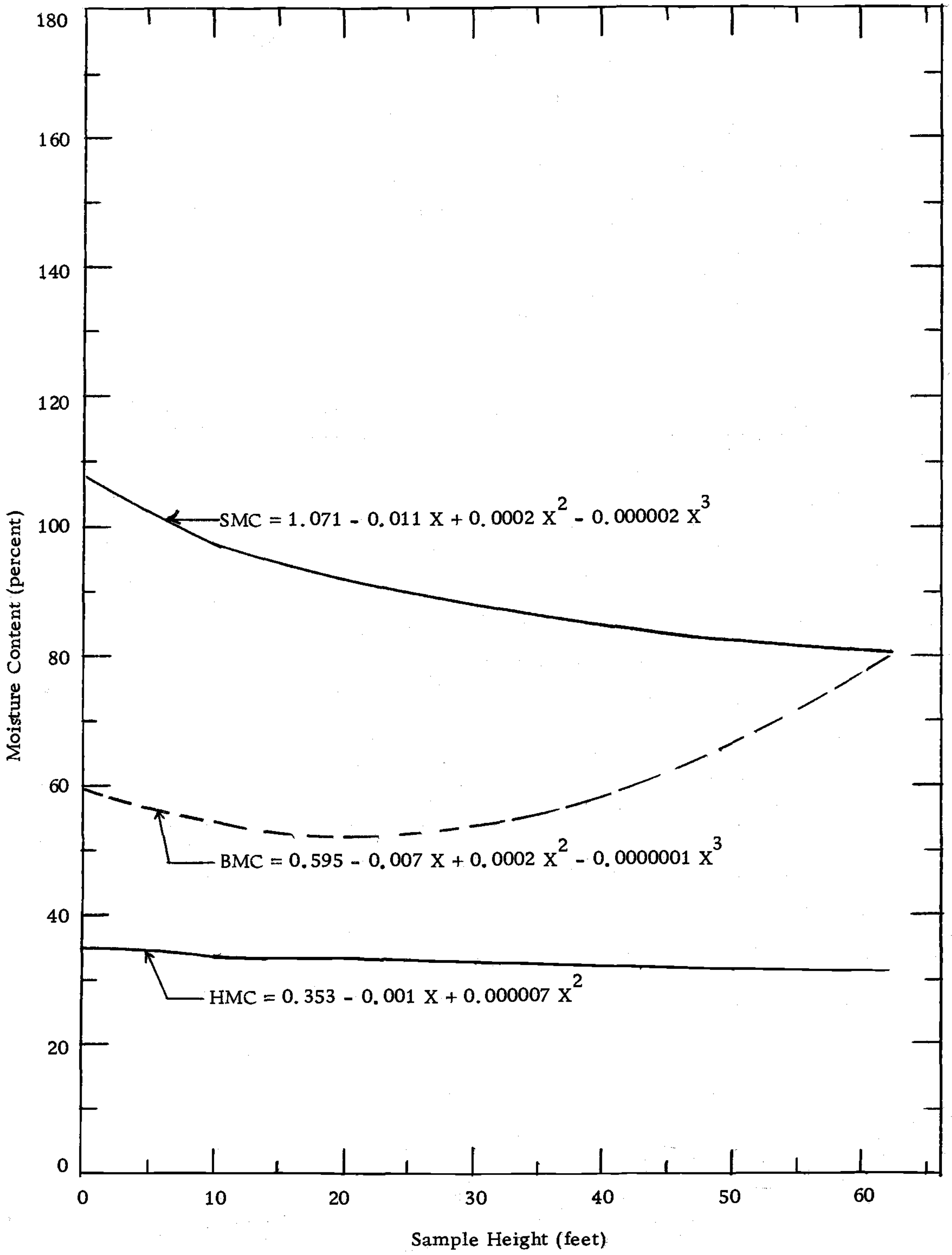


Figure 17. Moisture profiles of components of trees treated in February, 1967 with MSMA and cut in September, 1967.

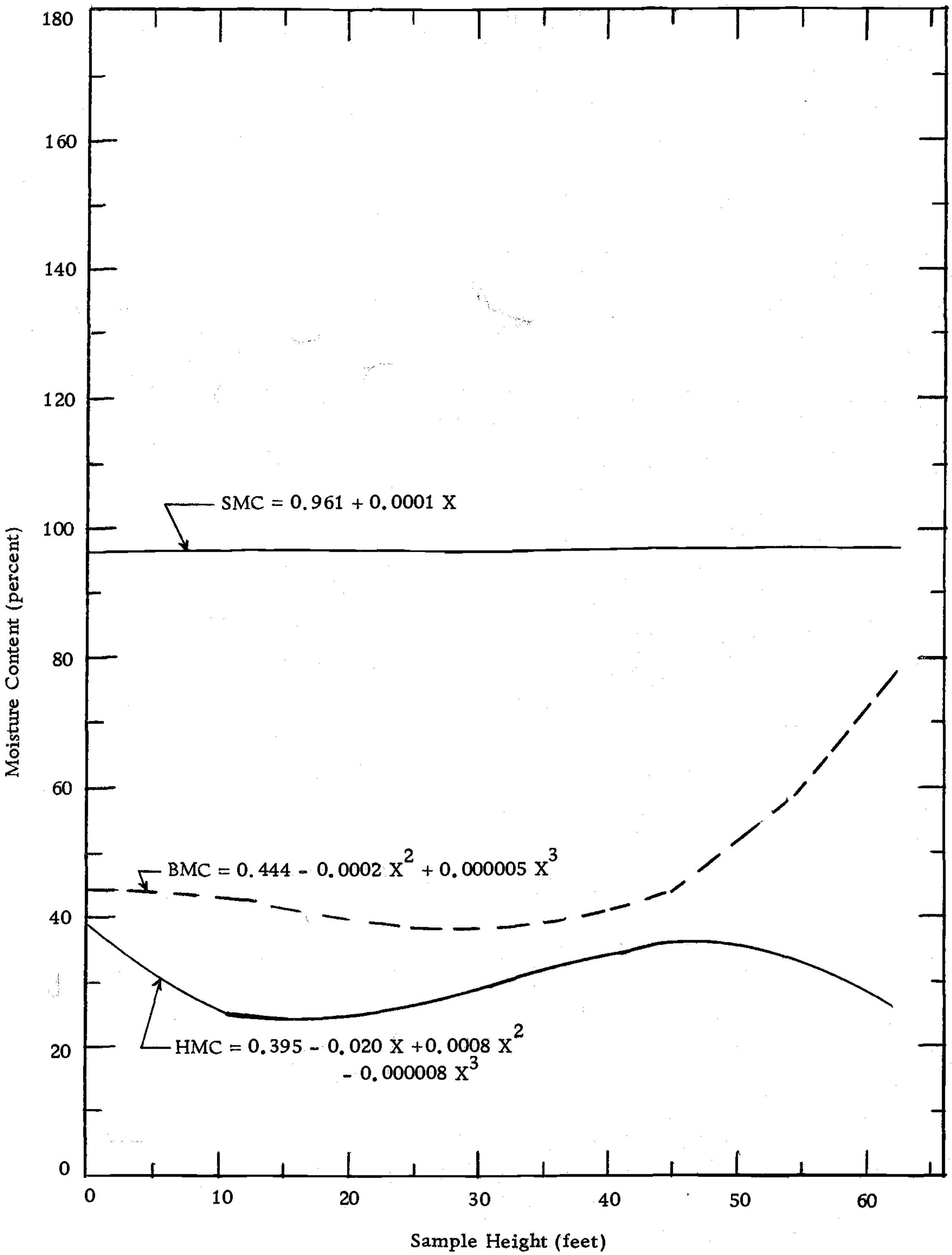


Figure 18. Moisture profiles of components of trees treated in March, 1967 with MSMA and cut in September, 1967.

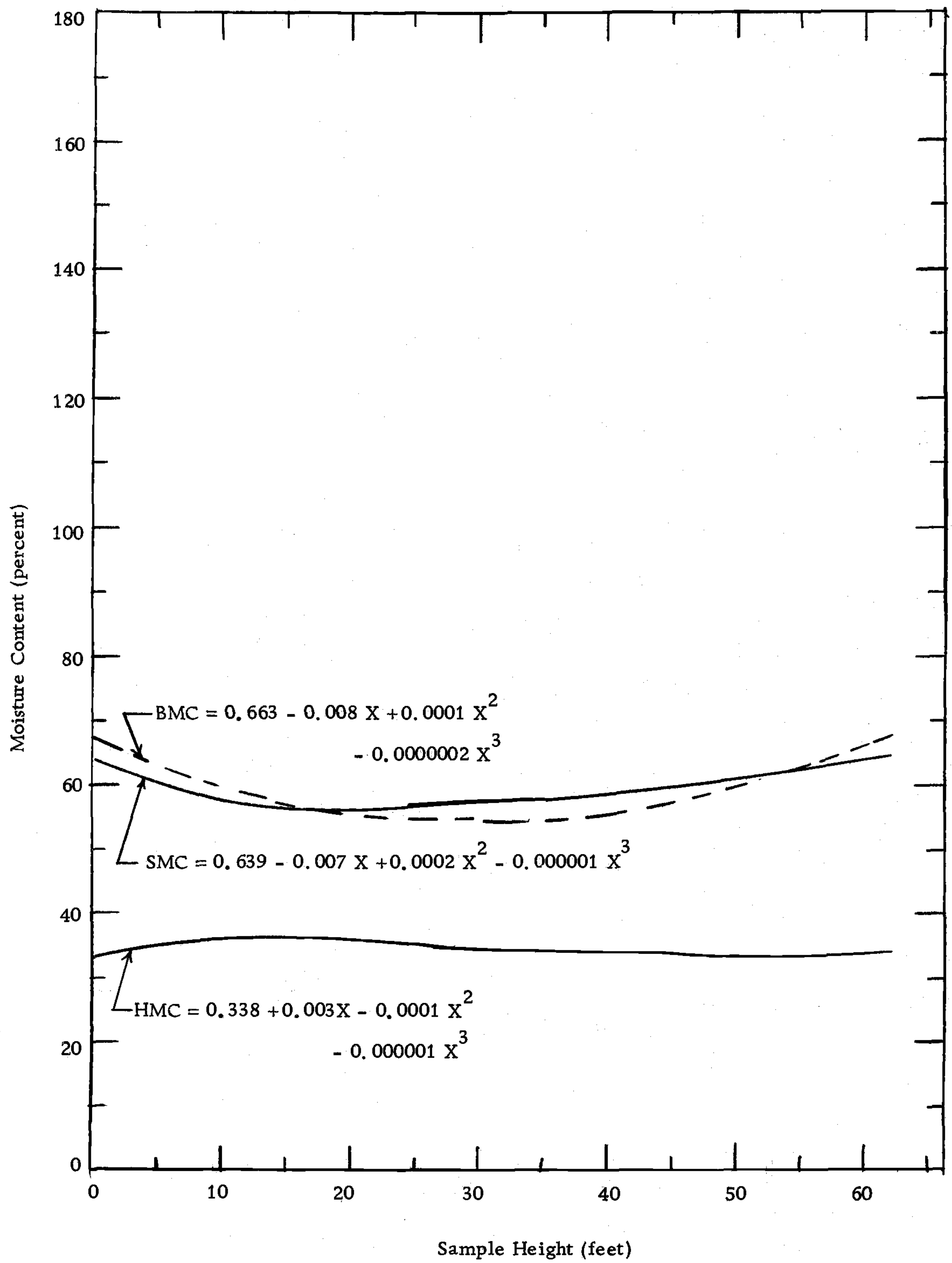


Figure 19. Moisture profiles of components of trees treated in April, 1967 with MSMA and cut in September, 1967.

