A STUDY OF THE DISTRIBUTION OF MOISTURE IN DOUGLAS FIR

by

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Introduction

The explanation of how water made its way to the top of the tall forest trees has long been a matter of interest both to scientist and the ordinary man that worked in the woods. When plant physiologists found out the large amounts of water that were given off by forest trees during the process of transpiration it was soon realized that the flow of water in the tree trunk must be quite rapid. The woods worker speaks of the sap being up when a tree will peel readily but whether there is more water in a tree at this time or not has not been known. Only in recent years have studies along this line been made.

Tied very closely to the problem of sap rise is the one of the distribution of the moisture in the tree. The object of this study has been to determine the distribution of this moisture vertically and horizontally in the tree trunk and also to see if there is any variation in this distribution with seasonal changes. It was considered that the type of weather experienced during the periods previous to taking of measurements might be of great importance; so a record of weather for a week previous was also kept.

Such a study is of interest to anybody interested in kiln drying as well as to the botanist. This is becoming of more importance now than in previous years due to the use of smaller trees with a greater proportion of sap wood.

This tendency is apt to increase in years to come and a knowledge of the moisture content of sap wood will be desirable on which to base drying schedules.

Douglas fir was selected for this study principally because it is the most important tree in the area making it comparatively easy to obtain samples. A secondary reason was that in most trees of this species the sap wood and heart wood are very distinct and this made sectionizing much easier.

Transpiration in Trees

The studies made by foresters and plant physiologists have shown that a large amount of water is consumed by a forest tree. The amount of leaf surface on a large tree is surprising and though moisture in any amount is only lost through the stomata these have been found to be ten times as effective as an equal area of free water surface. Toumey (12) reports one study where an acre of beech forest gave off 2140 tons of water in a year. This was 25% of the total amount of precipitation on this area for the entire year.

Many different theories have been advanced to explain the rise of the transpirational stream and a few of these will be discussed:

I The Vital Theory

Those that advance this theory believe that the rise of sap in the tree is due to the action of the living cells in the wood itself. They believe that these cells act as small pumps absorbing water from one vessel or tracheid and expelling it into another. A number of different men have made studies which have shown that the vital theory is not tenable. Dixon (2) brings up the experiments of Strasburger as proof of failure of the vital theory as an explanation. In these experiments the stems of trees were killed by heating or by poisons but the trees were still able to draw up water for some time. The vitalists came back with the statement that the leaves always died after a few days on such trees. Dixon explains this death as being due to the release of substances from the killed cells which act as poisons to the living cells which they plasmolize and also stop the transpiration stream by plugging the vessels. By using special methods in which he washed out these substances from the killed portion of a branch he was able to keep the leaves alive most indefinitely. Trees have been shown to be able to pull up some water even after all cells even in the leaves are dead. This has been proved by allowing them to pull up a strong poison like picric acid to the top of the tree and then setting them in a colored solution. This second solution was also pulled up into the crown.

Other studies have shown that it would be physically impossible for the cells that are in wood to pump the water fast enough. From careful measurements made on the proportion of living cells it has been found that when transpiration is at its maximum it would be necessary for this pumping to be eight to thirty thousand times as fast as would be possible under Bose's theory of protoplasmic streaming.

II Physical Theories

1. Imbibition

This theory attempts to account for the passage of water by imbibition or the affinity that a substance such as wood fiber has for water. Though a dry substance may have a great affinity for water, in some cases several hundred atmospheres, experiments have shown that this could only account for a fraction of the water that rises in the average tree for its passage would be confined to the cell walls only. Dixon (2) tested out the efficiency of the cell walls alone by plugging the cell cavities with paraffin. He found that though a little water was still able to rise it was not enough to prevent flagging of the leaves.

2. Osmosis

Osmosis as a means of raising the sap falls down due to the fact that the cells in the tree that carry the transpirational stream are not living cells and do not have a permeable membrane.

3. Cohesion

This theory was first brought out by Dixon and Joly (2).Extensive experiments have all tended to show that it is the correct theory until it has been generally accepted by plant physiologists. The basis of this theory is that tensions applied to the tops of columns of water in the leaves is transmitted through these columns to the roots.

The columns in the conducting elements are continuous through the perforations in the cell walls.

Dixon (2) made a number of studies to determine if water and cell sap had a cohesive force great enough to account for the rise in tall trees. He found it to be far more than any needed. Other experimenters have only verified his conclusions that this cohesive force may be as high as 200 to 300 atmospheres. By forcing water through stems by pressure he found that the resistance to a current of water moving through stems at the velocity of the transpiration stream is approximately equivalent to a head of water equal in length to the wood traversed. Doubling this to allow for the lift against gravity gives the total force necessary. For a 100 meter tree this is about 20 atmospheres which would not tax the cohesive force of water. What a tremendous force the cohesive force of water can exert is shown by the collapse of cells in kiln drying of cedar and some other woods.

Under ordinary conditions of transpiration evaporation from the exposed walls of cells adjoining intercellular spaces in the leaf is the primary source of these tensions. Evaporation can exert a force of several hundred atmospheres. The dried cell walls then pull water from the cell cavities by imbibition, and these in turn take in water by osmosis from the conducting tissue. Busgen and Munch (1) found osmotic pressures of as high as 40 atmospheres in leaves; and these high figures were in agreement with those of Dixon (2) while McDougal (10) states that the tensions set up in transpiring trees may reach 100 to 200 atmospheres. Tests made by Dixon showed that cell walls of cellulose can withstand osmotic pressures of 100 atm. It is probable that under ordinary conditions soil water passes into the root by osmosis though some experimenters seem to think that under conditions of excessive transpiration it may be actually pulled in by the cohesive force.

Under conditions of a saturated atmosphere we are no longer able to give evaporation as the primary cause of rise of the transpiration stream. We do know that it does rise and many leaves give off waters of guttation under these conditions. The cells of the leaf are thus seen to be able to force out some water. Dixon states, "The stored energy set free by respiration in the leaves is quite sufficient to do the work of secretion against the resistance of the transpirational stream."

The physical nature of cells in wood is very favorable to the cohesion theory. The pitted walls make a continuous column of water possible. The small size of the individual cells and the fact that the walls are thoroughly wet also favors the maintenance of cohesion. It seems very possible that the cell walls have been especially adapted to resist the pressures set up by the high tensions on the water column Busgen and Munch (1) remark:

> The great stiffening of the conducting channels of the vessels by the annular, spiral, reticulate, and scalariform thickening or general thickening with the exception of the bordered pits is necessary to sustain the great tensions to which the vessels of transpiring plants are exposed.

Any vessel that contains a bubble of gas will become entirely filled but this air will be unable to spread to other cells due to the saturated cell walls. These are kept in that condition by imbibition and capillarity. The small size of the element is here again an advantage for one out of the current does not cause much reduction in carrying ability.

4. Root Pressure

Root pressures have been suggested as a cause of the rise of sap but studies made along this line would seem to show that any pressures developed are entirely inadequate especially in the case of tall trees. McDougal (10) found pressures of from 2 to 4 atmospheres in Monterey pine at some periods but at others the pressures were negative. The loss from the cut stem of a grape is probably due to root pressures set up by the action of the root cells. Jones, Edson, and Morse (8) found that the pressures in sugar maple, a tree that is noted for the flow of sap, was not over 1.5 atmospheres. Sometimes during the period of flow the pressure was found to be negative. They consider that the flow of sap is due to the activity of the living cells in the wood. The flow ceases as soon as the leaves come out and transpiration becomes active.

If a tree developed adequate root pressure to force water up to a height of 300 feet you would look for water to squirt out of the stump when it is cut. This is not the case and Busgen and Munch (1) record examples of stumps of trees that were cut during periods of rapid transpiration that actually sucked in water placed on them. McDougal found that the pressures of the Hydrostatic system of trees varied from tensions or minus pressures of possibly as much as 100 atmospheres to positive pressures of 2 to 4 atmospheres.

Special Research on the Variation of Moisture Content in Trees

I Variations in the Area Occupied by the Hydrostatic and Pneumatic Systems in Trees

The Pneumatic system refers to the area occupied by gases in the interior of the tree. The gases here are of course not of the same composition as in the air. Carbon dioxide is a much more important component due to the fact that it is given off during the process of respiration. McDougal found that pressures in this system varied from $-\frac{1}{2}$ to $^{+}1$ or 2 atmospheres but that whenever pressure differences of more than one half an atmosphere existed between this system and the atmosphere gasses passed in or out through the bark to equalize these differences.

The part of the stem which is occupied by each system has been studied by observing the path of sap rising in stem. This is done by introducing colored solutions, such as eosin, into the stem and then after a period cutting the stem off farther up and noting what portions are stained. The portions in which movement is most rapid will of course be stained much farther up the tree.

McDougal (10) found that in conifers the most rapid movement was in the first four annual rings, while in those rings in the inner sapwood it was very slow. Dicotyledons showed a much more nearly equal rate of movement at least for periods up to 11 years. He states:

> Irregularly arranged tracts of tracheids in the pine and definite vertical zones of vessels within each untylosed annual layer of the willow, the walnut, and the alder are occupied by gasses during the summer months. The relative volumes of hydrostatic and pneumatic systems within the tree are subject to variations during the course of the season. Specific conducting elements may at one time be wholly filled with gas and at another entirely filled with water.

