THE MOISTURE CONTENT OF FOREST FUELS - II

COMPARISON OF MOISTURE CONTENT VARIATIONS ABOVE THE FIBER SATURATION POINT BETWEEN A NUMBER OF FUEL TYPES

By

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NOTE

This is the second in a series of papers on fuel moisture. Other papers in the series are:

The Moisture Content of Forest Fuels - I

A Review of the Basic Concepts

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INTRODUCTION

It is a well known fact that forest fire behavior is closely correlated with forest fuel moisture. It is for this reason that all the fire danger rating systems in use today make some effort to estimate the moisture content of forest fuels. Generally speaking, some form of bookkeeping system is usually involved. A certain amount is added to the index in the absence of rain, based on various drying factors. A certain amount is subtracted from the index when rain occurs, based on the amount of precipitation which falls.

A considerable amount of work has been done by the drying of forest fuels. Relatively little is known about the wetting process. It was shown by Simard (1968) that so long as the rate of rainfall exceeds the rate at which fuels can absorb water, it is the duration of precipitation and not the amount which governs the amount of water which the fuels will absorb. In other words, much of a heavy rainfall with only a short duration will not be absorbed, especially if the rate of percolation through the fuel complex is high.

To the author's knowledge, there is only one fire danger rating system which considers duration of precipitation. It was developed by Wright and Beall (1940). Unfortunately this feature had to be estimated, due to the difficulty of determining rainfall duration without fairly elaborate instrumentation.

The critical factor as to whether the duration or amount of precipitation is limiting with respect to absorption of water is the maximum rate of absorption by the fuels. The purpose of the present study is to determine the rate at which various fuels can absorb water. The present study is concerned primarily with relative absorption and drying rates between various types of fuels. Future research will attempt to determine actual rates, based on various environmental parameters, such as temperature, and in the case of drying, relative humidity.

EXPERIMENTAL PROCEDURE

A survey of the literature indicated that much work had been done on the moisture content of wood below the fiber saturation point, and to a more limited extent above the fiber saturation point. Although some efforts have been made to correlate the behavior of moisture content in wood with that in other fuels, most present fire danger rating systems are based on wood only. This is curious since the litter layer is normally the fuel component which propagates forest fires. For this reason it was decided that this study would concentrate on the various litter components.

For the purpose of this paper, moisture movements above the fiber saturation point are assumed to be in the form of liquid water only. All water vapor movements are assumed to take place below the fiber saturation point.

Since nothing could be found in the literature on the rate of absorption of liquid water, some basic experiments in the laboratory were planned which it was hoped would provide some preliminary information on this topic.

The moisture content of duff and litter, under constant environmental conditions, is a function of two general independent variables. They are internal structure of the material itself, and mechanical arrangement of the components. Only the material itself was investigated in this study. Subsequent investigation will attempt to combine the two variables. In order to determine the effect of internal structure, a number of fuel components of several species were selected for testing. Materials and species tested were:

1) White Spruce (Picea glacua Voss.) - Needles (old and new), twigs (several sizes, all with bark).

2) White Pine (Pinus Strobus L.) - Needles (old and new), twigs (several sizes, with and without bark).

3) Red Pine (Pinus resinosa Ait.) - Needles (old and new), twigs (with and without bark).

4) Jack Pine (Pinus Banksiana Lamb.) - Needles (old and new), twigs (with and without bark).

5) Sugar Maple (Acer saccharum Marsh.) - Leaves (new only), twigs (with and without bark).

6) Grass - Species not identified (new only).

For the purpose of this paper, weathering is defined as exposure to the elements for a period of several months with only minor physical changes taking place. Decomposition is defined as the physical breakdown (i.e. crumbling, falling apart) which accompanies prolonged exposure (usually several years). Old material is defined as anything which has undergone at least one summer of weathering but which retains its normal structural characteristics. New material is that which has recently fallen. It was decided that the following questions would be investigated:

1) - The total amount of water that can be held.

2) - The maximum rate of water absorption (i.e., submerged).

3) - The rate of water loss.

4) - The effect of age (needles only).

5) - The effect of size (twigs only).

6) - The effect of bark (twigs only).

7) - Any other observations which suggest themselves during the course of the investigation.