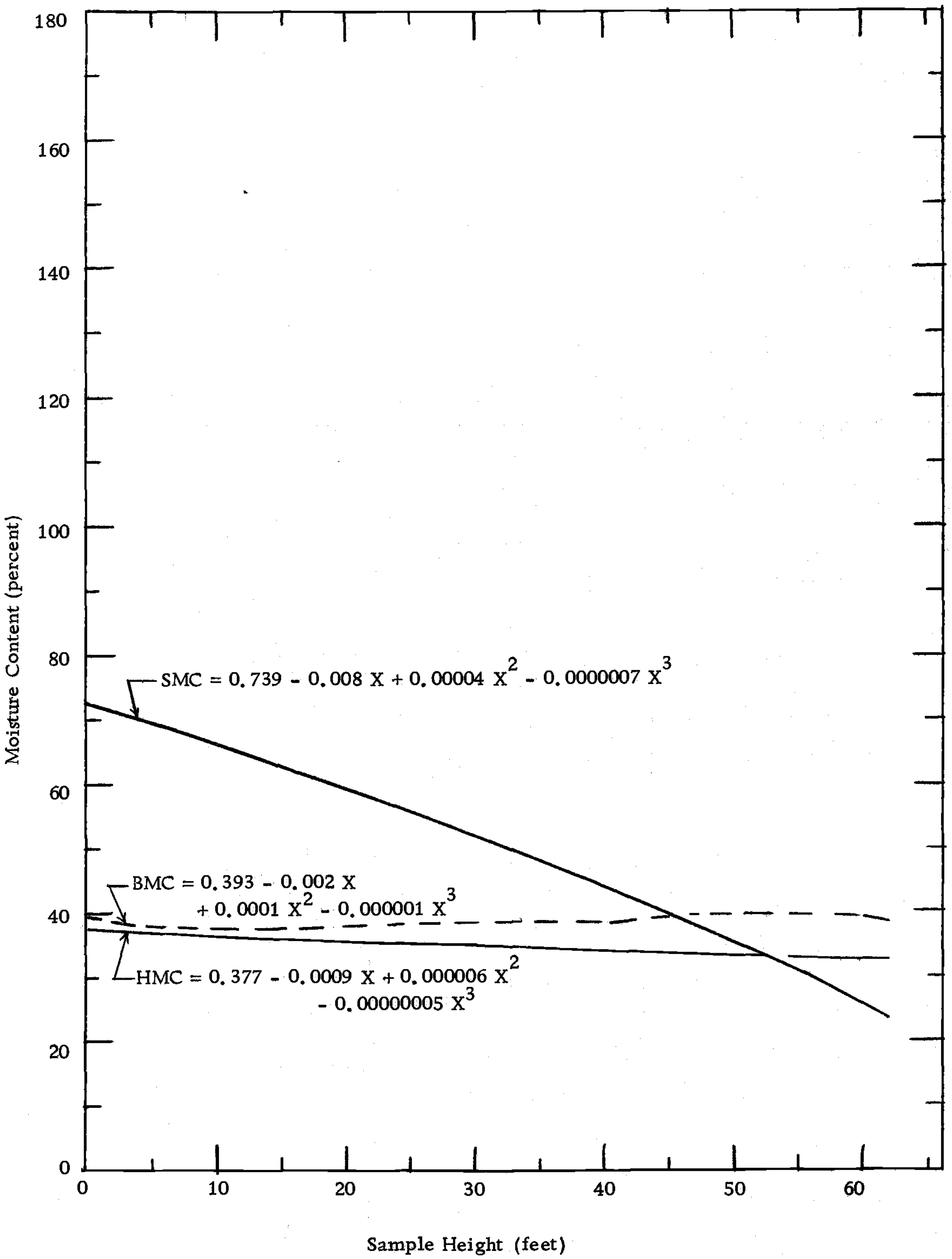


Figure 20. Moisture profiles of components of trees treated in February, 1967 with MSMA and cut in September, 1968.

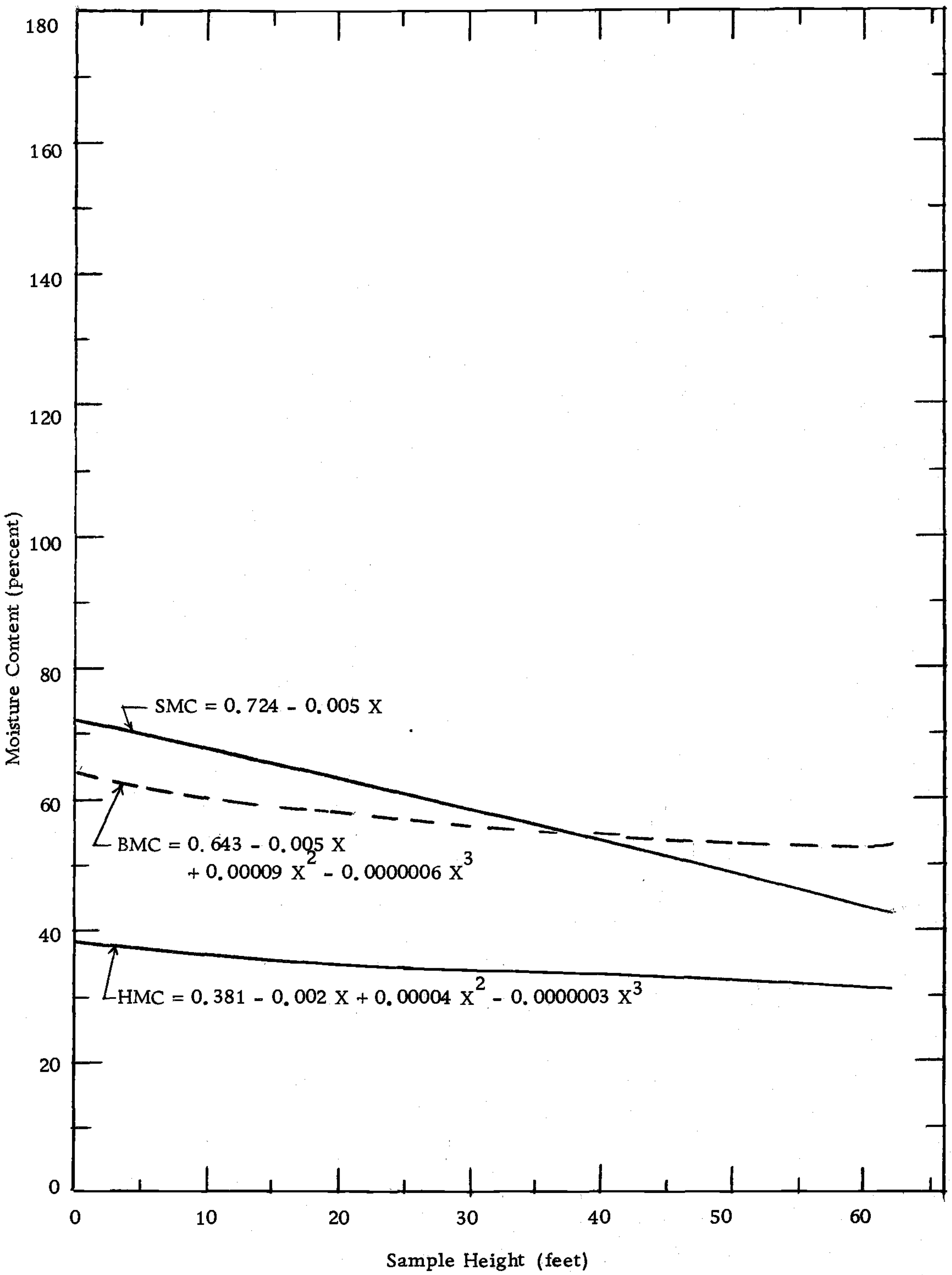


Figure 21. Moisture profiles of components of trees treated in March, 1967 with MSMA and cut in September, 1968.

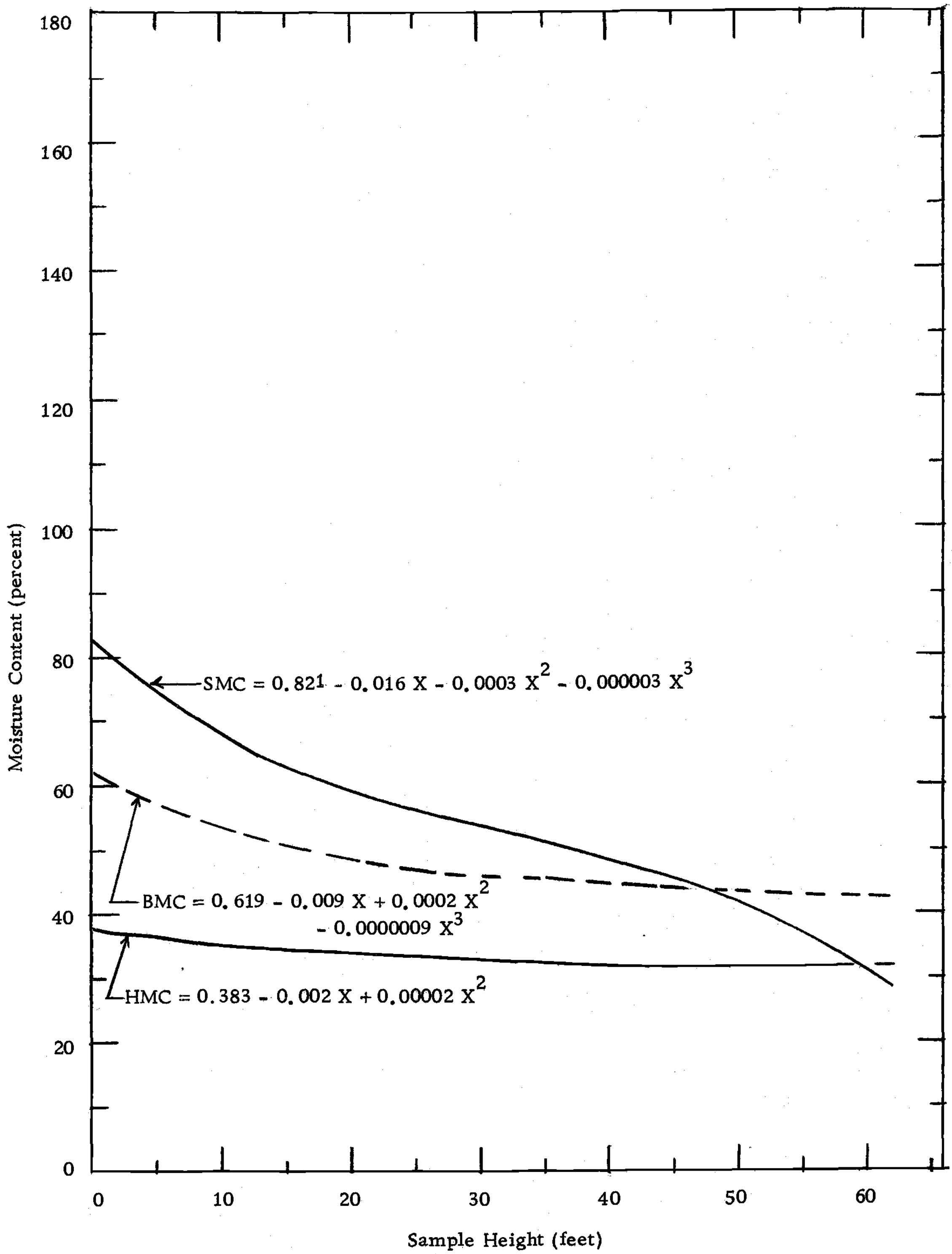


Figure 22. Moisture profiles of components of trees treated in April, 1967 with MSMA and cut September, 1968.