He found a marked seasonal variation in the width of the water conducting portion of each annual layer. In winter, frequently, almost the entire layer was filled with water. For any one species, the part of the ring occupied in the summer by the water conducting tissues was constant but the location varied as between different species such as alder and willow. For hardwoods he found that most movement from one annual ring to another took place at the point where the outer ring ensheaths and caps the inner one and that there was almost no radial movement and only a very moderate transverse movement of sap during the summer months.

Busgen (1) explains the more rapid transfer of water in the outer rings by the fact that these rings are more closely in connection with the new wood of rootlets and that other rings must acquire water through greater transverse movement. He states that, "The presence of spaces in the wood almost empty of water can not be avoided during great summer evaporation."

The refilling of emptied cell cavities by water is probably due to the action of living cells in the wood dur ing periods of low transpirational loss. One possible source is the water that is used as a solvent in carrying food to the cambium layer and then must be forced out of the cambium cells in order to maintain the desired osmotic pressures.

Busgen (1) believes that the inner sapwood forms a kind of water reservoir which is drawn upon only in case of necessity. He also notes that within the sphere of root pressure the filling up of water storing organs is done by the exudation sap and to a small extent by capillary action. McDougal recorded downward movement of colored sap from bore holes in the trunks of Walnut and Oak. He decided that these downward movements were due to capillarity.

II Dendrographic Measurements

That there are changes in the hydrostatic systems of trees has been confirmed by the measurements taken with the McDougal dendrograph. This instrument essentially consists of a tape of invar steel or some other metal with a low coefficient of expansion, that encircles the trunk of the tree. This tape is connected to one fixed and one movable rod. The movable rod through a system of levers actuates a recording pen and thus records any changes in the diameter of the tree that takes place.

The greatest changes usually recorded are of course those that take place during the season of rapid growth but there are both diurnal and seasonal variations that cannot be explained by growth action. Diurnal variations show up on the dendrographic record as a wavy line, the diameter being greatest at night or early morning and least during the late afternoon. During the period when growth is taking place it is a wavy rising line but at other times it may keep about level or even gradually drop. During periods when the daytime humidity is high due to rain or fog the line becomes almost flat thus showing that the action of transpiration is the cause of the waviness. Haasis (3) made special studies in which he measured the shrinking and swelling of both the entire tree and of an inner cylinder of half the diameter of the tree. He found that diurnal fluctuations took place here as well as in the entire stem. He also noted that the program of diurnal shrinking and swelling is much the same in the several parts of the tree, usually reaching its maximum about the end of the period of darkness. There is however, considerable variation as to time from day to day.

There are two factors that seem to explain these daily fluctuations. The most important of these is probably the transpiration pull which sets up such a tension that the walls of the individual cells are pulled in a little. At night with little pull, they are able to swell out again. The second cause may be in actual dehydration of the cell walls to the point where shrinkage sets in but this is probably not important in diurnal variations.

Haasis (4) made careful studies of seasonal shrinkage inMonterey pines and redwood trees. He found that:

> A detailed examination of the dendrographic records shows that an appreciable amount of shrinkage occurs during the autumn prior to the fall or winter

swelling which has been noted. ----- The date of the starting of this shrinkage varied with location. A tree located in a swampy spot did not begin to contract for nearly a month later than those located on a sand hill nearby. Exposure also varied the time of starting of the shrinkage.

Evidently we are dealing with a drying out and a subsequent rehydration of the tree tissue. Directly after the beginning of the dry season there will still be a certain amount of soil water available to the trees. Gradually, however, this supply becomes exhausted. With the advent of rain, soil moisture again becomes available and the trees are able to make up losses suffered during the dry season. It seems liable that the first diametral increases occuring after a dry period are not to be ascribed to the consequences of actual cell division, but simply to the swelling of the partially dried trees.

It seems very probable that growth may frequently mask shrinkage in trees so that it does not show up on the record as soon as it starts. That a tree may be shrinking in one part while growing in another was brought out in the study made by Haasis mentioned before in connection with daily fluctuations. He found that over a period of time the whole tree increased 1.8 mm., but during the same period the inner cylinder decreased .2 mm.

In one study made of a dwarfed redwood that was growing in a very exposed location Haasis (5) found a steady decrease in diameter, at the point at which measurements were taken over a period of five years. During this period this tree grew a little each year at the tips of the branches.

The factors which control shrinkage and swelling in trees are the rate of evaporation and the available soil moisture. The power of evaporation of the air depends on the humidity, temperature, and wind movement. The amount of soil moisture available was considered by Haasis as being most significant from the standpoint of seasonal fluctuations.

III Actual Measurements of Moisture Content

That there is variation in the amount of water present in trees has been considered probably by foresters for some time. Record (11), in his textbook on the properties of wood, remarks:

> So far as the sap is concerned there is fully as much if not more during the winter than during the summer. Winter cut wood is not drier to begin with than summer felled--in fact it is likely to be wetter.

Hartig made the first studies of variation in moisture content. He found that the whole tree increased during the fall until about December but after that it decreased somewhat. Such a decrease could be explained in a cold climate like that of Germany by continued slow transpirational losses during the period when the roots were unable to take any water from the frozen soil. This would check with measurements made on sugar maple (8), which increased from 36.5% M.C. to 47% M.C. between March 1 and April 28. This increase can be well explained by increased root action with little chance for water loss until the buds unfolded.

Glezonov (1) taking the entire tree found that pine trees contained 59.5 of water in summer, 62.2% to 63.3% in spring and autumn, and 64.5% in winter.

Welch made a study of the moisture content of Eucalyptus over a period of two years with the following results.

Season	Sapwood % of M. C.	Heartwood % of M. C.
January--February	87.2	95.3
March--April	88.6	93.7
June--July	94.8	85.1
September--October	92.4	105.5

This study showed a peculiar condition for the heartwood was consistently wetter than the sapwood except for one month during a period of heavy rainfall. It may be noted that the moisture content of the sapwood is lower during the summer months than during the winter months. The measurements were taken in Australia and the sections used were from small trees of about 6 inches. A section from near the stump was used.

All the above measurements were either for entire trees or for sections taken at certain levels and do not give us much of a picture of the distribution of the moisture. Some studies have been made on redwood and shortleaf pine showing the distribution of moisture but even these do not consider seasonal variations in this distribution. Luxford (9) made a study of the distribution in virgin redwood. His measurements were taken during the months of August, September, and October, which would be before the coming of the winter rains in the Redwood Region. The distribution he found is shown by the graph given below.

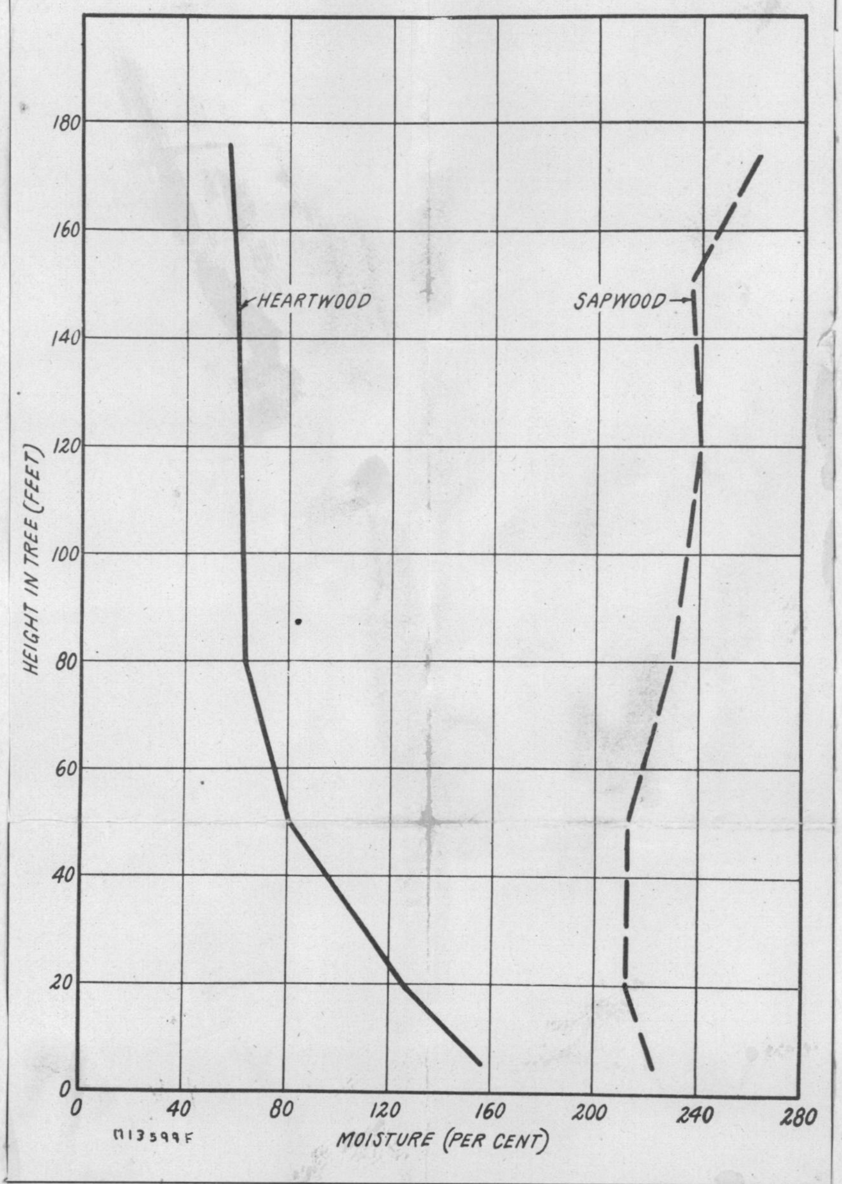


Figure 2—Average distribution of moisture content of heartwood and sapwood in redwood trees relative to height

Points of interest in this graph is the drop in the heartwood from about 160% at the ground to about 60% at 80 feet with little drop from that point on up; and the general upward trend in the sapwood. It is possible that the difference in the sapwood may possibly be correlated with density for there is a difference of 15% in the density of the butt and top of a large redwood. The variations in moisture content across the heartwood was found to be much greater in the sections taken near the ground than in those farther up the tree.