All samples were allowed to remain at room temperature and relative humidity (70°F. and 30-40%, respectively) for 3 weeks prior to starting to insure uniformity. Litter samples of from 1.5 to 2 grams were then selected. The range in weight of twig samples was 0.8 to 4.3 grams. Tap water was placed in a large container and its temperature allowed to come to equilibrium with the surrounding environment. Temperatures were measured with a mercury thermometer and a hygrothermograph. The large amount of water used helped to maintain a fairly constant temperature of 70°F. with a range of 69.5° to 71.5°F.

The litter samples were placed in individual containers covered with a fine nylon mesh. This insured free circulation of water, and complete submersion of the samples. The twig samples were placed in test tubes which were filled with water, covered and submerged in a water bath, to maintain a uniform temperature. The samples were then removed from the water at periodic intervals and weighed. An attempt was made to remove as much surface water as possible by shaking and drying with paper towels so that only absorbed water would be measured. Since it was impossible to remove all surface water, tests were conducted to determine the amount remaining, and the amount of variation in the drying process.

When the samples ceased to gain weight, they were removed from the water and allowed to dry at 78° (±2°) and 55% RH (±5%). They were again weighed at periodic intervals to determine the weight loss. A series of samples was maintained at room conditions for the duration of the experiment to be used for comparison with the soaked samples.

When the "soaked" samples had ceased to lose weight, both they and the control samples were oven dried and the oven-dry weights determined. These were then used to convert all previous weighings to percent moisture content. These were then compared, in an effort to provide answers to the previously mentioned questions.

Since, to the author's knowledge, this type of experiment has not been performed previously, a discussion of some of the problems involved would be in order at this point. The results of this study should be regarded as preliminary. The method used was such that only the more obvious results can be considered significant at this time.

1. Foliage Samples

The most outstanding difficulty encountered was the loss of weight by the samples between the initial weighing prior to soaking, and the final weighing after drying. In Table 1 it can be seen that some of the losses were very high, as in the case of maple leaves.

Table 1 Individual Foliage Weight Losses During Tests (in Percent of Oven Dry Weight)

Species	New	Old	Average
Maple Leaves	69%	-	69%
White Spruce	22%	16%	19%
Red Pine	4%	4%	4%
White Pine	4%	10%	7%
Jack Pine	14%	12%	13%
Grass	14%	-	14%

This loss was divided into two classes - lost material, and solubles from the samples going into the solution. The water was filtered at the end of the experiment, and the amount of material recovered was weighed. Distillation of the water recovered an additional part of the loss. The remainder was assumed to be material lost outside the water bath. Table 2 summarizes these losses.

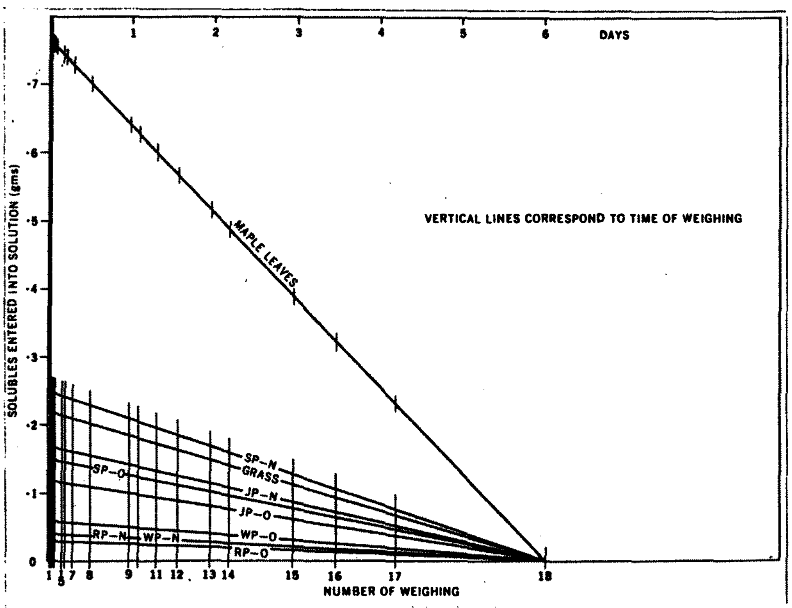
Table 2 Total weight losses during tests (in Percent of Oven Dry Weight)

	Total Loss	Solubles Recovered	Material Recovered	Lost Outside Water Bath
Foliage	15.6%	12.5%	1.3%	1.8%
Twigs	10.2%	9.1%	1.1%	-

One of the problems with the weighed material was the fact that a number of organisms seemed to thrive and increase in the solution during the tests. Their weight was added to that of the material, as there was no way to separate the two.