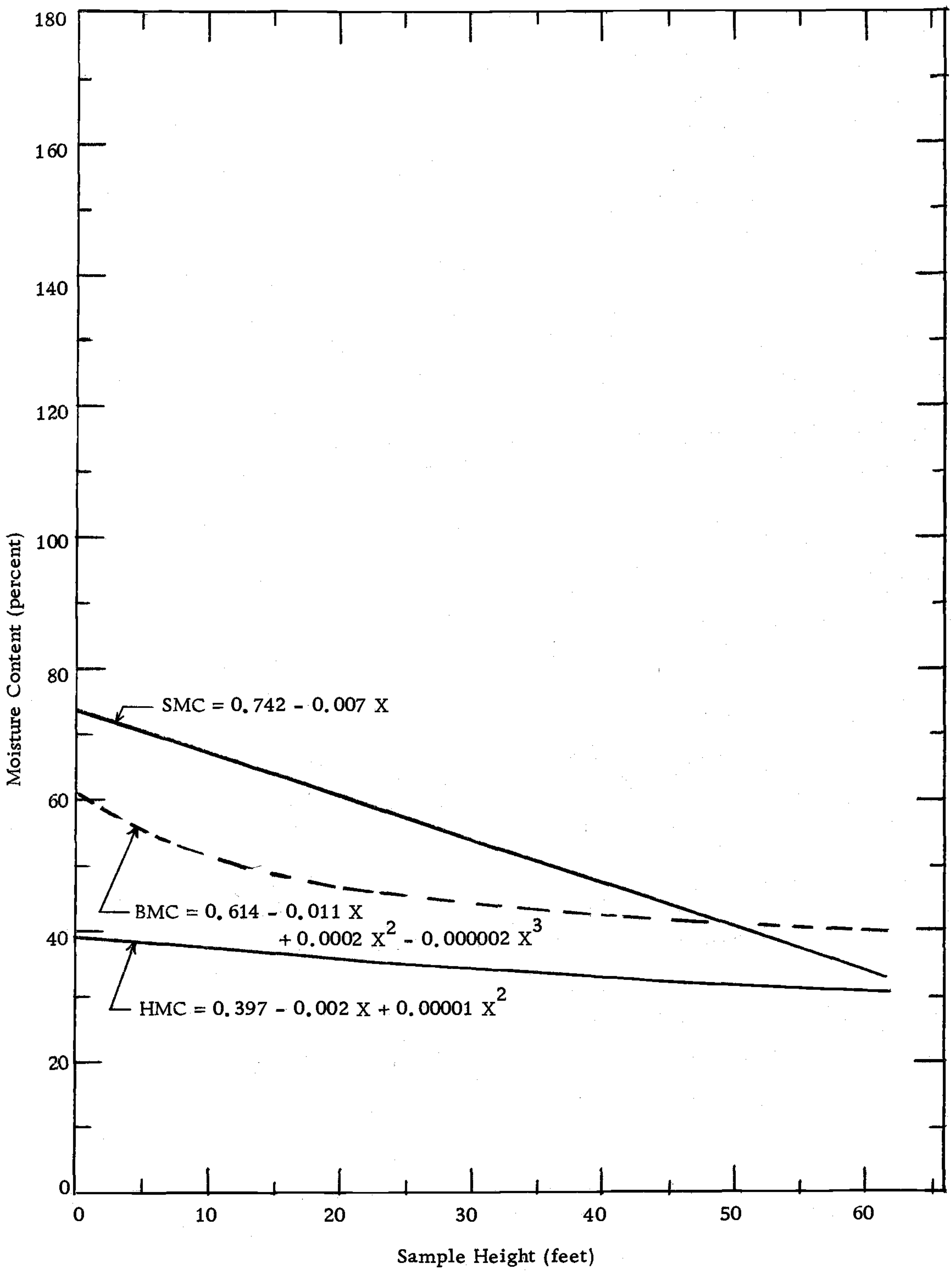


Figure 23. Moisture profiles of components of trees treated in June, 1967 with MSMA and cut in September, 1968.

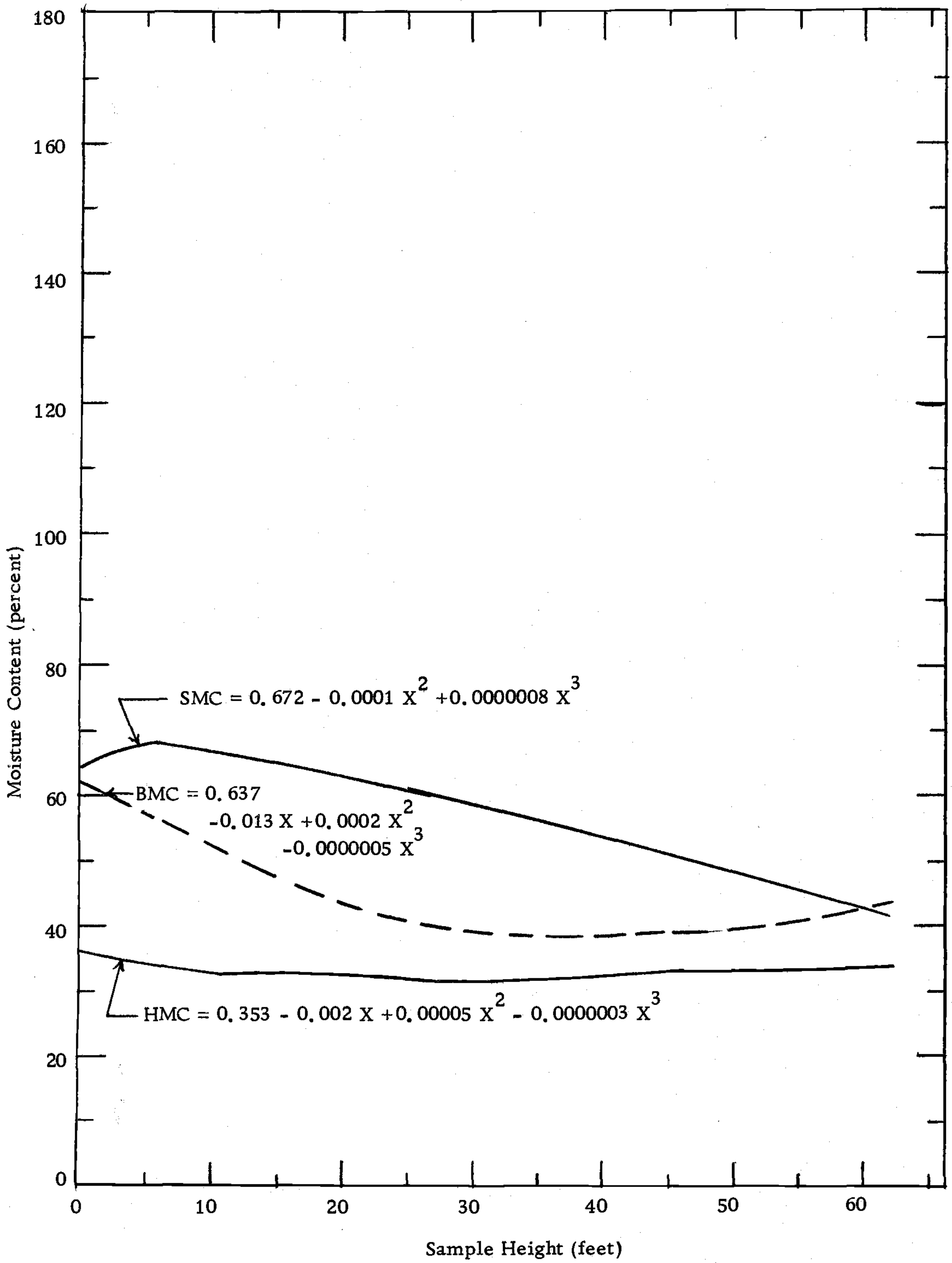


Figure 24. Moisture profiles of components of trees treated in July, 1967 with MSMA and cut in September, 1968.

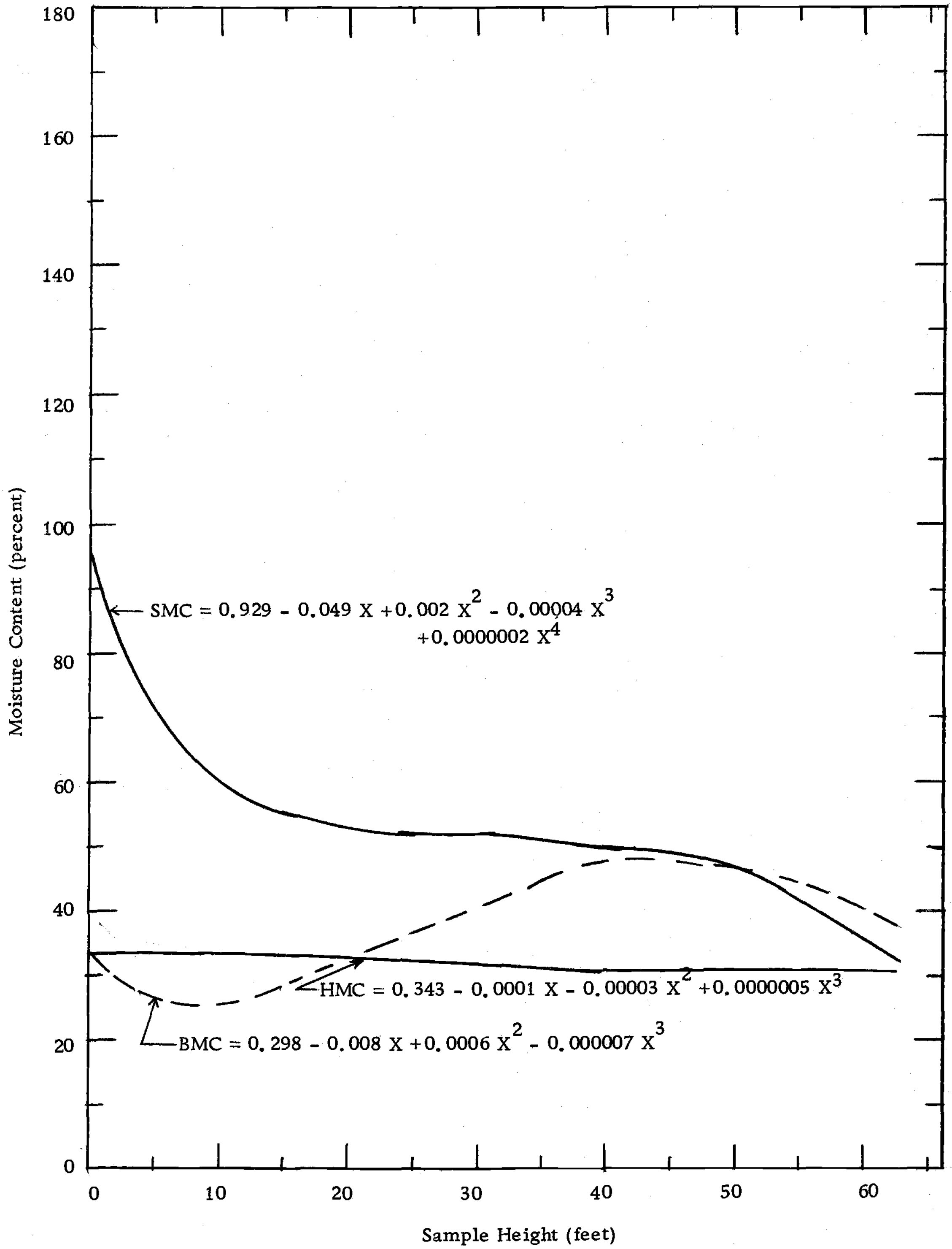


Figure 25. Moisture profiles of components of trees treated in August, 1967 with MSMA and cut in September, 1968.