Huckenpahler (6) has recently made a study on the moisture content of shortleaf pine. This study was made on comparatively small trees of about $5\frac{1}{2}$ inches in diameter and 30 feet in height. The results are shown in the following graph:

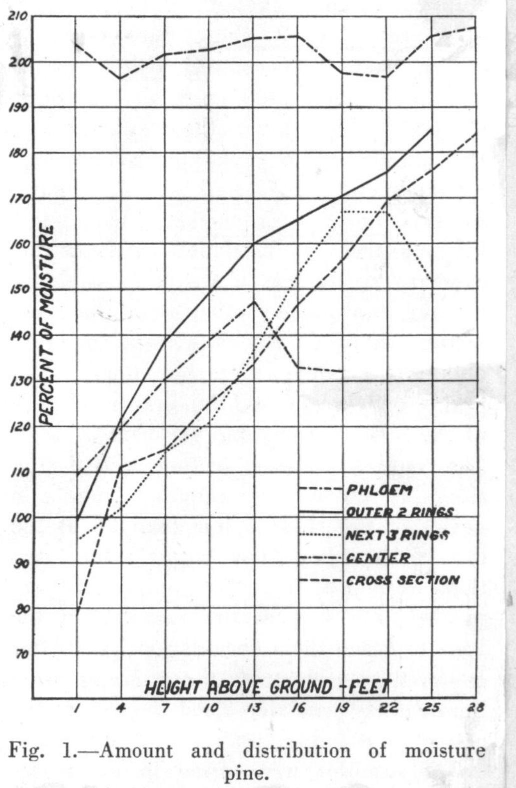


Fig. 1.—Amount and distribution of moisture pine.

Like Luxford's work on redwood, this study shows an increasing moisture content as you go up the tree. The general tendency is for increasing moisture from the center out though at the ground the center is wettest. These trees are too small to show any heartwood and not tall enough to show if there is any point where the moisture content reaches a maximum.

In an earlier investigation on the same species the same author (7) found a variation for the whole sap from 78% at the stump to about 180% in the top of the tree. He also states that his preliminary investigations indicate that the moisture content of this tree is higher in the spring and summer than in the fall and winter.

Methods Used in the Present Study

In selecting trees for this study an effort was made to pick trees with well developed crowns of the dominant or co-dominant class. Most of the trees were between 80 and 100 feet in height though one much larger tree was included. The selected tree was fallen and a wafer taken off the butt. Other wafers were taken every 16 feet up the tree. These wafers averaged about 1½ inches in thickness. If there was to be any delay in sectionizing or the weather was dry the wafers were wrapped in oiled paper.

As soon as the wafers were all cut out of a tree they were brought into the laboratory and sectionized. The method of sectionizing used was to cut along each radii a strip about 1½ inches wide. The samples taken from each radii consisted of the outer half of the sap, the inner half of the sap, a heartwood sample next to the sap, a sample from the center of the heart, and for larger wafers a sample half way across the heart. In numbering along radii, outer sap was number 1 sample. Usually there was only one center heart sample taken and for some trees it was not possible to take samples right at the heart due to presence of pitch. A few samples had to be discarded on this account. As sections farther up the tree were taken it was of course not possible to get all these samples. The side of the tree, cardinal direction, from which the sample was obtained was recorded as it was desired to see if there was any correlation of this with moisture content. As soon as sectionized the samples were immediately weighed and put in the electric oven to dry. Wafers not in the process of being sectionized were kept wrapped up to prevent water loss. The samples were dried in an electric oven at a temperature of from 95 to 110 degrees until they no longer showed any loss. This usually took about three days. An attempt to keep all samples between 20 and 60 grams was made but this was not always adhered to due to variations in width of sap and the fact that the wafers were not the same thickness throughout.

In arriving at the final percentages an average was taken of all samples taken from like positions in the same wafer; for example, the four outer sapwood samples would be averaged together. These moisture contents were then graphed up for each tree. For four trees the distribution for outer sapwood was worked out on graphs for the cardinal directions but as there was apparently no correlation this practice was not continued. No attempt was made to graph the distribution across each wafer in this study.

Records kept for each tree showed, date cut, weather for day and previous week, site, exposure, location, height, age, and diameter at the stump. For a permanent record being kept by the school, the diameter nearest an eight inch top and that of the wafer half way between this and the stump was kept. In arriving at the age, 3 years was added to ring count to allow for time to reach stump height.

Record of Measurements

For each tree taken the following data will be given:

1. A table showing the average moisture contents by location in the tree.

2. A graphical representation of the data recorded in this table.

3. The general information recorded for this tree.

In addition to this data for each tree, a table for one of the trees showing the method used in recording the measurements will be given; and the graph based on cardinal directions for one tree will be given in order to illustrate the conclusions reached.

Tree No. 1

Date--December 14, 1936

Age--34 years

Location--T.11S. R.6 W.

Sec. 28 NW ½

Height--85 feet

D.I.B.--16 inches

Aspect--Northeast

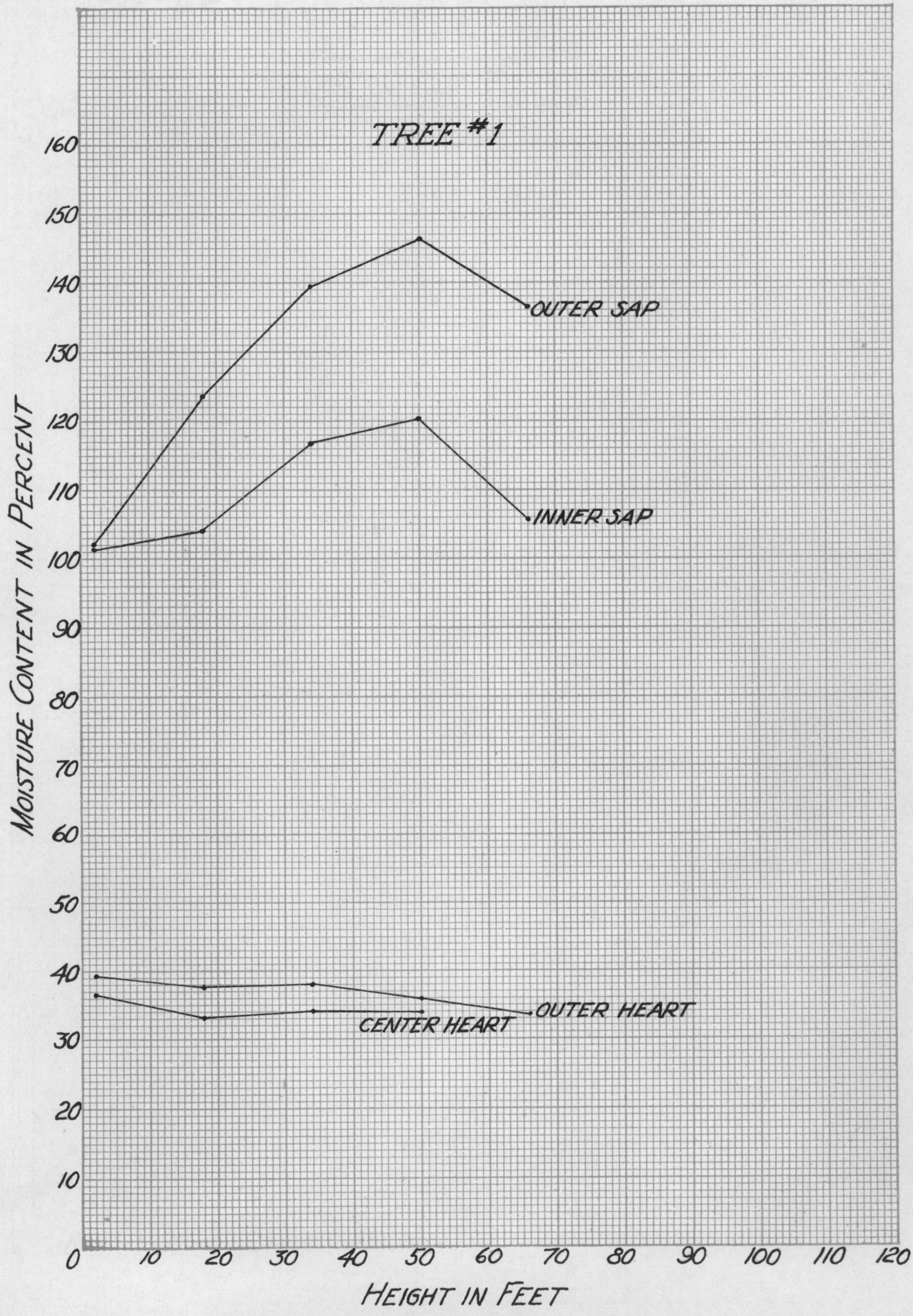
Weather for day--clear with valley fog and frost

Elevation--450 feet

Site--III

Weather for week--generally fair except for a few light showers.