Assuming that everything not recovered by distillation was lost material (probably not entirely valid but necessary), the measurements were adjusted for each type of weight loss. Based on the experience derived while handling the samples, each was assigned a portion of the total weight of lost material. The portions were determined by simply ranking the samples as to their susceptibility of losing material. The remaining weight lost for each sample (solubles) was further assumed to have taken place at a constant rate from the start to the end of the soaking test. Again this is probably not true, as nothing can go into solution until after water has entered the fuel. Lacking measurements on the rate of dissolving, a constant rate was assumed. A further assumption was made that anything which dissolved was replaced by an equal volume of water regardless of the moisture content of the fuel. All the previous weighings were then adjusted to make them comparable to the final weight by subtracting the amount of soluble that would have been lost at the time of each measurement. The diagram which was used for the foliage samples is shown below.

Adjustments for solubles lost by foliage samples during soaking test.



The lost material was accounted for in an entirely different manner. Examination of the graphs of moisture content over time indicated that there were several instances where the moisture content dropped in subsequent readings. This was assumed to be partially due to material being lost between the measurements. The weight of material (at room conditions) was then adjusted to the percent moisture at the time of the weight loss and subtracted from the first weighing. In most cases this was only sufficient to reduce the loss, not eliminate it entirely.

The loss of weight while submerged requires further elaboration. As previously mentioned, the total amount of lost material was unable to compensate for many of these losses. A number of other possible causes are:

1. Weighing error - the scales used measured to an accuracy of .01 gm. This is equivalent to 0.8% and 0.6% of oven dry weight for the lightest and heaviest samples, respectively. All percents were rounded off to whole numbers. Any errors here are considerably less than the measured weight losses, and cannot be considered a significant causative factor.
2. Incorrect measurements - this may be the cause in the case of an individual low (or high) reading followed by one which seems to continue the original trend. In the case of several subsequent low readings this is not the likely cause.
3. Inaccuracy of drying technique. Each sample was shaken and blotted with paper towels to remove excess water prior to weighing. An attempt to determine the accuracy of the technique proved to be inconclusive. Visual examination of

the graphs in the latter part of the soaking test indicated that the error of the individual moisture content measurements is probably less than ± 10% of oven dry weight and certainly not greater than ± 20%. This again might account for individual errors, but not likely for a series of low readings after a series of high ones.

4. Effect of solubles entering solutions - At this time there can be little more than conjecture as to what occurs when a soluble compound dissolves within the fuel and enters the surrounding water. Does its diffusion outward impede the diffusion of water inward? Or, more likely, do the two occur simultaneously and independently? It is conceivable that the rate at which substances dissolve and diffuse outward might be sufficiently great that all the water entering the fuel simply replaces these substances, and there is no net gain of weight. No conclusions are being drawn on this point at this time. It is only intended that some questions be presented which require answering.

5. Possible oxidation of organic matter by bacteria - No observations are available to confirm or contradict this possibility.

2. Twig Samples

Prior to soaking, the twig samples were first coated with wax at the ends to seal the pores. A coat of varnish was then applied. The purpose of sealing the ends was to eliminate longitudinal diffusion. The wax was applied first in an effort to prevent absorption of a large amount of varnish. This proved unsatisfactory, as the wax was softened by the varnish, and required more than a week to dry. Further, much of the wax melted during oven drying, and was absorbed by the wood. Since the total weight of the wax would not change by being absorbed, and since oven drying took place after completion of the experiment, this was assumed to have had no effect on the moisture content during the tests.

Distillation of the water and weighing the material which was filtered out resulted in recovery of slightly more than was lost by the samples. This was assumed to be bacteria which was weighed with the lost material. An appropriate amount was subtracted from the recovered material to give 100 percent recovery.

The drying technique appeared to be much more consistent in the case of the twigs. Consequently, more reliance can be placed on the values obtained during this portion of the test. The error of the individual moisture content measurements is estimated to be within $\pm$ 15% of oven dry weight. Weighing accuracy ranges from 0.2% to 2.3% for the heaviest and lightest samples, respectively.

On the basis of a visual examination, the solution in which the foliage samples had soaked was determined to be more opaque than the solution which contained the twig samples. Despite this, the water in which the twigs had been soaked contained almost 3 times as much dissolved solubles. The amounts were 0.510 g/l and 0.185 g/l for the twigs and foliage samples respectively. This indicates that much of what is going into solution from the twigs is colorless and any attempt to measure the rate of entry into solution on the basis of color change will run into difficulty. Table 3 lists the loss of weight by individual twigs.