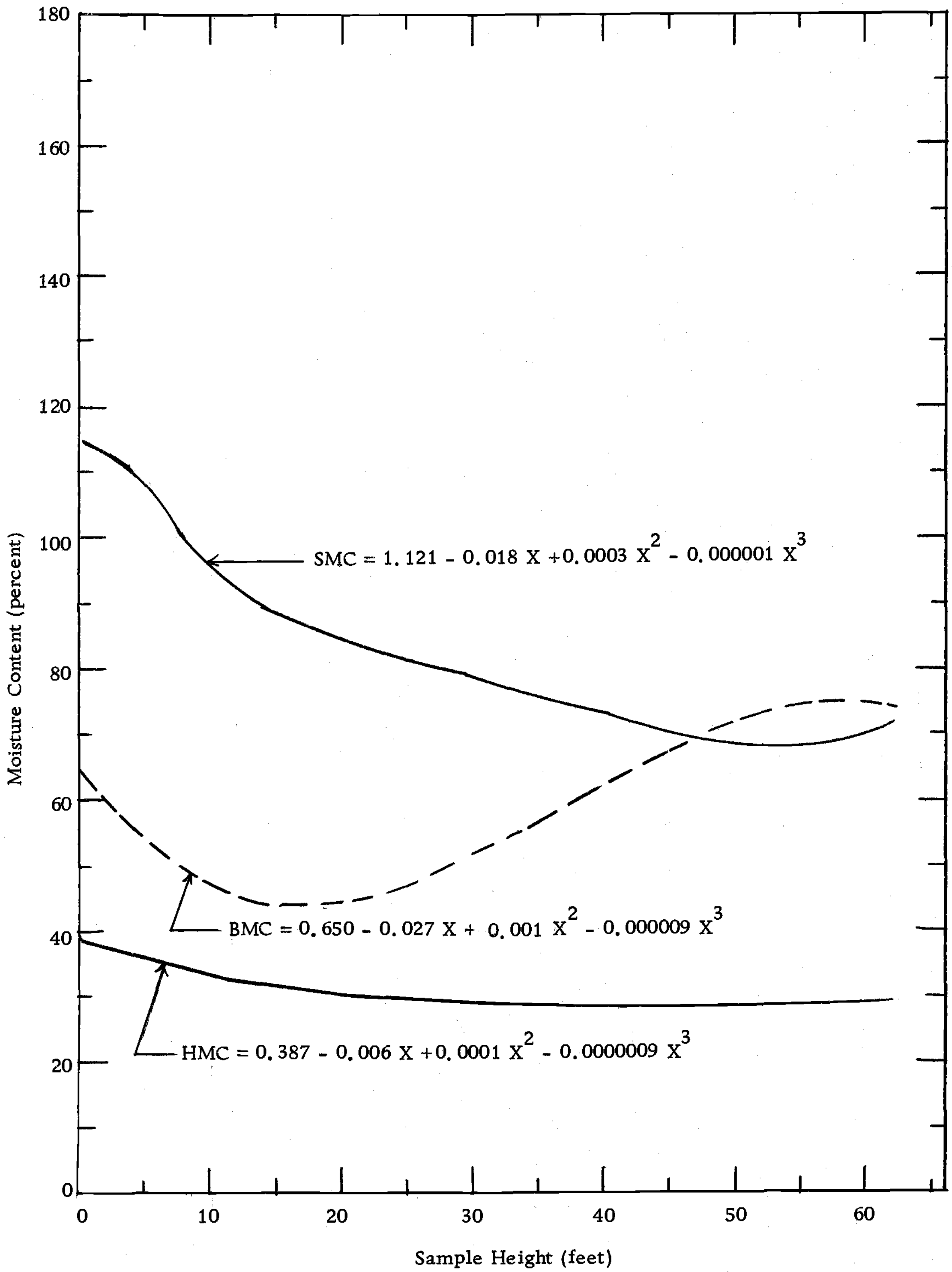


Figure 26. Moisture profiles of components of trees treated in September, 1967 with MSMA and cut in September, 1968.

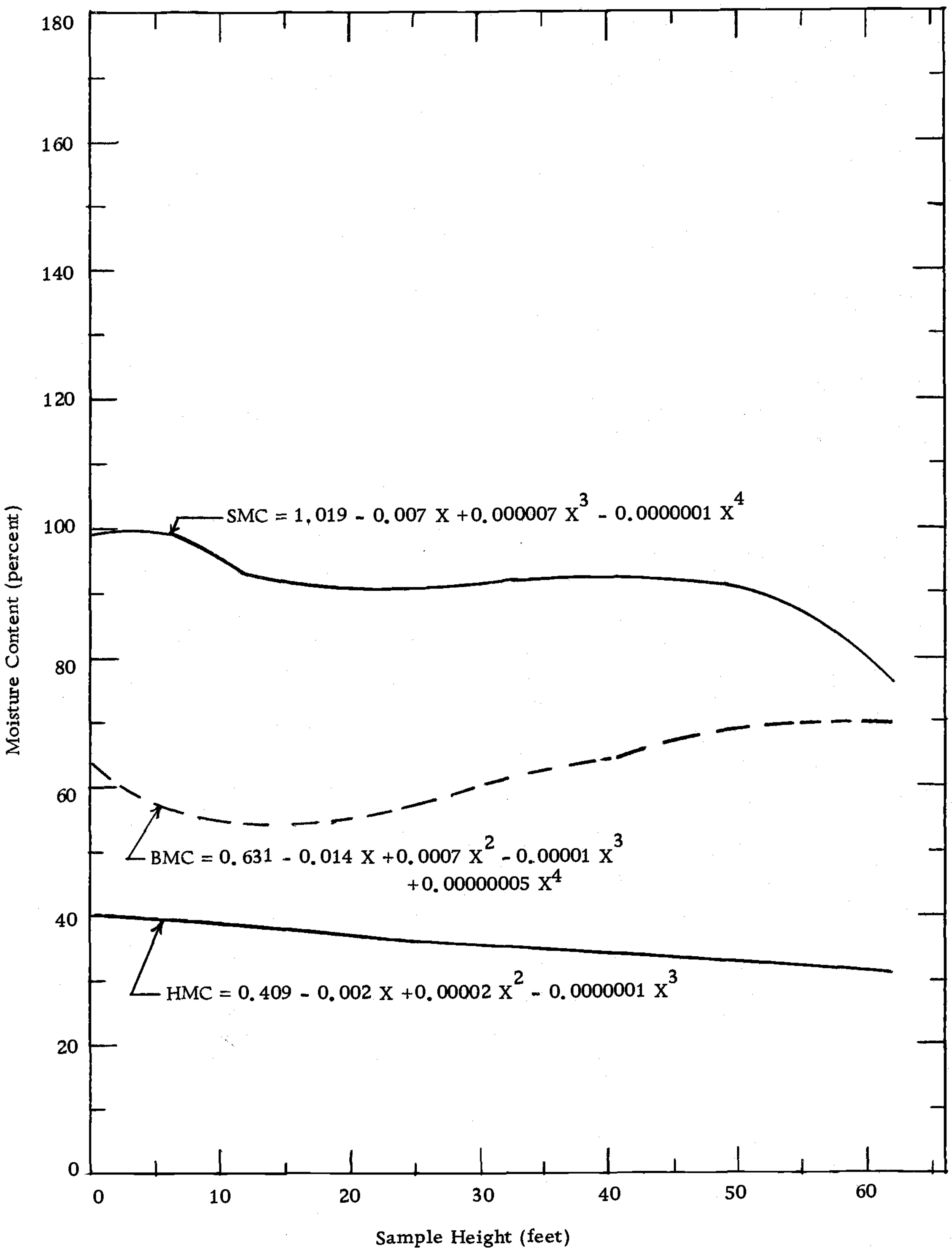


Figure 27. Moisture profiles of components of trees treated in October, 1967 with MSMA and cut in September, 1968.

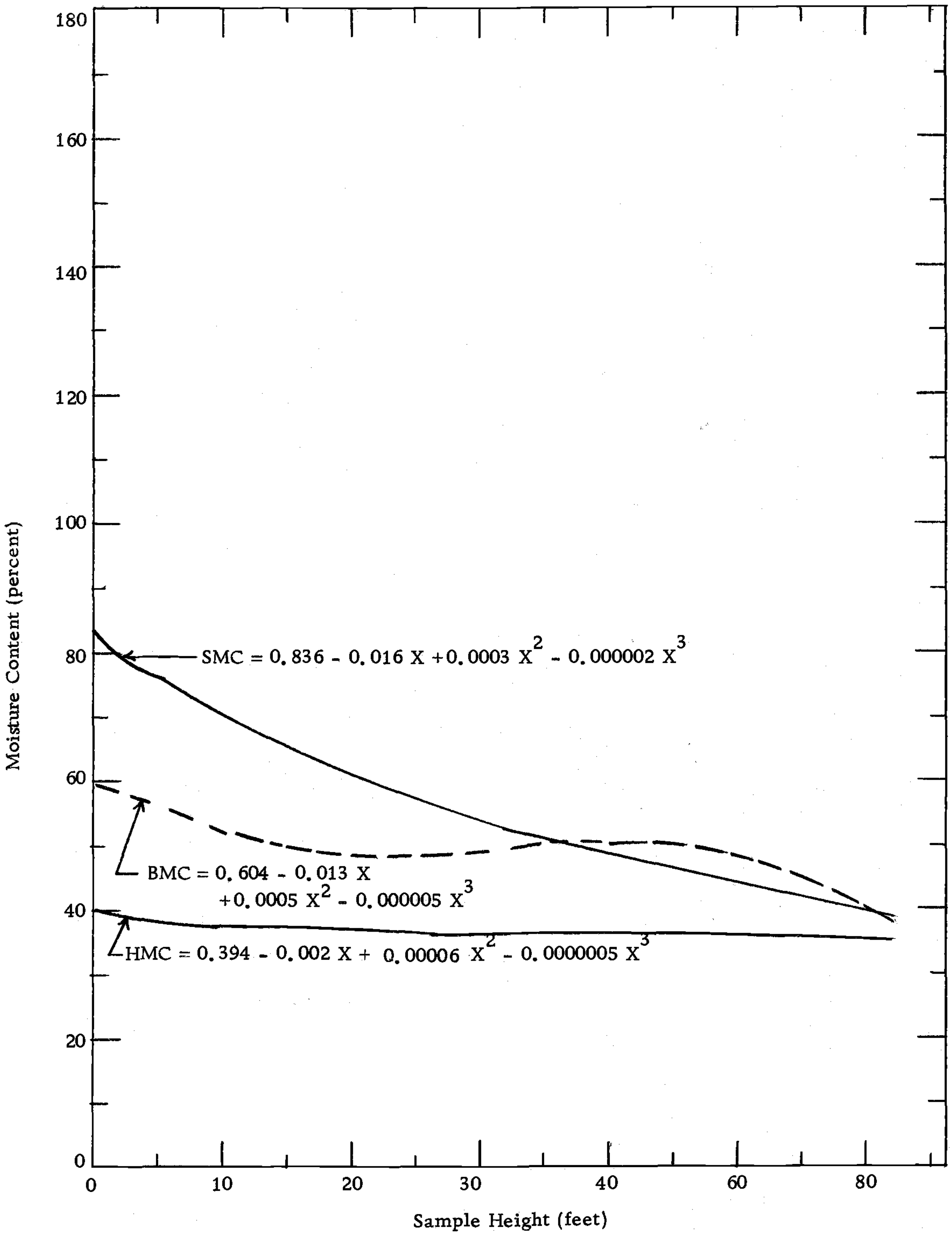


Figure 28. Moisture profiles and components of trees treated in June, 1967 with cacodylic acid and cut in September, 1968.