Height Feet	Outer Sap	Inner Sap	Outer Heart	Center Heart
2	102.0	101.2	39.4	36.4
18	123.8	104.0	37.9	33.1
34	139.7	116.9	38.1	34.1
50	146.4	120.2	36.0	34.0
66	136.4	105.7	33.6	


TREE #1
OUTER SAP
INNER SAP
OUTER HEART
CENTER HEART
MOISTURE CONTENT IN PERCENT
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90 100 110 120
HEIGHT IN FEET

<u>Tree No. 2</u>

Age--48 years

Height--99 feet

D.I.B.--20.6 inches

Weather for day--Cloudy

Weather for week--Occasional rains.

Date--December 26, 1935

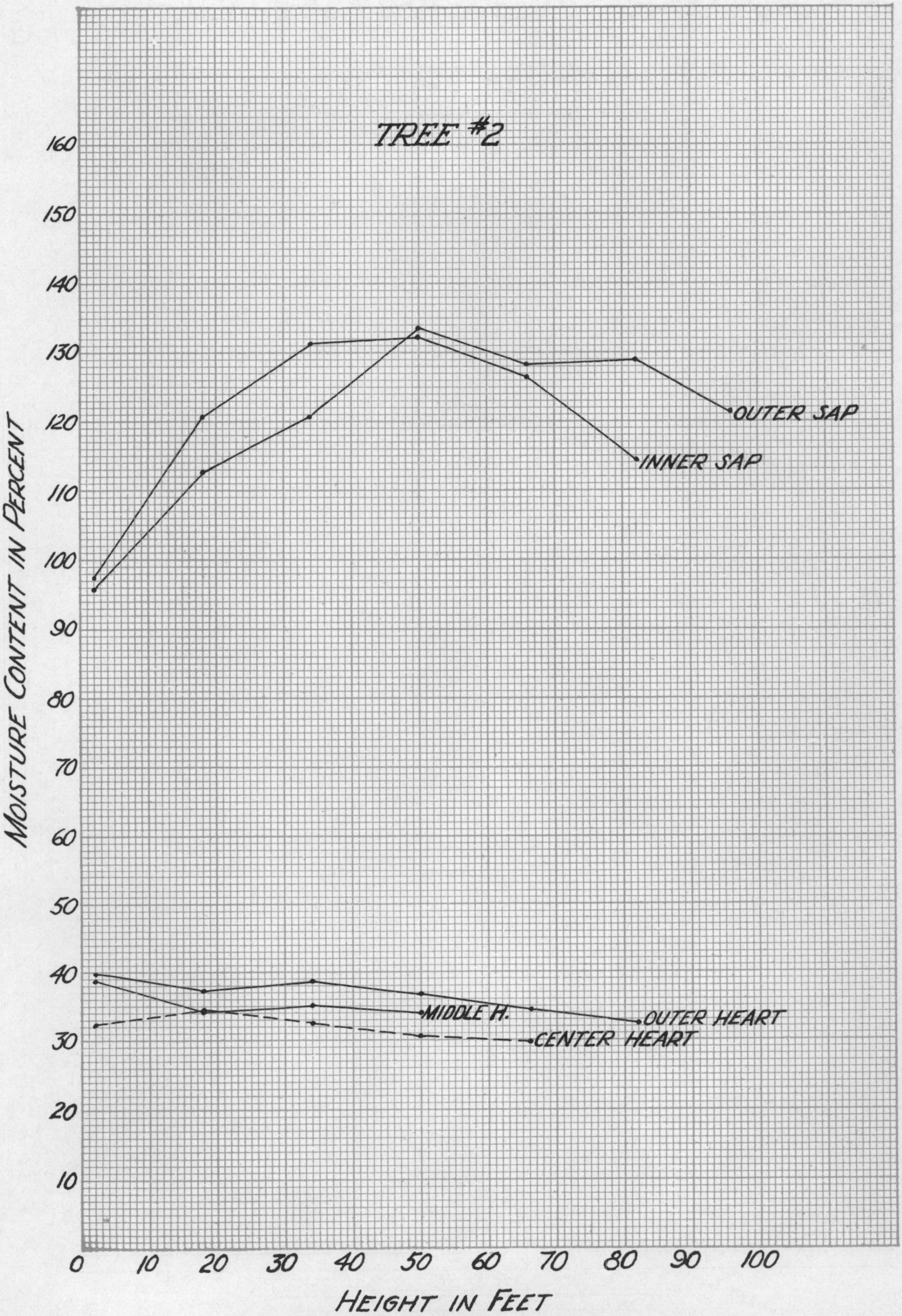
Location-- T.11S. R.6 W. Sec. 28 NW $\frac{1}{4}$

Aspect--Northeast

Elevation--450 feet

Site--III

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	95.3	97.3	39.7	38.7	32.1
18	112.7	120.6	37.1	34.1	34.4
34	120.6	131.1	38.7	35.2	32.6
50	133.5	132.2	36.8	34.0	30.9
66	128.2	126.3	34.4		29.8
82	129.0	114.3	32.3		
96	121.1				


TREE #2
MOISTURE CONTENT IN PERCENT
HEIGHT IN FEET
OUTER SAP
INNER SAP
MIDDLE H.
OUTER HEART
CENTER HEART
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Tree No. 3

Age--52 years

Height--98 feet

D.I.B.--21.5 inches

Weather for day--Occasional, very light showers

Weather for week--very heavy and continusous rains.

Date--January 11, 1936

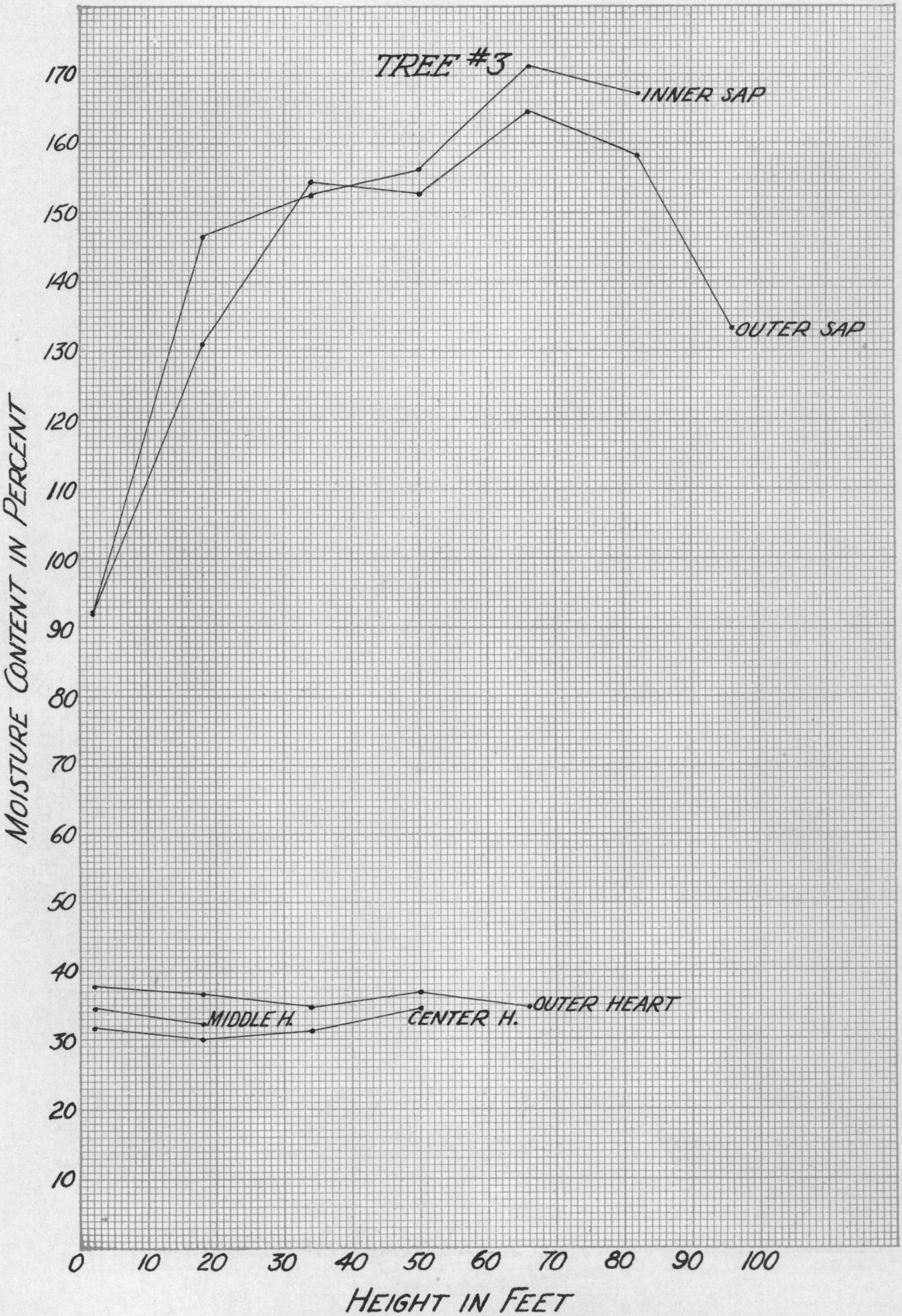
Location--T.11S. R.6 W. Sec. 28 NW $\frac{1}{4}$

Aspect--Northeast

Elevation--450 feet

Site--III

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	92.0	92.1	37.9	34.5	31.6
18	131.0	146.6	36.5	32.1	30.0
34	154.4	152.8	34.8		31.1
50	152.9	156.3	36.9		34.7
66	164.8	171.2	34.7		
82	158.3	167.1			
96	133.3				


TREE #3
INNER SAP
OUTER SAP
MIDDLE H.
CENTER H.
OUTER HEART
MOISTURE CONTENT IN PERCENT
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET

<u>Tree No. 4</u>

Age--46 years

Height--88 feet

D.I.B.--18.5 inches

Weather for day--cloudy and freezing hard

Weather for week--clear and cold after light rains.