Table 3 Individual Twig Weight Losses Between Initial and Final Weighings (in Percent of Oven Dry Weight) (all sizes in mm)

Hard Maple Size	Hard Maple Loss	White Spruce Size	White Spruce Loss	Red Pine Size	Red Pine Loss	White Pine Size	White Pine Loss	Jack Pine Size	Jack Pine Loss
*B2.8	11.3%	B1.6	16.6%	B3.3	20.0%	B2.2	25.5%	2.4	19.0%
4.0	13.2%	B2.9	23.4%	B4.8	15.3%	3.1	17.5%	B2.4	11.6%
B4.0	9.6%	B3.5	17.2%	4.2	8.5%	B5.2	11.6%	4.2	6.6%
5.3	7.2%	B4.8	13.7%	6.4	16.3%	4.5	6.0%	7.1	7.8%
7.6	8.4%	B4.6	12.5%	5.6	10.9%	B7.3	9.0%	9.1	5.1%
8.2	4.8%	B6.4	10.2%	9.5	6.3%	6.7	5.2%	14.4	4.3%
Average									
6.5	9.1%	4.0	15.6%	5.6	12.9%	4.6	12.5%	6.6	9.1%

*B = With bark

Before leaving this topic, it should be mentioned that equipment is being designed which will, it is hoped, eliminate most of the problems encountered in this first attempt. Some of the improvements will be:

1 - No handling of the material will be necessary after soaking has started - thus eliminating loss of material.

2 - Continuous readings will be possible - especially important in the early stages.

3 - Each sample will be in an individual container - thus making possible a more detailed analysis of the residual water at the end of the test.

4 - An attempt will be made to measure the amount of solute entering into solution. This will then be correlated with changes in the rate of moisture content increase.

5 - The sample will be totally submerged at all times. Only water entering the fuel will be considered - thereby eliminating the problem of residual surface water.

RESULTS AND DISCUSSION

1. Foliage Samples

A. Total Water Retention

The total amounts of water which the individual samples absorbed can be found in the appendix. These amounts include the surface water which could not be removed by the previously mentioned drying process. By dunking the samples, and immediately drying and weighing them, values for surface water were obtained. Subtracting these from the total weight gives the net total absorbed water. Table 4 presents a summary of these values.

Table 4 Net Water Absorbed by the Foliage Samples (in Percent of Oven Dry Weight)

Species	Average	Old	New
Maple leaves	388%	-	-
Grass	282%	-	-
White spruce	177%	166%	187%
White pine	175%	211%	138%
Red pine	139%	144%	134%
Jack pine	188%	184%	191%
Average (needles only)	170%	176%	162%

There is a considerable range in the average net total values - from 134% for new red pine to 388% for maple leaves. There does not appear to be significant difference between the various needle samples, with the exception of red pine which was lower than the other species. The total range for needle samples is 77%.

There does not appear to be any consistent difference in the net total water absorbed between old and new samples, which is surprising, since on the basis of short term measurements, one would expect the older material to hold more water. The work of Stocks and Walker (1967) indicates that different layers of duff do have different total moisture holding capacity. Their conclusions are based, however, on soaking periods of 24 hours or less. They found that the capacity increased as progressively deeper measurements were made, starting at the top layer. A maximum moisture holding capacity was measured in the center of the duff. From the center, the capacity decreased as the measurements progressed downward through the remainder of the organic material. It appeared to be correlated with the state of decomposition of the material.

Wright (1930) noted that the moisture content of a fuel sample was noticably influenced by the extent to which the lower layers were decayed. Subsequent investigation (Wright, 1935) disclosed a difference in the moisture holding capacity between the top and full layers of duff. Furthermore, there is excellent agreement between the total absorption data in the present experiment and the absorption by the top layer of duff as determined by Wright. He determined that the top layer of duff of Red, White, and Jack pine absorbed 152%, 166% and 170% moisture respectively. Hardwood leaves absorbed 336%. The full layer of duff absorbed 50% to 85% more moisture than the top layer.

The present experiment indicates that a difference in water holding capacity does exist initially. After a prolonged period of soaking, however, it is gradually reduced, and almost eliminated. With the exception of white pine, there appears to be relatively little difference in the absolute amount of water that can be absorbed by old and new needles. It must be pointed out, however, that the samples used in this experiment were not decomposed, the only difference being one or more summers of weathering. Stocks and Walker used the entire organic layer, which included some considerably decomposed material. It is possible that weathering affects primarily the rate of water absorption, while decomposition also affects the physical properties in such a way that the material can hold a greater amount of water.