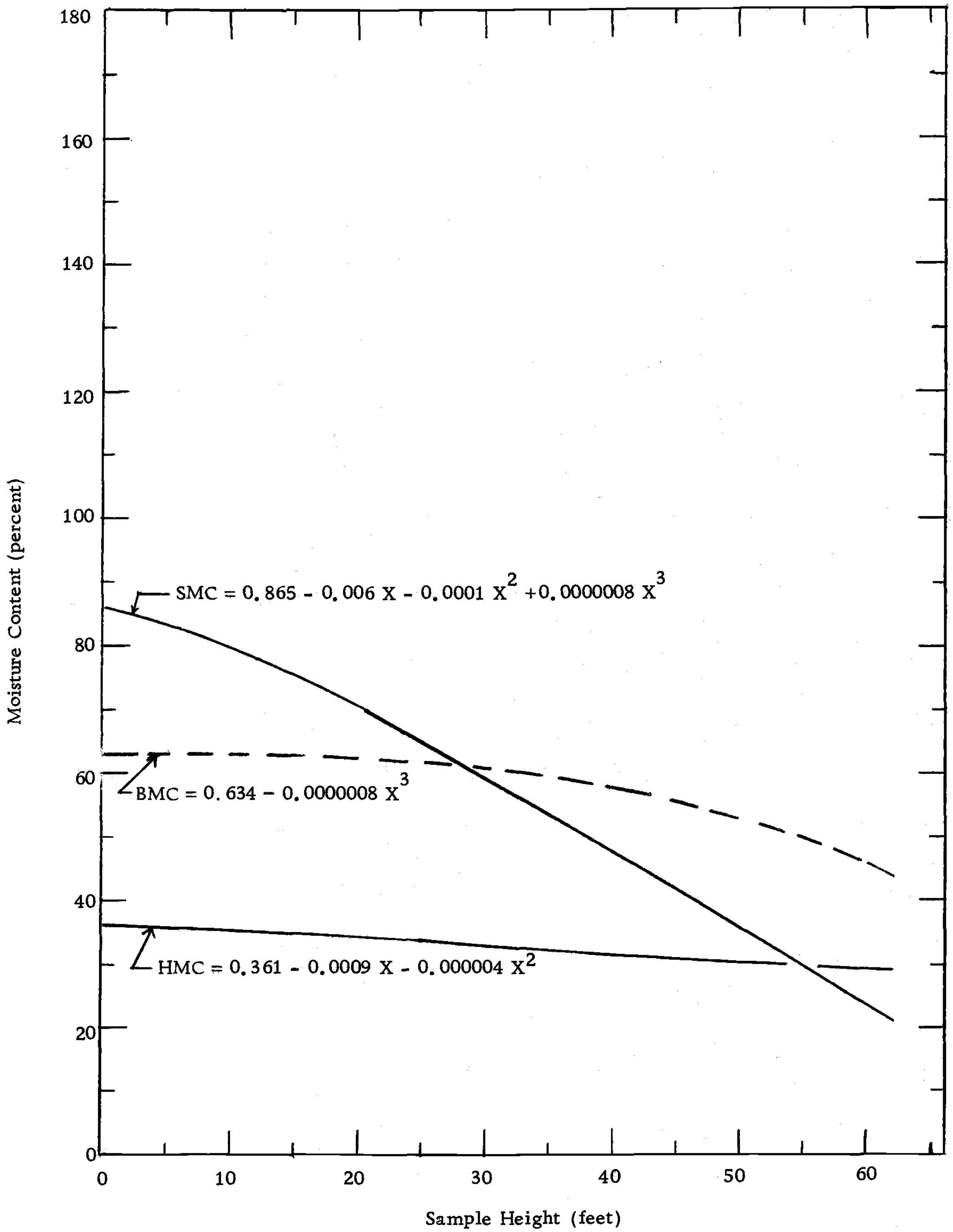


Figure 29. Moisture profiles of components of trees treated in July, 1967 with cacodylic acid and cut in September, 1968.

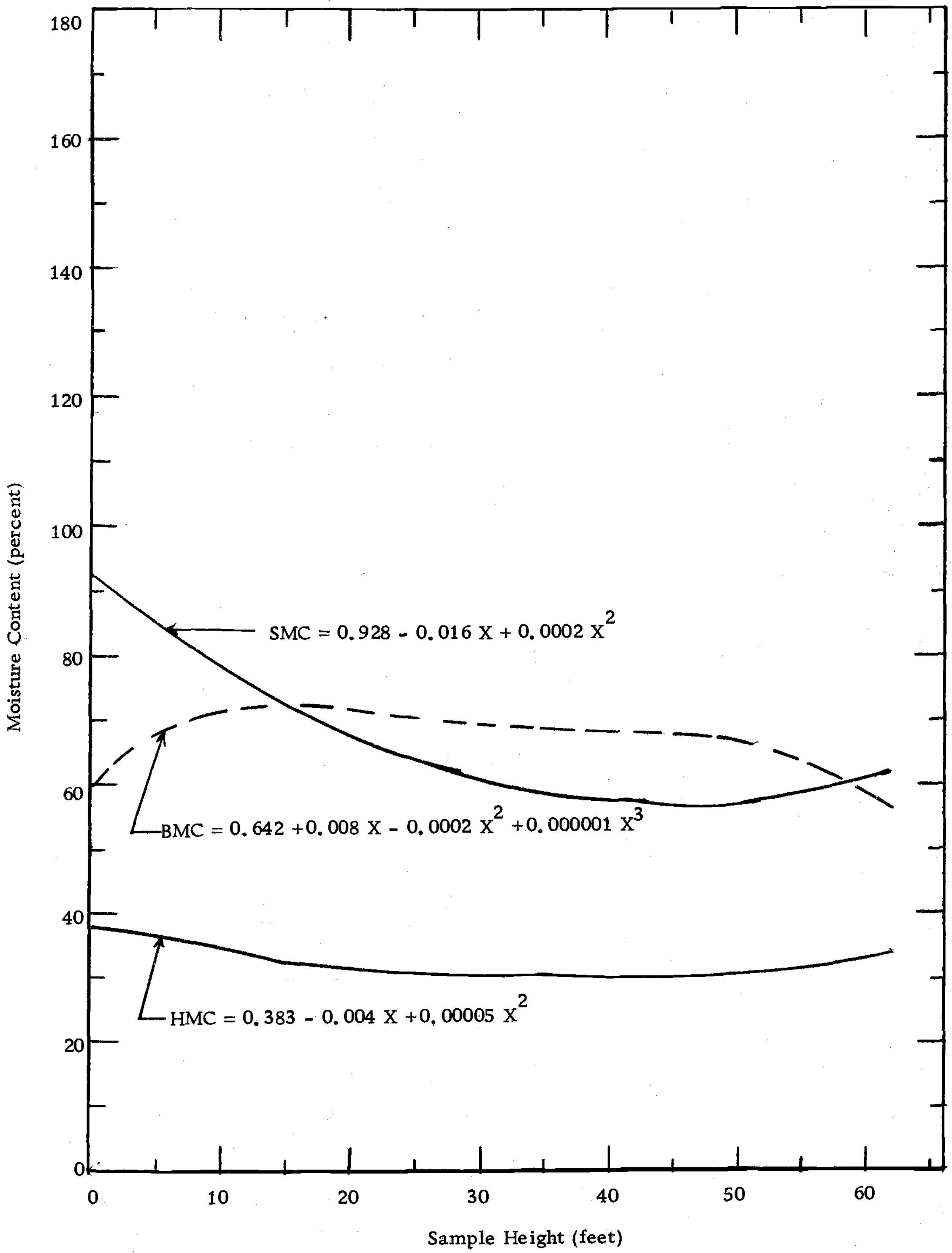


Figure 30. Moisture profiles of components of trees treated in August, 1967 with cacodylic acid and cut in September, 1968.

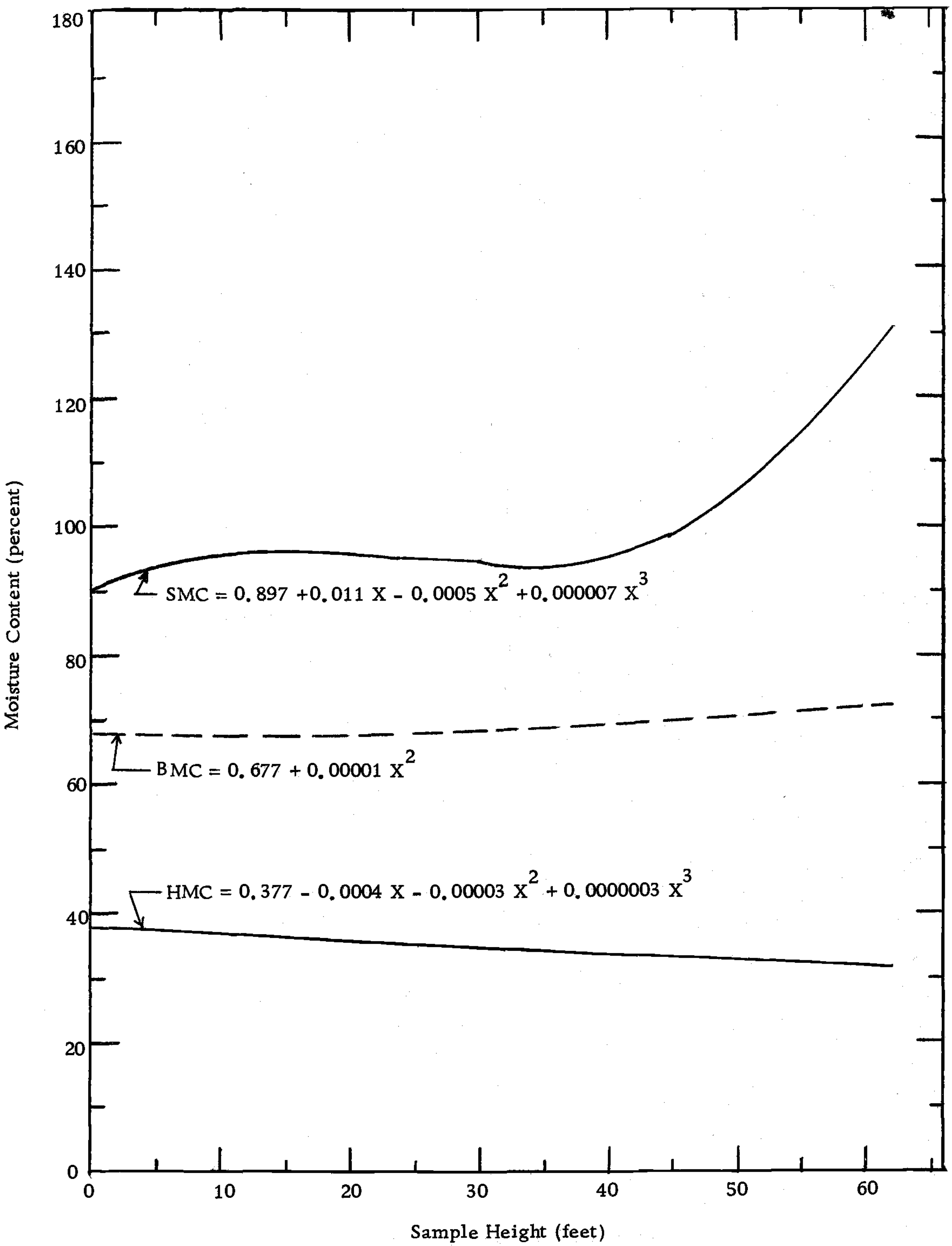


Figure 31. Moisture profiles of components of trees treated in September, 1967 with cacodylic acid and cut in September, 1968.