Date--February 15, 1936

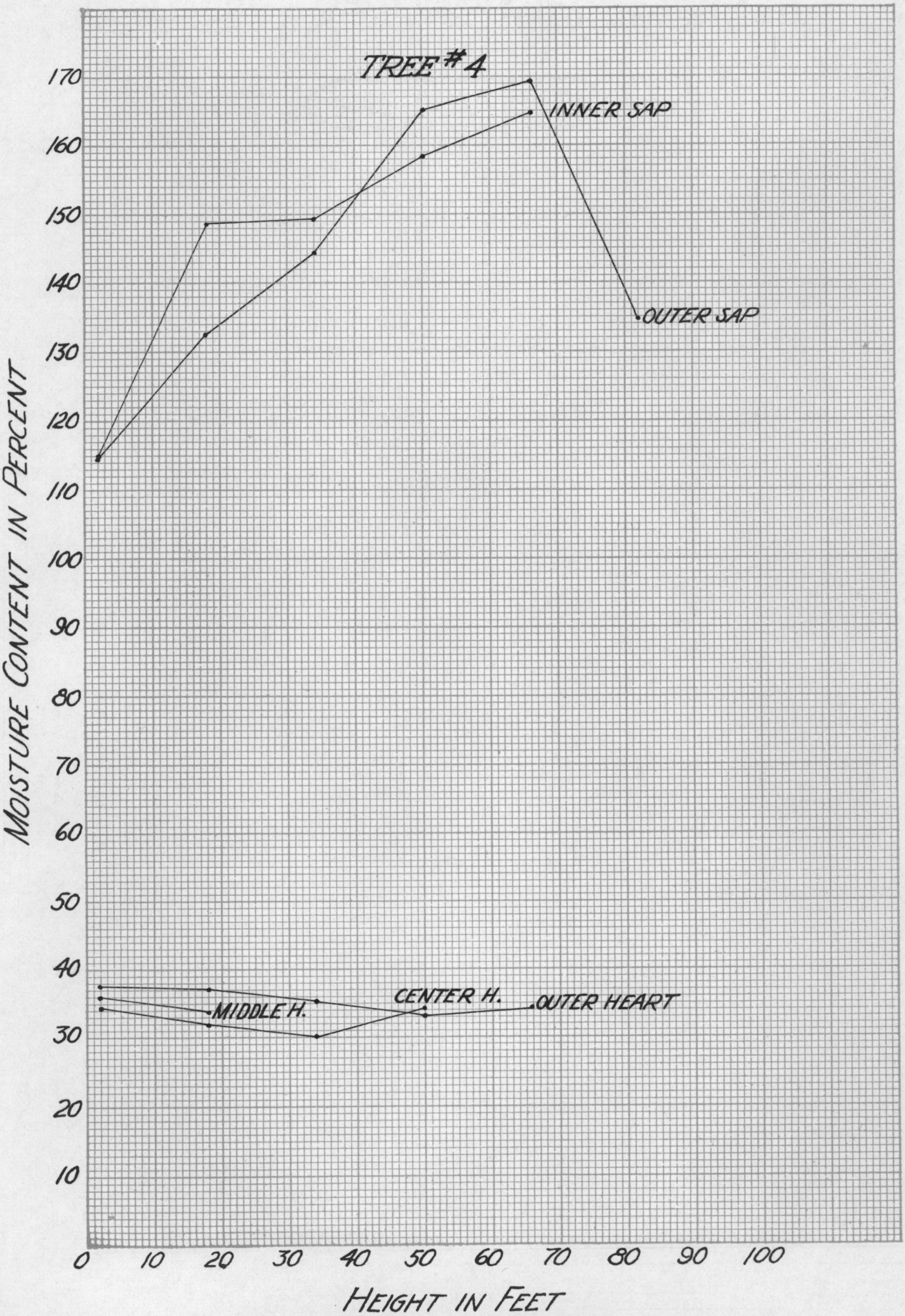
Location--T.11S. R6 W. Sec. 28 NW$\frac{1}{4}$

Aspect--Northeast

Elevation--450 feet

Site--III

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	114.5	115.0	37.7	36.0	34.2
18	132.6	148.9	37.1	33.7	32.0
34	144.2	149.2	35.4		30.0
50	165.1	158.4	33.2		34.1
66	169.5	164.6	33.4		
82	134.9				


TREE #4
INNER SAP
OUTER SAP
CENTER H.
MIDDLE H.
OUTER HEART
MOISTURE CONTENT IN PERCENT
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET

Tree No. 5

Date--February 20, 1936

Age--80 years

Location--T.12S. R.5 W.

Height--165 feet

Sec. 2 SW $\frac{1}{4}$

D.I.B.--31.7 inches

Aspect--Level

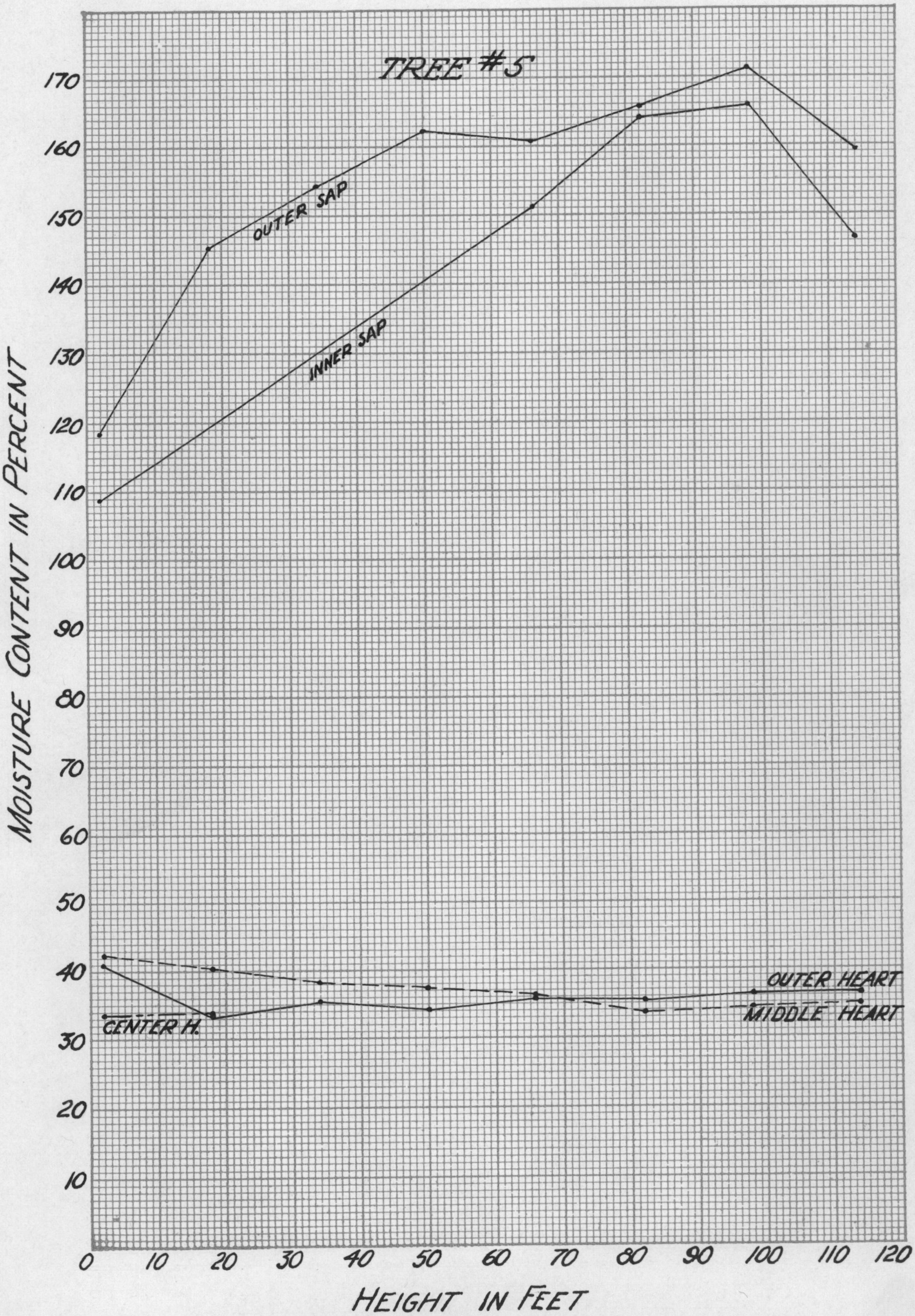
Weather for day--It started to rain in afternoon

Elevation--300 feet

Site--II

Weather for week--Freezing weather with an ice storm.