B. Rate of Water Absorption

The relationships between moisture content and time for all samples are shown in Figs. 1 through 5. The upper half represents the drying curves, with the inserts showing drying after a momentary dunking. This is labelled surface water drying, for simplicity, and will be discussed in greater detail subsequently. The lower half represents the wetting curves. All curves are plotted with the adjusted moisture content values found in the appendix. Surface water has not been subtracted from these values.

Visual inspection discloses that there are three basic behavior patterns which appear in every wetting curve. Initially, all samples gain water very rapidly, for a short period. This initial period is followed by a longer interval of variable but reduced rates of absorption. It is tentatively suggested that this is the period during which the various solutes are being dissolved. Lastly, there is a long period of slow increase which asymptotically approaches a final value. In some cases, there is practically no increase at all during this final period.

The lack of smoothness in the wetting curves makes direct comparisons between samples somewhat difficult. The use of a wetting time lag constant[1/] is of limited value because, as will be discussed subsequently, great differences occur, depending on whether the value is reached before or after the rate of increase slows down. Also, a time lag constant assumes a smooth exponential curve, which in most cases does not exist.

To compare the wetting phase of the various samples with each other, the behavior during the first two periods will be studied. The initial period is defined as the interval immediately following initial dunking during which the moisture content increases rapidly. The transition in rates was so marked that the terminal point for this period was determined visually from the graphs. The second period is defined as the 48-hour interval which immediately follows the rapid increase.

Table 2 summarizes the moisture content values and rates of increase during a number of periods. Column A is the duration of the period. Columns B and C are the moisture content increases which occurred during the respective periods. In Column B the values are expressed as a fraction of the total change which will ultimately occur. Columns D and E are the average rates of increase during the respective periods. (D = B/A, and E = C/A), D is also in terms of a fraction of the total eventual change.

1/ *The amount of time required to go through 63% of the ultimate change which will eventually occur.*

Table 5 Summary of Rates of Increase and Moisture Content Values for Old and New Samples

		Conditions at End of Period		Av. Rate of Increase (Pct./Hr.)	
	A Duration (Hrs.)	B As Fraction of Total Change	C (1) Percent Moisture Content	D As Fraction of Total Change	E (1) Percent Moisture Content
		Rapid Increase Period			
Old	(2) 5.5	.70	166%	.142	30.5%
New	5.2	.50	98%	.104	18.4%
Sig. Level of Difference (3)	N.S.D. (4)	.06	.12	.14	.06
		Variable Increase Period			
Old	48	.92	213%	.0045	0.98%
New	48	.77	154%	.0057	1.16%
Sig. Level of Difference	-	.02	.12	N.S.D.	N.S.D.
		Time Lag Period			
Old	8.3	.63	146%	.151	33.6%
New	25.2	.63	124%	.030	5.8%
Sig. Level of Difference	.07	-	.50	.04	.05

1. % of oven dry weight
2. As determined from the graph
3. Significance
4. No significant difference

Looking first at the rapid increase period, we can see that on the average the duration for both old and new samples is essentially the same. On the other hand, the new samples had absorbed only about two-thirds as much water as the old at the time of transition. Looking at the rates of increase, it can be seen that the same ratio applies. These differences were found to be significant, despite the small sample size and large standard deviations.

Turning to the variable increase period, it can be seen that a number of changes occur in addition to the marked reduction in rates of increase. During this period the new samples actually appear to increase faster than the old, which is in direct contrast to the previous interval. This difference is very small, however. As a result, the amount of water absorbed by the old needles after two days of soaking was still significantly higher than that absorbed by the new. By the end of the variable increase period the new needles had absorbed about three-fourths as much as the old, only a slight increase from the previous two-thirds, at the end of the rapid increase period.

Looking at the time lag period, it can be noted that the old samples appeared to gain water five times as fast as the new ones. On the other hand, we can see that the old needles require only about one-third as much time as the new ones to go through 63 per cent of the ultimate change. This gives a false impression, however, as the rates of change varied considerably, depending on whether the .63 value was attained prior to or after the end of the rapid rise period. As mentioned, the actual ratios between old and new are approximately 1.5:1, and not 5:1. Therefore, it is felt that any comparison of wetting time lags would be of rather questionable value.