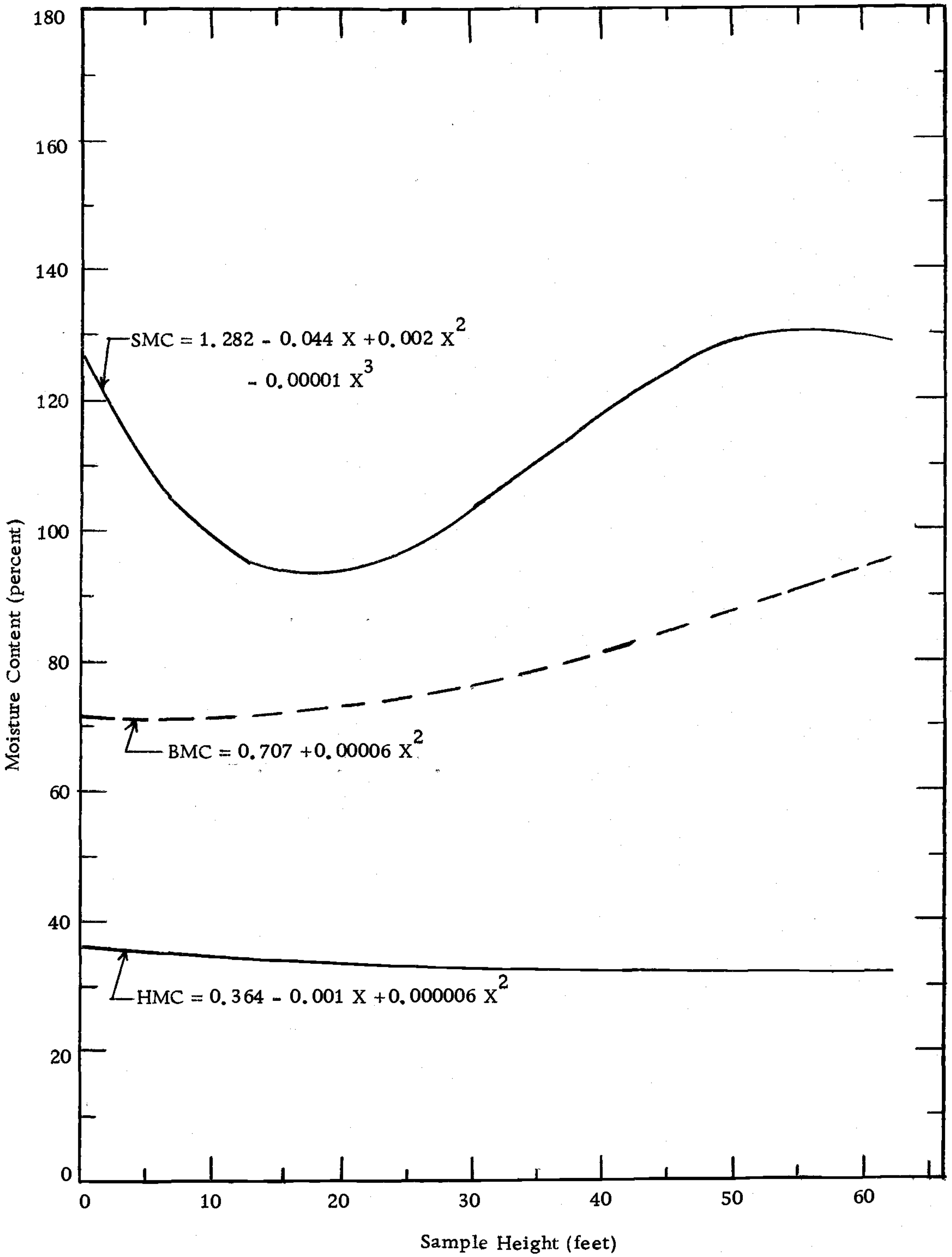


Figure 32. Moisture profiles of components of trees treated in October, 1967 with cacodylic acid and cut in September, 1968.

APPENDIX D. Computing weights from derived equations

The following general equations have been derived, as explained in the text, for each log constituent "I" (I=B, S or H for bark, sapwood and heartwood, respectively):

$$R_I = \text{Radius}_I = A_I + B_I X + C_I X^2 + D_I X^3$$

$$SG_I = \text{Specific Gravity}_I = A_I + B_I X + C_I X^2$$

$$MC_I = \text{Moisture Content}_I = A_I + B_I X + C_I X^2 + D_I X^3 + E_I X^4$$
(by treatment)

where X = sample height

Radius coefficients: $C_H = D_H = 0$

Specific gravity coefficients: $B_B = C_B = 0$;

$A_S = A_H$; $B_S = B_H$; $C_S = C_H$

Equation (5) is derived from:

$$W_{a,b} = \pi(62.4)\int_{x=a}^{b} (SG_I)\,(1 + MC_I)\,(R_I)^2 dx$$

and equation (4):

$$V_{a,b} = \pi\int_{x=a}^{b} [R_I]^2\, dx$$

so:

$$W_{a,b} = (62.4)\int_{x=a}^{b} (SG_I)(1+MC_I)\pi[R_I]^2 dx = 62.4\int_{x=a}^{b} (SG_I)(1+MC_I)\, dV_I$$

Therefore the weight of a desired constituent is:

$$W_{a,b} = 62.4 \int_{x=a}^{b} (SG_I)(1+MC_I)\, dV_I$$

$$\text{where} \quad dV_I = \begin{cases} \pi R_H^2\, dx & \text{for heartwood} \\ \pi (R_B^2 - R_H^2)\, dx & \text{for sapwood} \\ \pi (R_B^2 - R_S^2)\, dx & \text{for bark} \end{cases}$$

The computing algorithm is as follows:

define: R_B, R_S, R_H

SG_B, SG_S, SG_H

MC_B, MC_S, MC_H (by treatment)

formulae:

$$W_{a,b}(H) = \pi(62.4) \int_{x=a}^{b} (SG_H)(1+MC_H)(R_H^2)\, dx = W_{a,b}(H, R_H)$$

$$W_{a,b}(S) = \pi(62.4) \left[\int_{x=a}^{b} (SG_S)(1+MC_S)(R_S^2)\, dx - \int_{x=a}^{b} (SG_S)(1+MC_S)(R_H^2)\, dx \right]$$

$$= W_{a,b}(S, R_S) - W_{a,b}(S, R_H)$$

$$W_{a,b}(B) = \pi(62.4) \left[\int_{x=a}^{b} (SG_B)(1+MC_B)(R_B^2) dx - \int_{x=a}^{b} (SG_B)(1\ \ MC_B)(R_S^2)\, dx \right]$$

$$= W_{a,b}(B, R_B) - W_{a,b}(B, R_S)$$

where

$W_{a,b}(H, R_H)$ is composed of SG_H, MC_H, R_H

$W_{a,b}(S, R_S)$ is composed of SG_S, MC_S, R_S

$W_{a,b}(S, R_H)$ is composed of SG_S, MC_S, R_H

$W_{a,b}(B, R_B)$ is composed of SG_B, MC_B, R_B

$W_{a,b}(B, R_S)$ is composed of SG_B, MC_B, R_S

This algorithm computes the weight of the sapwood by first computing the weight of the total volume of sapwood radius and then subtracting out the weight of the heartwood volume when evaluated with sapwood moisture and specific gravity. Similarly the weight of the bark is the difference between the weight of the total volume with bark radius evaluated with bark moisture and specific gravity and the weight of the volume with sapwood radius evaluated with bark moisture and bark specific gravity.

The calculation of a particular integral, say $W_{a,b}(H, R_H)$, involves computing the product of the equations of (R_H), (R_H), (SG_H) and $(1+MC_H)$ and evaluating at the two limits of integration, "a" and "b" or

$$W = [\quad]X + [\quad]X^2 + \ldots + [\quad]X^{13} \Big|_a^b$$

Solution of this equation for one component of one treatment is a messy operation. A computer program was developed to compute the volumes and weights by treatment of the bark, sapwood and heartwood. The addition of these values gives the total weight of the tree or of the wood. In addition, the program computes these weights by integrating over any desired interval. Figure 33 illustrates the way in which the following program operates.