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	118.5	108.9	40.1	42.2	33.6
18	145.4		33.3	40.4	33.8
34	154.5		35.5	38.3	
50	162.1		34.1	37.5	
66	160.6	151.1	35.8	36.1	
82	165.7	164.3	35.3	33.6	
98	171.1	166.0	36.3	34.2	
114	159.4	146.6	36.4	34.2	
130	154.5	146.5	34.1	32.1	
146	144.5	144.3	33.2		
160	142.4				


TREE #5
OUTER SAP
INNER SAP
OUTER HEART
MIDDLE HEART
CENTER H.
MOISTURE CONTENT IN PERCENT
HEIGHT IN FEET
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
110
120

Tree No. 6

Age--53 years

Height--94 feet

D.I.B.--20 inches

Weather for day--Fair

Weather for week--Three days fair preceded by light showers.

Date--April 6, 1936

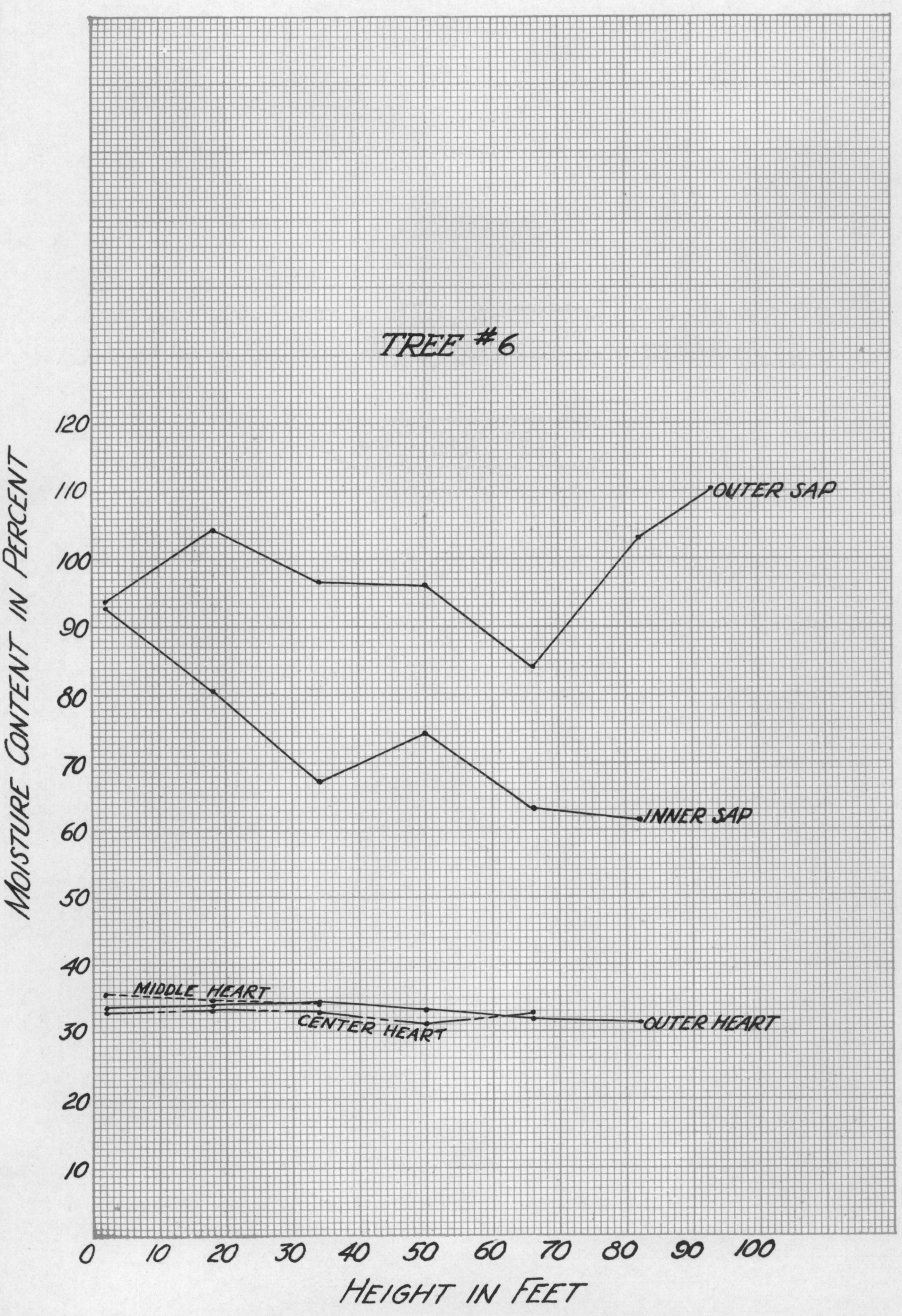
Location--T.10S. R.5 W. Sec. 36 SW $\frac{1}{4}$.

Aspect--East

Elevation--475

Site--III

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	93.8	92.9	33.6	35.8	33.6
18	104.3	80.8	34.0	34.6	33.5
34	96.6	67.2	34.2	34.1	32.9
50	96.3	74.6	33.1		31.0
66	84.3	63.2	31.3		32.8
82	103.1	61.5	31.5		
93	110.3				


TREE #6
MOISTURE CONTENT IN PERCENT
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET
OUTER SAP
INNER SAP
MIDDLE HEART
CENTER HEART
OUTER HEART

Tree No. 7

Date--April 10, 1936

Age--63 years

Location--T.10S. R.5 W. Sec. 25 SW $\frac{1}{4}$.

Height--100 feet

D.I.B.--22.1 inches

Aspect--Northwest

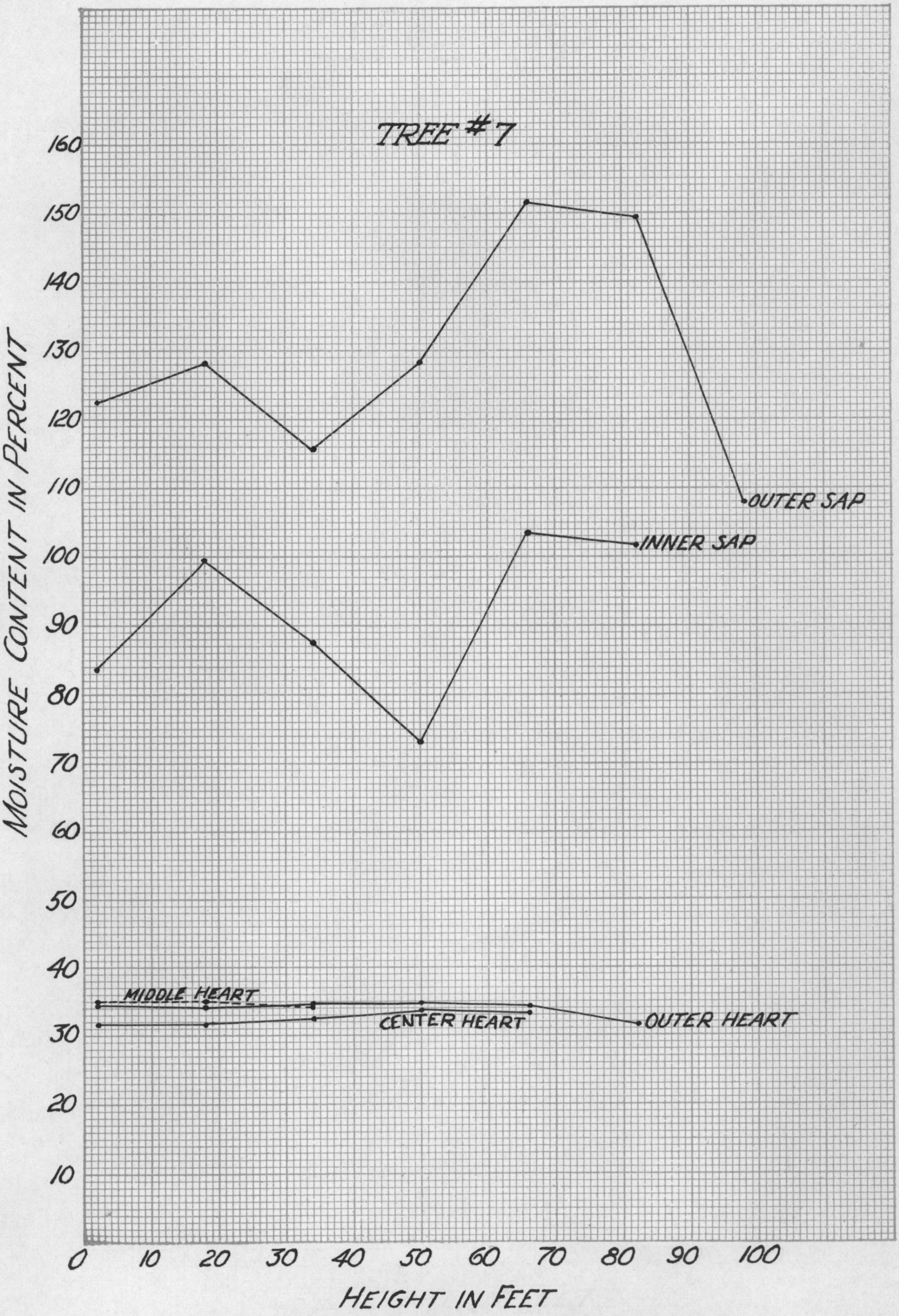
Weather for day--fair and warm

Elevation--700 feet

Site--IV

Weather for week--fair but with some cloudiness.