In summary, due to the greater initial rate of absorption, the old needles gain about one and a half times as much as the new by the end of the rapid increase period. The actual difference in moisture content is fairly large (68 per cent) despite the relatively short period, due to the rapid rates of increase. This initial difference persists for several days, with the new needles slowly catching up to the old.

C. Rate of Water Loss

Visual inspection of the drying curves in Figs. 1 through 5 indicates a considerable difference between the rates of drying of new and old material. This is confirmed by the summary of water loss measurements and significance of differences given in Table 6. (The individual measurements can be found in the appendix.) Columns A, B, C, E and F correspond to the values given in Columns A through E respectively of Table 5. Column D is the actual moisture content value at the end of the time lag period.

Table 6 Summary of Water Loss

	A	B	C (1)	D (1)	E	F (1)
Old	4.9	.63	138%	92%	.129	20.4%
New	17.6	.63	119%	79%	.036	4.6%
Sig. Level of Difference	.01	-	.50	.50	.02	.02

(1) In Percent of Oven Dry Weight.

The smoothness of the curves indicates that this phase of the test was more accurate than the wetting portion, which allows greater reliance to be placed on the drying values. This also makes the use of a time lag constant more meaningful. Although, as in the case of wetting, the time lag for the new material was about three times that for the old, the significance of the difference is considerably greater due to the smaller amount of variation while drying. It can be noted that there is little difference in the water lost by the end of the time lag period. One would expect a small difference, since the amount of water lost during the time lag period is a function of the total water gained, in which there is little difference. The rates of loss

Figure 1 Moisture content as a function of time.