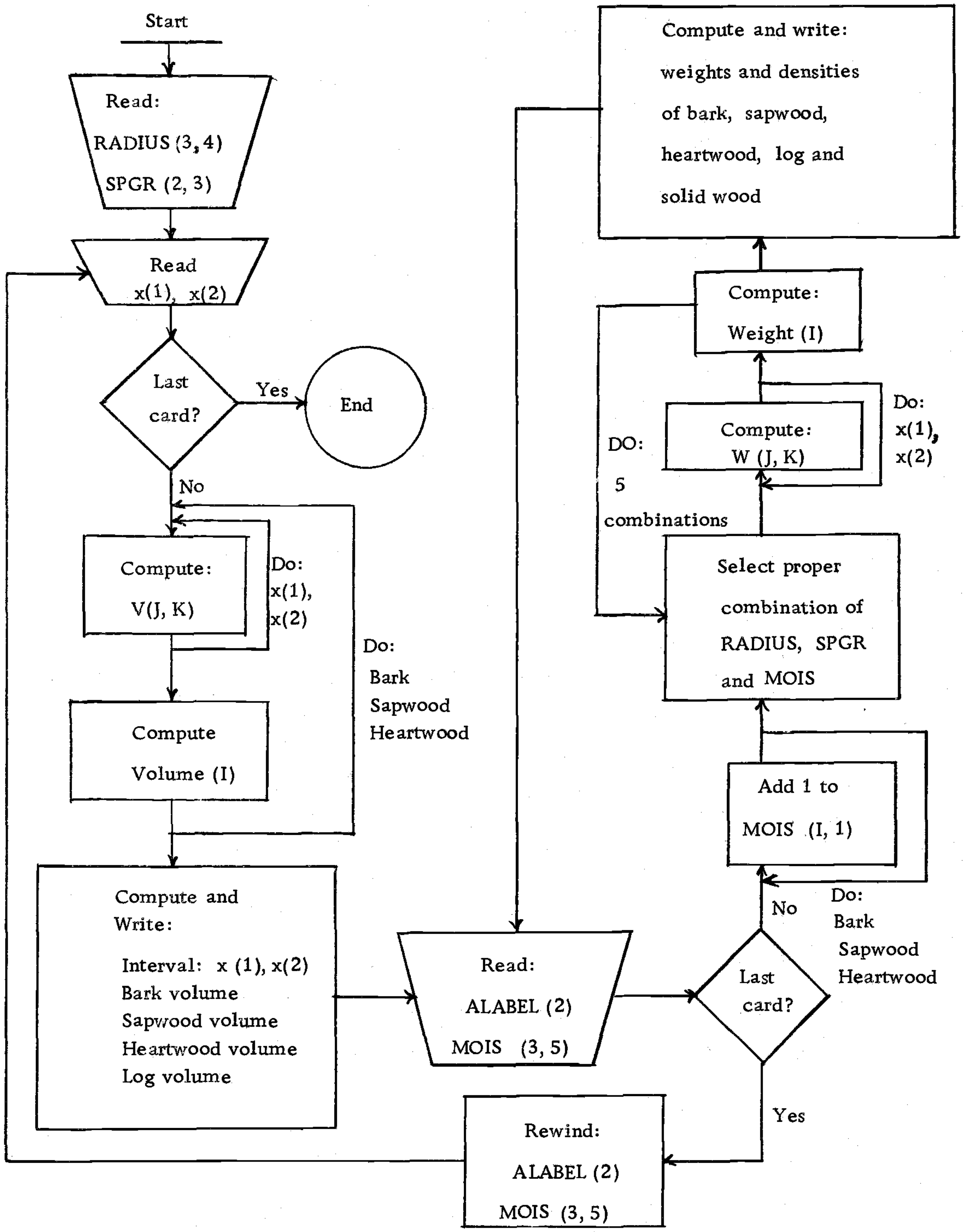


Figure 33. Flow chart of computer program for computing weights.

```
      PROGRAM WEIGHT
C     COMPUTES WEIGHTS BY INTEGRATION OF MOISTURE CONTENT, SPECIFIC
C     GRAVITY AND RADIUS OVER ANY GIVEN INTERVAL.
C     ESTABLISH DATA FILES OF RADIUS, MOISTURE, SPECIFIC GRAVITY AND
C     INTEGRATION INTERVAL--X(1),X(2).
C     INPUT -- EQUIP:  21=RADIUS(3,4); 22=SPGR(2,3); 23=MOIS(3,5): 24=X(1),X(2)
C     OUTPUT ON LUN 30
C     HARVEY A. HOLT  JULY 21, 1970
      DIMENSION RADIUS(3,4),SPGR(2,3),V(2,7),VOL(3),WGHT(5),ALABEL(2),
     1MOIS(3,5),X(2),W(2,13)
      REAL MOIS
      READ(21,2)((RADIUS(I,J),J=1,4),I=1,3)
    2 FORMAT(4E12.4)
      READ(22,4)((SPGR(I,J),J=1,3),I=1,2)
    4 FORMAT(3E12.4)
   25 READ(24,31) X(1), X(2)
   31 FORMAT(2F3.0)
      GO TO (32,33)EOFCKF(24)
   33 DO 5 I=1,3
      DO 6 J=1,2
      V(J,1)=(RADIUS(I,1)**2)*X(J)
      V(J,2)=((2.*RADIUS(I,1)*RADIUS(I,2))*X(J)**2)/2.
      V(J,3)=((2.*RADIUS(I,1)*RADIUS(I,3)+(RADIUS(I,2)**2))*X(J)**3)/3.
      V(J,4)=((2.*(RADIUS(I,1)*RADIUS(I,4)+RADIUS(I,2)*RADIUS(I,3)))
     1*X(J)**4)/4.
      V(J,5)=((2.*RADIUS(I,2)*RADIUS(I,4)+(RADIUS(I,3)**2))*X(J)**5)/5.
      V(J,6)=((2.*RADIUS(I,3)*RADIUS(I,4))*X(J)**6)/6.
      V(J,7)=((RADIUS(I,4)**2)*X(J)**7)/7.
    6 CONTINUE
      VLOW=VUP=0.
      DO 7 K=1,7
      VLOW=VLOW+V(1,K)
      VUP=VUP+V(2,K)
    7 CONTINUE
      VOL(I)=3.1416*(VUP-VLOW)
    5 CONTINUE
      VOLBRK=VOL(1)-VOL(2)
      VOLSAP=VOL(2)-VOL(3)
      VOLHRT=VOL(3)
      VOLLOG=VOLBRK+VOLSAP+VOLHRT
      WRITE(30,34) X(1),X(2)
   34 FORMAT(/////1X,11HINTERVAL:  ,F3.0,6H  TO  ,F3.0/)
      WRITE(30,8)VOLBRK
      WRITE(30,9)VOLSAP
      WRITE(30,10)VOLHRT
      WRITE(30,27)VOLLOG
   10 FORMAT(1X,18HHEARTWOOD VOLUME =,E12.4)
    9 FORMAT(1X,18HSAPWOOD   VOLUME =,E12.4)
    8 FORMAT(1X,18HBARK      VOLUME =,E12.4)
   27 FORMAT(1X,18HLOG       VOLUME =,E12.4/)
   29 READ(23,11)(ALABEL(I),I=1,2),((MOIS(I,J),J=1,5),I=1,3)
   11 FORMAT(1X,2A8,3X,5E12.4/20X,5E12.4/20X,5E12.4)
      GO TO (1,3)EOFCKF(23)
    3 DO 12 I=1,3
   12 MOIS(I,1)=MOIS(I,1)+1.
      DO 13 I=1,5
      GO TO (14,15,16,17,18)I
   14 IR=IS=IM=1
      GO TO 19
   15 IR=2
      GO TO 19
```

```
16 IS=IM=2
   GO TO 19
17 IR=3
   GO TO 19
18 IM=3
19 DO 20 J=1,2
   A=RADIUS(IR,1)**2*SPGR(IS,1)
   B=2.*RADIUS(IR,1)*RADIUS(IR,2)*SPGR(IS,1)+RADIUS(IR,1)**2*SPGR
  1(IS,2)
   C=(2.*RADIUS(IR,1)*RADIUS(IR,3)+RADIUS(IR,2)**2)*SPGR(IS,1)+
  12.*RADIUS(IR,1)*RADIUS(IR,2)*SPGR(IS,2)+RADIUS(IR,1)*SPGR(IS,3)
   D=2.*(RADIUS(IR,1)*RADIUS(IR,4)+RADIUS(IR,2)*RADIUS(IR,3))*
  1SPGR(IS,1)+(2.*RADIUS(IR,1)*RADIUS(IR,3)+RADIUS(IR,2)**2)*SPGR
  2(IS,2)+2.*RADIUS(IR,1)*RADIUS(IR,2)*SPGR(IS,3)
   E=(2.*RADIUS(IR,2)*RADIUS(IR,4)+RADIUS(IR,3)**2)*SPGR(IS,1)+
  12.*(RADIUS(IR,1)*RADIUS(IR,4)+RADIUS(IR,2)*RADIUS(IR,3))*SPGR(IS,
  22)+(2.*RADIUS(IR,1)*RADIUS(IR,3)+RADIUS(IR,2)**2)*SPGR(IS,3)
   F=2.*RADIUS(IR,3)*RADIUS(IR,4)*SPGR(IS,1)+(2.*RADIUS(IR,2)
  1*RADIUS(IR,4)+RADIUS(IR,3)**2)*SPGR(IS,2)+2.*(RADIUS(IR,1)
  2*RADIUS(IR,4)+RADIUS(IR,2)*RADIUS(IR,3))*SPGR(IS,3)
   G=RADIUS(IR,4)**2*SPGR(IS,1)+2.*RADIUS(IR,3)*RADIUS(IR,4)*
  1SPGR(IS,2)+(2.*RADIUS(IR,2)*RADIUS(IR,4)+RADIUS(IR,3)**2)
  2*SPGR(IS,3)
   H=RADIUS(IR,4)**2*SPGR(IS,2)+2.*RADIUS(IR,3)*RADIUS(IR,4)*SPGR
  1(IS,3)
   P=RADIUS(IR,4)**2*SPGR(IS,3)
   W(J,1)=A*MOIS(IM,1)*X(J)
   W(J,2)=((MOIS(IM,1)*B+A*MOIS(IM,2))/2.)*X(J)**2
   W(J,3)=((MOIS(IM,1)*C+MOIS(IM,2)*B+A*MOIS(IM,3))/3.)*X(J)**3
   W(J,4)=((MOIS(IM,1)*D+MOIS(IM,2)*C+B*MOIS(IM,3)+A*MOIS(IM,4))/4.)
  1*X(J)**4
   W(J,5)=((MOIS(IM,1)*E+MOIS(IM,2)*D+MOIS(IM,3)*C+B*MOIS(IM,4)
  1+A*MOIS(IM,5))/5.)*X(J)**5
   W(J,6)=((MOIS(IM,1)*F+MOIS(IM,2)*E+MOIS(IM,3)*D+C*MOIS(IM,4)
  1+B*MOIS(IM,5))/6.)*X(J)**6
   W(J,7)=((MOIS(IM,1)*G+MOIS(IM,2)*F+MOIS(IM,3)*E+MOIS(IM,4)*D
  1+C*MOIS(IM,5))/7.)*X(J)**7
   W(J,8)=((MOIS(IM,1)*H+MOIS(IM,2)*G+MOIS(IM,3)*F+MOIS(IM,4)*E
  1+D*MOIS(IM,5))/8.)*X(J)**8
   W(J,9)=((MOIS(IM,1)*P+MOIS(IM,2)*H+MOIS(IM,3)*G+MOIS(IM,4)*F
  1+MOIS(IM,5)*E)/9.)*X(J)**9
   W(J,10)=((MOIS(IM,2)*P+MOIS(IM,3)*H+MOIS(IM,4)*G+MOIS(IM,5)*F)
  1/10.)*X(J)**10
   W(J,11)=((MOIS(IM,3)*P+MOIS(IM,4)*H+MOIS(IM,5)*G)/11.)*X(J)**11
   W(J,12)=((MOIS(IM,4)*P+MOIS(IM,5)*H)/12.)*X(J)**12
   W(J,13)=((MOIS(IM,5)*P)/13.)*X(J)**13
20 CONTINUE
   WLOW=WUP=0.
   DO 26 K=1,13
   WLOW=WLOW+W(1,K)
   WUP=WUP+W(2,K)
26 CONTINUE
   WGHT(I)=3.1416*62.4*(WUP-WLOW)
13 CONTINUE
   WBARK=WGHT(1)-WGHT(2)
   WSAP=WGHT(3)-WGHT(4)
   WHART=WGHT(5)
   WLOG=WBARK+WSAP+WHART
   WWOOD=WSAP+WHART
   DENBRK=WBARK/VOLBRK
   DENSAP=WSAP/VOLSAP
   DENHRT=WHART/VOLHRT
   DENLOG=WLOG/VOLLOG
   DENWOOD=WWOOD/(VOLSAP+VOLHRT)
   WRITE(30,28)ALABEL,WBARK,WSAP,WHART,WLOG,WWOOD,DENBRK,DENSAP,
  1DENHRT,DENLOG,DENWOOD
28 FORMAT(1X,2A8,5E12.4/17X,5E12.4)
   GO TO 29
 1 REWIND 23
   GO TO 25
32 CALL EXIT
   END
```

APPENDIX E Weights, densities and percentages of weight reductions.

The following tables present the weights of log components for each treatment as determined from the descriptive models. Weights for the total tree and for three 20 foot logs are given. The percentages of weight reductions are also presented for the total tree and each log segment, for each component and for each treatment.

Table 6. Computed Weights and Densities by Treatment: Total Merchantable Length. ($w = \int_1^{61}$)

TREATMENT	Bark weight (lb)	Sapwood weight (lb)	Heartwood weight (lb)	Tree weight (lb)	Wood weight (lb)	Bark density (lb/ft^3)	Sapwood density (lb/ft^3)	Heartwood density (lb/ft^3)	Tree density (lb/ft^3)	Wood density (lb/ft^3)
Control - Cut 2/67	291.1	689.2	466.9	1, 1447.2	1, 156.1	53.6	57.2	41.5	50.4	49.6
Control - Cut 9/67	226.7	670.9	470.8	1, 368.4	1, 141.7	41.8	55.7	41.8	47.6	49.0
Feb - MSMA - Cut 9/67	224.2	643.4	471.2	1, 341.3	1, 117.1	41.3	53.4	41.8	46.7	47.9
March " " "	204.6	659.6	457.4	1, 324.2	1, 119.6	37.7	54.8	40.6	46.1	48.0
April " " "	227.3	535.0	475.8	1, 240.3	1, 013.0	41.9	44.4	42.2	43.2	43.5
Control - Cut 9/68	226.4	624.0	474.2	1, 324.6	1, 098.2	41.7	51.9	42.1	46.1	47.1
Feb - MSMA - Cut 9/68	197.9	522.8	479.1	1, 199.8	1, 001.9	36.4	43.4	42.5	41.7	43.0
March " " "	226.7	540.1	475.2	1, 242.0	1, 015.3	41.7	44.8	42.2	43.2	43.6
April " " "	216.5	531.0	474.1	1, 223.5	1, 007.1	39.9	44.1	42.1	42.6	43.2
June " " "	213.9	527.4	478.0	1, 221.2	1, 007.3	39.4	43.8	42.4	42.5	43.2
July " " "	211.9	536.15	469.4	1, 219.4	1, 007.5	39.0	44.5	41.7	42.4	43.2
Aug " " "	191.6	526.5	468.4	1, 188.4	996.9	35.3	43.7	41.6	41.4	42.8
Sept " " "	219.8	621.6	464.5	1, 308.1	1, 088.4	40.5	51.6	41.2	45.5	46.7
Oct. " " "	227.3	648.1	481.7	1, 359.6	1, 132.4	41.9	53.8	42.8	47.3	48.6
June - CACO - Cut 9/68	216.2	535.2	482.3	1, 235.6	1, 019.4	39.8	44.4	42.8	43.0	43.7
July " " "	230.6	546.0	471.0	1, 249.5	1, 018.9	42.5	45.3	41.8	43.5	43.7
Aug. " " "	241.7	569.2	469.7	1, 280.6	1, 039.0	44.5	47.3	41.7	44.6	44.6
Sept. " " "	240.9	664.5	477.5	1, 385.6	1, 144.7	44.4	55.2	42.4	48.2	49.1
Oct. " " "	250.2	702.1	473.1	1, 428.3	1, 178.1	46.1	58.3	42.0	49.7	50.5