Height Feet	Outer Sap	Inner Sap	Outer Heart	Middle Heart	Center Heart
2	122.6	83.8	34.6	34.9	31.6
18	128.1	99.5	34.4	35.0	31.9
34	115.7	87.7	34.7	34.3	32.7
50	128.3	73.1	34.6		33.8
66	151.5	103.5	34.3		33.1
82	149.4	101.6	31.9		
98	108.0				


TREE #7
MOISTURE CONTENT IN PERCENT
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
OUTER SAP
INNER SAP
MIDDLE HEART
CENTER HEART
OUTER HEART
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET

Tree No. 8 — Date--May 8, 1936

Age--50 years — Location--T.11S. R.4 W.

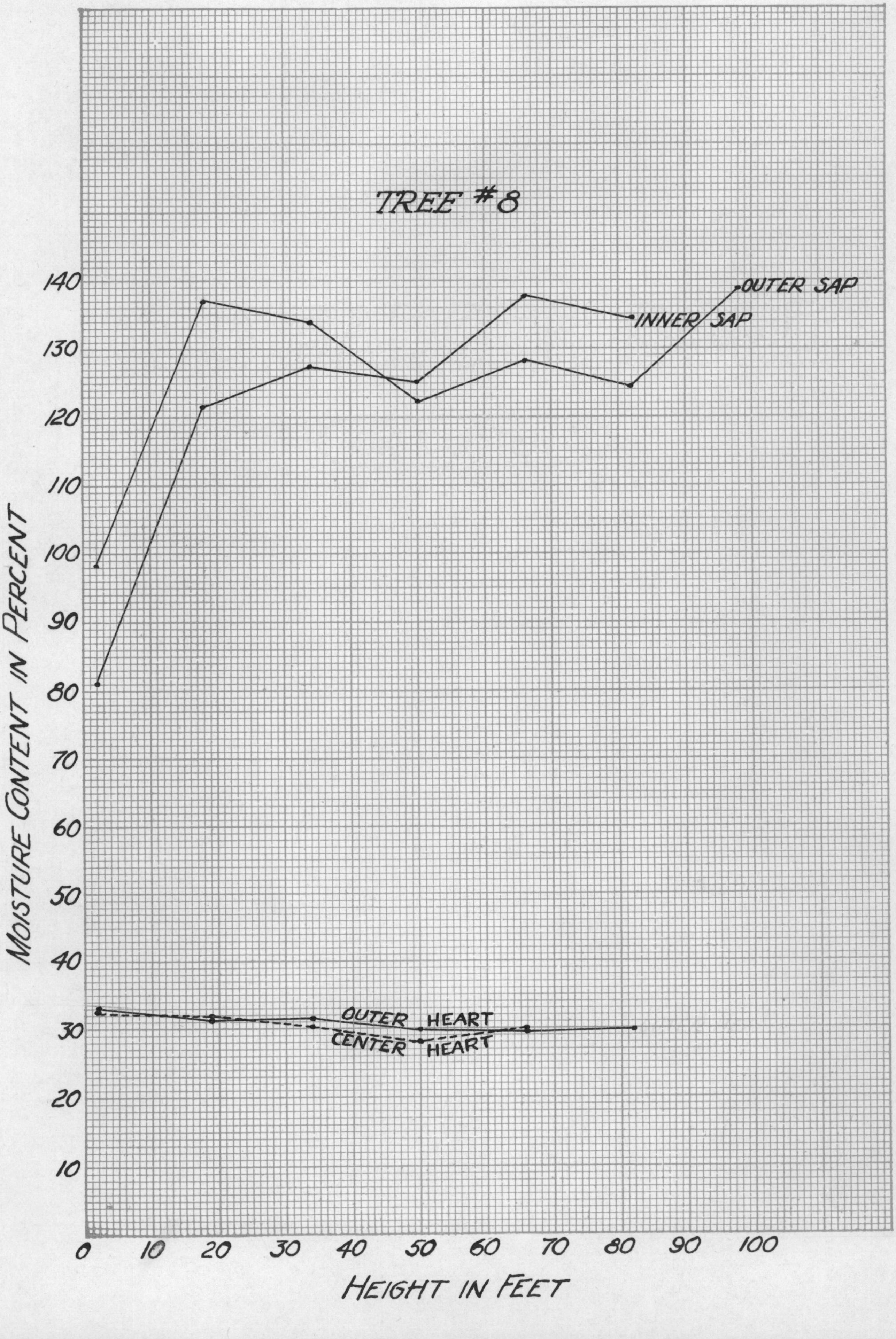
Height--100 feet — Sec. 31 NW. $\frac{1}{4}$

D.I.B.--16.4 inches — Aspect--Southeast

Weather for day--Fair — Elevation--350 feet

Weather for week--generally rainy. — Site--III

Height Feet	Outer Sap	Inner Sap	Outer Heart	Center Heart
2	98.4	81.0	33.0	32.6
18	137.0	121.7	31.2	31.4
34	134.0	127.7	31.6	30.1
50	122.3	125.1	29.8	28.0
66	128.3	137.9	29.5	30.0
82	124.4	134.4	29.9	
98	138.7			


TREE #8
OUTER SAP
INNER SAP
OUTER HEART
CENTER HEART
140
130
120
110
100
90
80
70
60
50
40
30
20
10
MOISTURE CONTENT IN PERCENT
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET