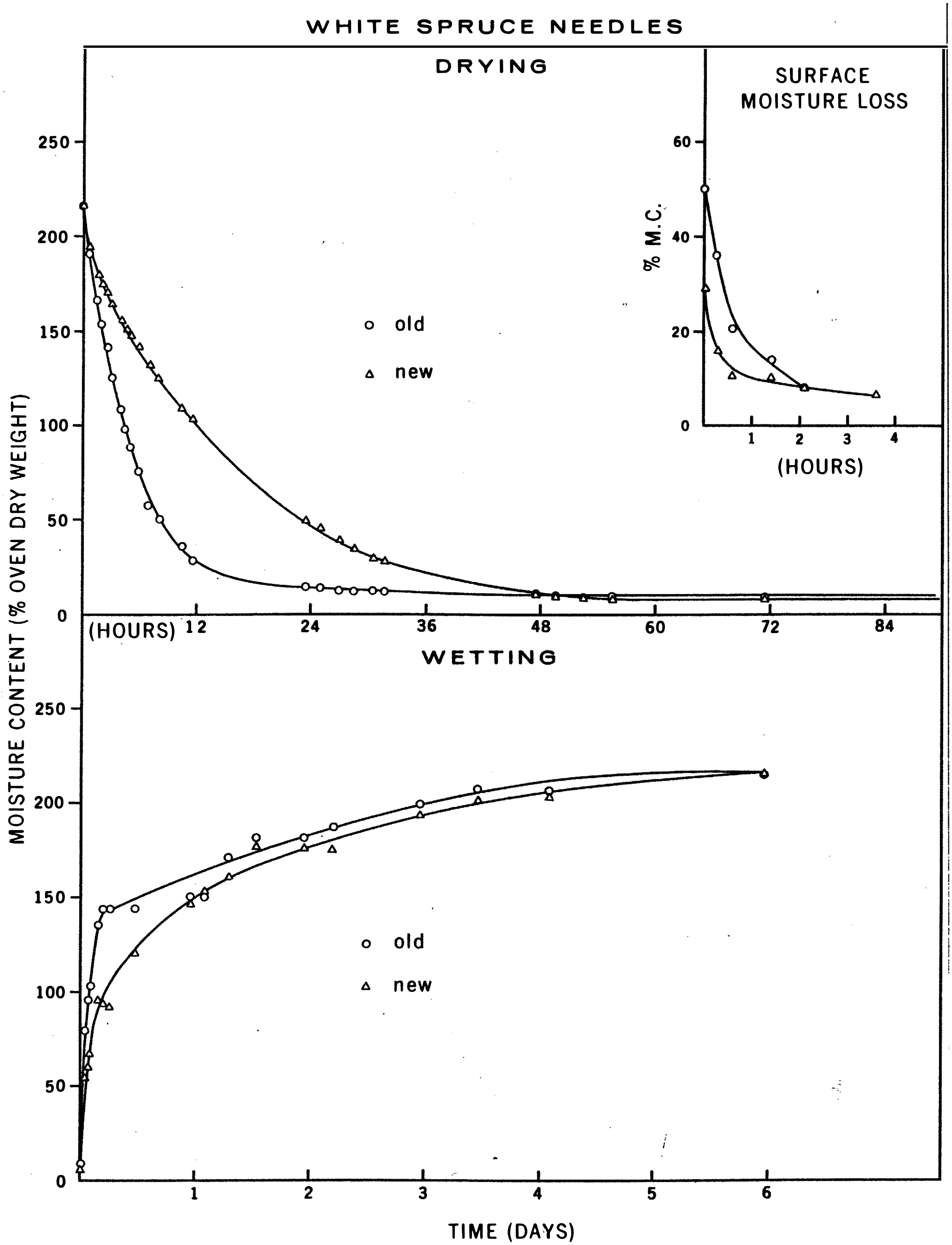


Figure 2 Moisture content as a function of time.

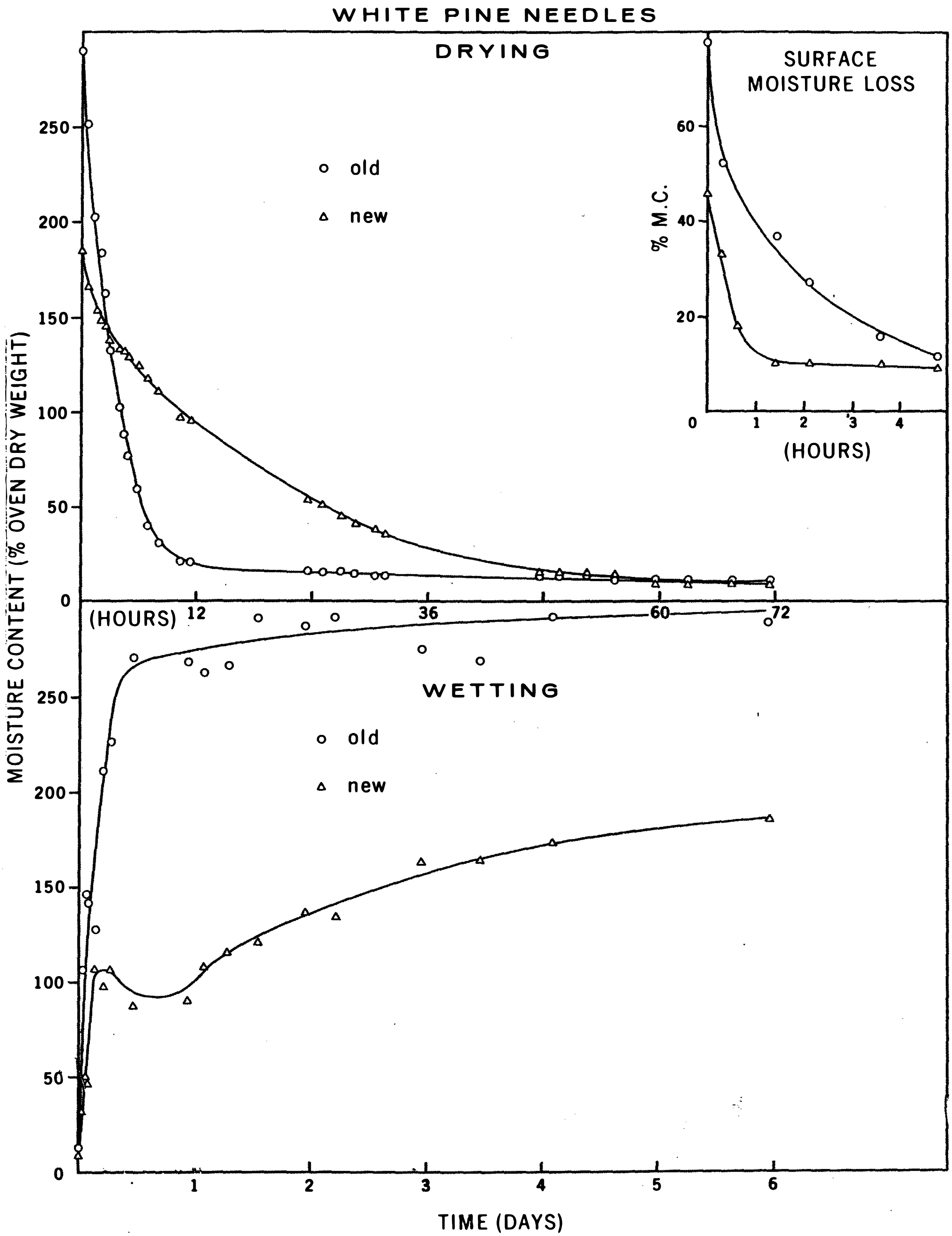


Figure 3 Moisture content as a function of time.