Bark Volume = 5.4 cu. ft.
Sapwood Volume = 12.0 cu. ft.
Heartwood Volume = 11.2 cu. ft.
28.6

Table 7. Computed Weights and Densities by Treatment: Butt Log. $\left(w = \int_1^{21} \right)$

TREATMENT	Bark weight (lb)	Sapwood weight (lb)	Heartwood weight (lb)	Log weight (lb)	Wood weight (lb)	Bark density (lb/ft^3)	Sapwood density (lb/ft^3)	Heartwood density (lb/ft^3)	Log density (lb/ft^3)	Wood density (lb/ft^3)
Control - Cut 2/67	164.0	300.7	234.3	699.1	535.1	50.4	56.1	38.8	47.7	47.0
Control - Cut 9/67	130.2	299.8	235.7	665.7	535.6	40.0	56.0	39.1	45.5	47.0
Feb.-MSMA "	133.0	306.8	234.0	673.8	540.8	40.9	57.3	38.8	46.0	47.5
March " "	122.2	303.6	223.1	649.0	526.8	37.6	56.7	37.0	44.3	46.3
April " "	137.4	246.6	235.8	619.9	482.4	42.2	46.1	39.1	42.3	42.3
Control - Cut 9/68	129.2	282.7	232.2	645.1	515.9	39.7	52.8	38.7	44.1	45.3
Feb. - MSMA - Cut 9/68	118.3	258.1	238.2	614.6	496.4	36.4	48.2	39.5	42.0	43.6
March " "	137.7	259.5	237.2	634.4	496.7	42.3	48.4	39.3	43.3	43.6
April " "	133.0	262.4	237.1	632.4	499.4	40.9	49.0	39.3	43.2	43.9
June " "	131.7	259.3	239.7	630.7	499.0	40.5	48.4	39.7	43.1	43.8
July " "	131.5	256.7	232.5	620.7	489.2	40.4	47.9	38.6	42.4	43.0
Aug. " "	110.0	255.8	232.9	598.7	488.7	33.8	47.8	38.6	40.9	42.9
Sept. " "	128.6	305.1	233.2	666.9	538.3	39.5	57.0	38.7	45.6	47.3
Oct. " "	134.0	303.2	241.7	678.9	544.8	41.2	56.6	40.1	46.4	47.8
June-CACO - Cut 9/68	131.0	264.1	239.6	634.7	503.7	40.3	49.3	39.7	43.4	44.2
July " "	139.9	276.9	235.2	652.0	512.1	43.0	51.7	39.0	44.5	45.0
Aug " "	144.8	277.6	234.8	657.2	512.4	44.5	51.8	38.9	44.9	45.0
Sept. " "	143.8	301.5	238.3	683.6	539.8	44.2	56.3	39.5	46.7	47.4
Oct. " "	147.0	314.0	235.5	696.4	549.5	45.2	58.6	39.0	47.6	48.3

Bark Volume = 3.3 cu. ft.
Sapwood Volume = 5.4 cu. ft.
Heartwood Volume = 6.0 cu. ft.
14.7

Table 8. Computed Weight and Densities by Treatment: Middle Log $(w = \int_{21}^{41})$

TREATMENT	Bark weight (lb)	Sapwood weight (lb)	Heartwood weight (lb)	Log weight (lb)	Wood weight (lb)	Bark density (lb/ft^3)	Sapwood density (lb/ft^3)	Heartwood density (lb/ft^3)	Log density (lb/ft^3)	Wood density (lb/ft^3)
Control - Cut 2/67	77.4	210.1	139.0	426.5	349.2	54.6	56.5	39.4	49.2	48.2
Control - Cut 9/67	60.6	203.8	140.9	405.4	344.7	42.8	54.8	40.0	46.8	47.6
Feb. - MSMA "	57.8	191.1	141.3	390.8	333.0	40.8	51.4	40.0	45.1	45.9
March " "	51.8	199.9	137.1	389.4	337.6	36.6	53.8	38.8	44.9	46.6
April " "	57.8	160.3	143.3	362.0	304.1	40.8	43.1	40.6	41.8	42.0
Control - Cut 9/68	60.4	189.5	142.0	392.0	331.6	42.6	51.0	40.2	45.2	45.7
Feb - MSMA - Cut 9/68	51.7	154.9	143.7	350.8	299.2	36.5	41.7	40.7	40.5	41.3
March " " "	58.2	160.7	142.2	361.6	303.4	41.1	43.2	40.3	41.7	41.9
April " " "	54.7	156.7	141.4	353.4	298.7	38.6	42.2	40.0	40.8	41.2
June " " "	53.9	156.5	142.6	353.6	299.7	38.1	42.1	40.4	40.8	41.3
July " " "	52.4	161.5	140.5	355.0	302.6	37.0	43.4	40.0	41.0	41.7
Aug " " "	52.2	155.4	140.3	348.4	296.2	36.8	41.8	39.7	40.2	40.9
Sept " " "	56.8	181.0	137.6	376.0	319.2	40.1	48.7	38.9	43.4	44.0
Oct " " "	59.5	195.0	143.8	399.0	339.5	42.0	52.4	40.7	46.0	46.8
June - CACO - Cut 9/68	55.7	156.5	144.5	357.3	301.5	39.3	42.1	40.9	41.2	41.6
July - " " "	60.1	161.5	141.2	363.3	303.2	42.4	43.4	40.0	41.9	41.8
Aug " " "	63.8	164.2	139.3	367.9	304.0	45.1	44.2	39.4	42.4	41.9
Sept " " "	63.0	198.4	143.0	405.0	342.1	44.4	53.4	40.5	46.7	47.2
Oct " " "	65.9	207.6	141.7	416.0	350.1	46.5	55.8	40.1	48.0	482.9

Bark Volume = 1.4 cu. ft.
Sapwood Volume = 3.7 cu. ft.
Heartwood Volume = 3.5 cu. ft.
8.9

Table 9. Computed Weight and Densities by Treatment: Top Log (w = $\int_{41}^{61}$)

TREATMENT	Bark weight (lb)	Sapwood weight (lb)	Heartwood weight (lb)	Log weight (lb)	Wood weight (lb)	Bark density (lb/ft^3)	Sapwood density (lb/ft^3)	Heartwood density (lb/ft^3)	Log density (lb/ft^3)	Wood density (lb/ft^3)
Control - Cut 2/67	49.7	178.4	93.5	321.6	271.9	65.5	60.1	55.0	59.2	58.2
Control - Cut 9/67	35.9	167.2	94.2	297.3	261.4	47.3	56.3	55.4	54.8	56.0
Feb. - MSMA - Cut 9/67	33.5	145.5	93.9	274.5	241.1	44.0	49.0	55.2	50.6	51.6
March " " "	30.6	156.0	95.3	283.7	253.1	40.3	52.5	56.0	52.2	54.2
April " " "	32.1	128.1	94.6	256.2	224.2	42.2	43.1	55.6	47.2	48.0
Control - Cut 9/68	36.8	150.0	98.9	287.5	250.7	48.5	50.5	58.2	52.9	53.7
Feb. MSMA - Cut 9/68	28.0	107.9	95.0	232.1	204.2	36.8	36.3	55.9	42.7	43.7
March " " "	30.8	117.9	93.7	243.7	213.0	40.5	39.7	55.1	44.9	45.6
April " " "	28.8	111.9	93.6	235.5	206.8	37.9	37.7	55.0	43.4	44.3
June " " "	28.3	111.6	93.5	234.7	206.4	37.0	37.6	55.0	43.2	44.2
July " " "	28.0	117.9	94.4	241.6	213.6	36.9	39.7	55.5	44.5	45.7
Aug " " "	29.3	115.4	93.1	239.1	209.8	38.6	38.9	54.7	44.0	44.9
Sept " " "	34.3	135.5	91.7	263.0	228.8	85.1	45.6	53.9	48.4	49.0
Oct. " " "	33.7	150.0	94.1	279.4	245.8	44.3	50.5	55.3	51.5	52.6
June - CACO Cut 9/68	29.5	114.5	96.1	241.4	211.9	38.8	38.6	56.5	44.4	45.4
July " " "	30.6	107.6	92.6	232.0	201.4	40.3	36.2	54.4	42.7	43.1
Aug " " "	33.0	125.4	93.6	253.4	220.4	43.4	42.2	55.0	46.7	47.2
Sept. " " "	34.2	164.6	94.1	294.7	260.6	44.9	55.4	55.3	54.3	55.8
Oct " " "	37.4	180.4	93.8	313.7	276.3	49.2	60.8	55.1	57.8	59.2

Bark Volume = 0.8 cu. ft.
Sapwood Volume = 3.0 cu. ft.
Heartwood Volume = 1.7 cu. ft.
5.5

Table 10. Percent Weight Reduction Based on Computed Weights by Treatment[1]

TREATMENT	BARK Whole tree	BARK Butt log	BARK Mid. log	BARK Top log	SAPWOOD Whole tree	SAPWOOD Butt log	SAPWOOD Mid. log	SAPWOOD Top log	HEARTWOOD Whole tree	HEARTWOOD Butt log	HEARTWOOD Mid. log	HEARTWOOD Top log	TREE Whole tree	TREE Butt log	TREE Mid. log	TREE Top log	SOLID WOOD Whole tree	SOLID WOOD Butt log	SOLID WOOD Mid. log	SOLID WOOD Top log
Control - Cut 9/67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Feb.-MSMA - Cut 9/67	1	-2	5	7	4	-2	6	12	--	--	--	--	2	-2	4	9	2	-1	4	9
March " " "	10	6	15	15	1	-1	2	6	3	5	3	-1	3	2	4	5	2	1	2	4
April " " "	--	-6	5	11	20	18	21	22	-1	-1	2	--	10	7	11	16	12	10	12	16
Control - Cut 9/68	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Feb.- MSMA - Cut 9/68	13	8	14	24	16	9	18	28	-2	-3	-1	4	(15)[2] 10	4	11	21	9	3	10	21
March " " "	--	-7	4	16	13	8	15	21	-1	-3	--	5	(14) 6	1	8	17	8	3	9	17
April " " "	4	-3	9	22	15	7	17	25	-1	-3	--	5	(11) 8	2	10	20	8	3	10	20
June " " "	6	-2	11	23	15	8	17	26	-1	-4	-1	5	8	2	10	20	8	3	10	20
July " " "	6	-2	13	24	14	9	15	21	1	-1	1	4	[12] 8	3	10	18	8	5	9	16
Aug. " " "	15	15	14	20	15	9	18	23	1	-1	1	6	10	7	11	18	9	5	11	18
Sept. " " "	3	5	6	7	--	-8	4	10	2	-1	3	7	1	-4	4	9	1	-5	4	9
Oct. " " "	--	-4	2	8	-4	-7	-3	--	-2	-5	-1	5	-3	-6	-2	2	-3	-6	-2	1
June - CACO - Cut 9/68	5	-1	8	20	14	7	17	24	-2	-4	-2	3	7	1	9	18	7	2	9	18
July " " "	-2	-8	--	17	12	2	15	28	--	-2	--	6	6	-1	8	21	7	--	9	22
Aug. " " "	-7	-12	-6	10	9	2	13	16	--	-2	2	5	3	-2	6	13	5	--	9	13
Sept. " " "	-6	-11	-4	7	-7	-7	-5	-10	-1	-3	-1	5	-5	-6	-3	-4	-5	-5	-3	-6
Oct. " " "	-11	-14	-9	-2	-13	-11	-10	-20	--	-2	--	5	-8	-8	-6	-11	-8	-7	-6	-13

[1] $\text{Percent weight reduction} = \left[\frac{(\text{Control weight}) - (\text{Treatment weight})}{(\text{Control weight})}\right] \times 100$

[2] Figures in bracket indicate percent weight reduction with allowance for bark loss