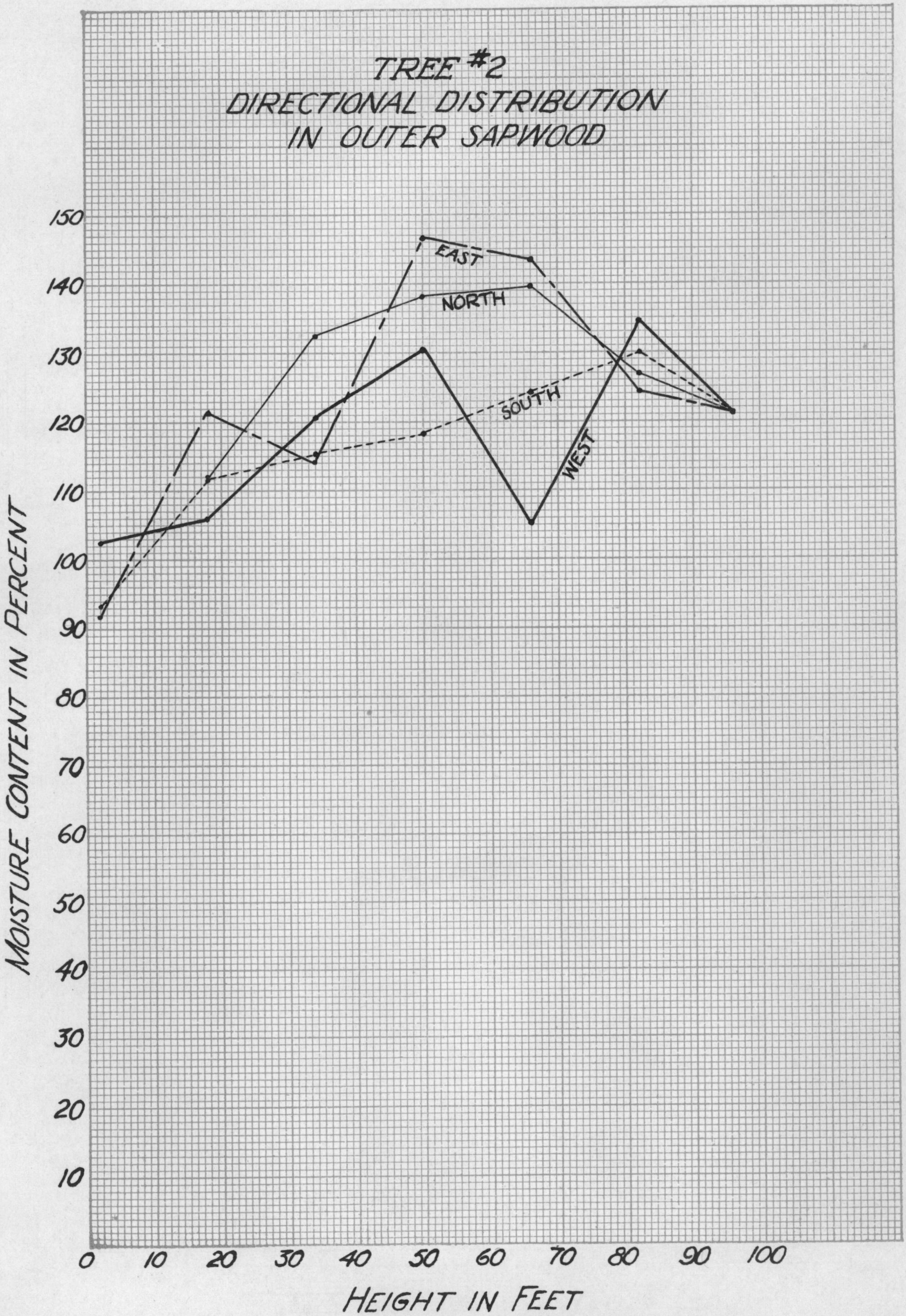
Record of Samples
Tree No. 2

Height Feet	Direction & Number	Wet Weight	Dry Weight	M. C.
2"	W 1	53.79	26.59	102.3
	2	54.06	27.20	98.0
	3	36.78	26.30	39.8
	4	33.81	24.44	38.3
	5	37.39	28.30	32.1
	E 1	55.79	29.07	91.9
	2	54.55	27.08	101.4
	3	33.66	23.95	40.5
	4	31.83	22.92	38.9
	S 1	49.16	25.45	93.2
	2	41.15	21.36	92.6
	3	37.70	27.14	38.9
	4	33.52	24.11	39.0
18"	N 1	40.06	18.90	112.0
	2	34.13	15.65	118.1
	3	30.03	22.10	35.9
	4	24.13	18.15	33.0
	5	23.91	17.79	34.4
	S 1	47.29	22.34	111.7
	2	41.34	19.02	117.4
	3	29.72	21.61	37.5
	4	30.50	22.60	35.0
	W 1	49.70	24.13	106.0
	2	44.93	20.28	121.5

Height Feet	Direction & Number	Wet Weight	Dry Weight	M. C.
18"	W 3	32.09	23.30	37.7
	4	27.90	20.71	34.7
	E 1	42.34	19.12	121.4
	2	38.62	17.14	125.3
	3	29.24	21.29	37.3
	4	26.81	20.06	33.6
34"	N 1	61.20	26.33	132.5
	2	66.21	28.01	136.4
	3	42.12	30.21	39.4
	4	43.03	31.68	35.8
	5	43.73	32.98	32.6
	S 1	55.99	25.96	115.3
	2	52.14	22.90	127.7
	3	38.75	27.98	38.5
	4	35.89	27.67	34.6
	W 1	48.96	22.18	120.7
	2	47.73	20.50	132.8
	3	36.08	25.99	38.8
	4	35.92	26.70	34.5
	E 1	62.88	29.37	114.1
	2	66.71	29.31	127.6
	3	44.30	32.11	38.0
	4	41.96	30.89	35.8
50'	E 1	46.97	19.04	146.7
	2	43.51	18.35	137.1
	3	36.11	26.30	37.3

Height Feet	Direction & Number	Wet Weight	Dry Weight	M. C.
50'	E 4	31.62	23.54	34.3
	5	46.81	35.77	30.9
	W 1	69.06	29.92	130.8
	2	54.96	23.11	137.8
	3	36.67	27.30	34.3
	4	39.26	29.32	33.9
	S 1	58.41	26.75	118.4
	2	47.90	21.79	119.8
	3	35.48	25.61	38.5
	4	34.99	26.13	33.9
	N 1	53.43	22.42	138.1
	2	45.89	19.62	133.9
	3	34.79	25.36	37.2
	4	35.05	26.15	34.0
66'	W 1	50.77	24.76	105.1
	2	44.46	20.93	112.4
	3	34.95	26.16	33.6
	4	45.93	35.38	29.8
	E 1	27.24	11.18	143.6
	2	25.67	10.48	144.9
	3	29.24	21.89	33.6
	S 1	35.65	15.89	124.4
	2	42.72	18.74	128.0
	3	35.25	25.88	36.2
82'	N 1	38.73	16.18	139.8
	2	34.77	15.80	120.1

Height Feet	Direction & Number	Wet Weight	Dry Weight	M. C.
82'	W 3	29.92	22.62	32.3
	E 1	21.68	9.67	124.1
	2	20.33	9.76	108.3
	S 1	21.19	9.21	130.0
	2	21.90	9.65	125.3
	N 1	23.72	10.45	127.0
	2	24.20	11.33	113.6
96'	W 1	6.39	2.89	121.1


TREE #2
DIRECTIONAL DISTRIBUTION
IN OUTER SAPWOOD
EAST
NORTH
SOUTH
WEST
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
MOISTURE CONTENT IN PERCENT
0
10
20
30
40
50
60
70
80
90
100
HEIGHT IN FEET

Summary of Results

1. In the first measurements taken, the inner sapwood was consistently drier than the outer sapwood. Both showed a rise from the ground level to 50 feet and a drop from there to the top. The first measurements were taken after, for Oregon, a comparatively dry fall.

2. By the time the next tree was taken, the M.C. of the inner sap had risen to equal that of the outer sapwood.

3. Before the next tree was taken the heavy rains of early January occurred and the moisture content of both the inner and outer sap took an abrupt rise, except near the ground where it remained farily constant.

4. The next two trees show the same high moisture content. Apparently trees of about 100 feet reach the peak of moisture content at from 60 to 70 feet. These last two trees also showed a noticeable rise in the 2 foot section. This action may have been caused by root activity bringing about root pressure to force water up into the lower part of the stem. One of the trees taken in April also showed this tendency.

5. Tree No. 6 taken on April 6th showed a great drop in water content in both the inner and outer sapwood being the lowest of any tree taken. The inner sap instead of rising declined about 30% from the ground to the top. Tree No. 7 taken at about the same time also showed a large drop in the sapwood, but not nearly as much as in tree No. 6. The difference between these two trees is probably due

to differences in environment. Tree No. 6 was standing by itself on a ridge, the other timber around it having been cut several years previously. Tree No. 6 was thus fully exposed to wind and sunshine which would bring about increased transpiration. Tree No. 7 was located in an unopened stand.

6. Between the time that these two trees were taken and when tree No. 8 was taken there was a period of rainy weather. The inner sapwood of this tree shows the result of this as it has evidently filled up again. However, the moisture content does not approach that of the trees taken in the middle of the winter.

7. In all these trees considerable variation was found between sapwood samples taken in comparative positions along the different radii of the same wafer. This is brought out by the graph of the distribution of the moisture content in the outer sapwood of tree No. 2. One outer sap sample may vary as much as 30% from another taken one-fourth or one-half way around the tree. One possible reason for some of this variation is that the number of rings in a sample would vary due to the uneven rate of growth. Sampling along one radius would not appear to be very satisfactory.

8. In the four trees for which curves were worked out, there appeared to be little correlation between cardinal direction and moisture content. In some trees where one side started high, it remained high most of the distance up the tree but the high sides varied as between trees.

9. From inspection of the data sheets, it appeared that there was a tendency for a sample with high outer sap to go with a sample with high moisture content in the inner sap; but there were a large number of exceptions to this as low and high samples for a wafer were sometimes adjacent.

10. In all the trees, the moisture content of the heartwood was much more constant. Samples from comparative positions in the same wafer rarely varied more than 2%. The trend for all trees seems to be for a lower moisture content as you go toward the top and pith of the tree, though quite frequently the heartwood halfway in is moister than that next to the sap.

11. The three trees taken during the spring months show a lower moisture content in the heartwood than any of those taken during the winter, but more samples would have to be taken before one could say that there was really a seasonal variation.

Conclusions

1. Douglas fir trees, during the winter when both the soil and air are near the saturation point, show a decided rise in the moisture content of the sapwood. This is especially noticeable higher in the tree. Part of the difference in moisture content as you go up the tree is probably due to the decrease in density. This rise from the ground level as you go upward agrees with results obtained in studies made on redwood and shortleaf pine.

2. With the coming of spring, there is a drop in the

moisture content of the sapwood. This is especially noticeable in the inner sap. This bears out Munch's belief that the inner sapwood acts as a reservoir which fills up during periods when water is plentiful and is drawn upon when transpiration increases.

3. If the trend so far indicated continues it is possible that some of the inner sap will approach the moisture content of heartwood before the end of the summer. Death of living cells would then prevent rehydration of some of it and the change to heartwood would take place.

4. Trees Nos. 4, 5, and 7 would seem to indicate that root pressure may be effective in increasing the moisture content of sapwood near the ground.

5. Environmental conditions are apparently rather important in determining what the moisture content will be. This brought out by the comparison of tree no. 6 and with tree no. 7. This would check with the results obtained by Haasis and McDougal with the dendrograph.

6. The belief that the sap comes up in the spring, in the sense that there is more water in the tree, does not seem to be true of Douglas fir in Oregon. The fact that a tree peels easily is probably due to the production of tender tissue by the activity of the cambium. Of course, it seems probable that the actual cells in processes of division and growth have a very high moisture content.

7. Comparison of cardinal direction with moisture content did not show any correlation. In some trees there appeared to be a tendency for a side that was high at the

base to continue comparatively high on up the tree. Straightness of grain would probably be a factor here.

8. The comparative constancy of the moisture content of the heartwood stood out sharply in contrast to the wide diametral, altitudinal, and seasonal variation found in the sapwood.

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