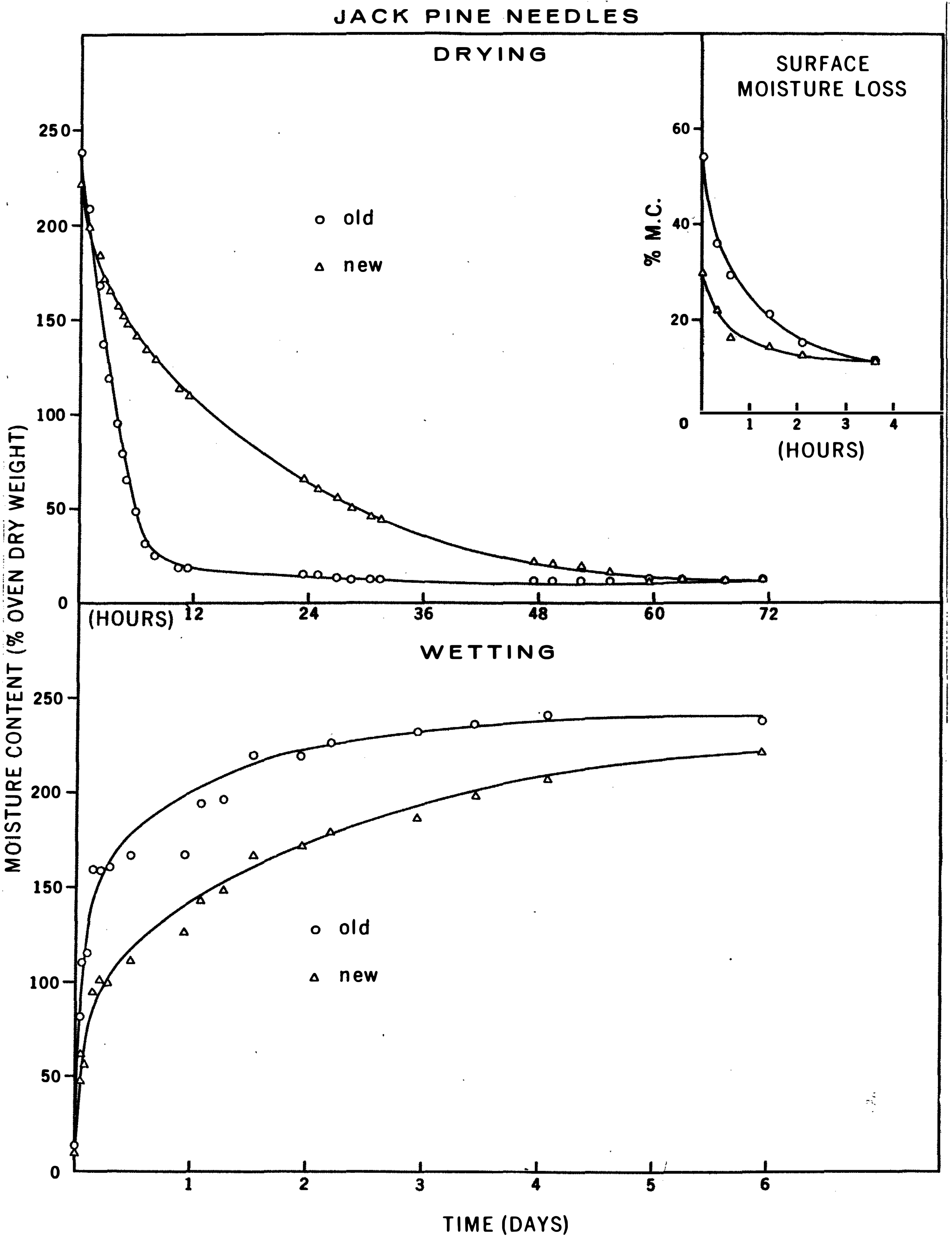


Figure 4 Moisture content as a function of time.

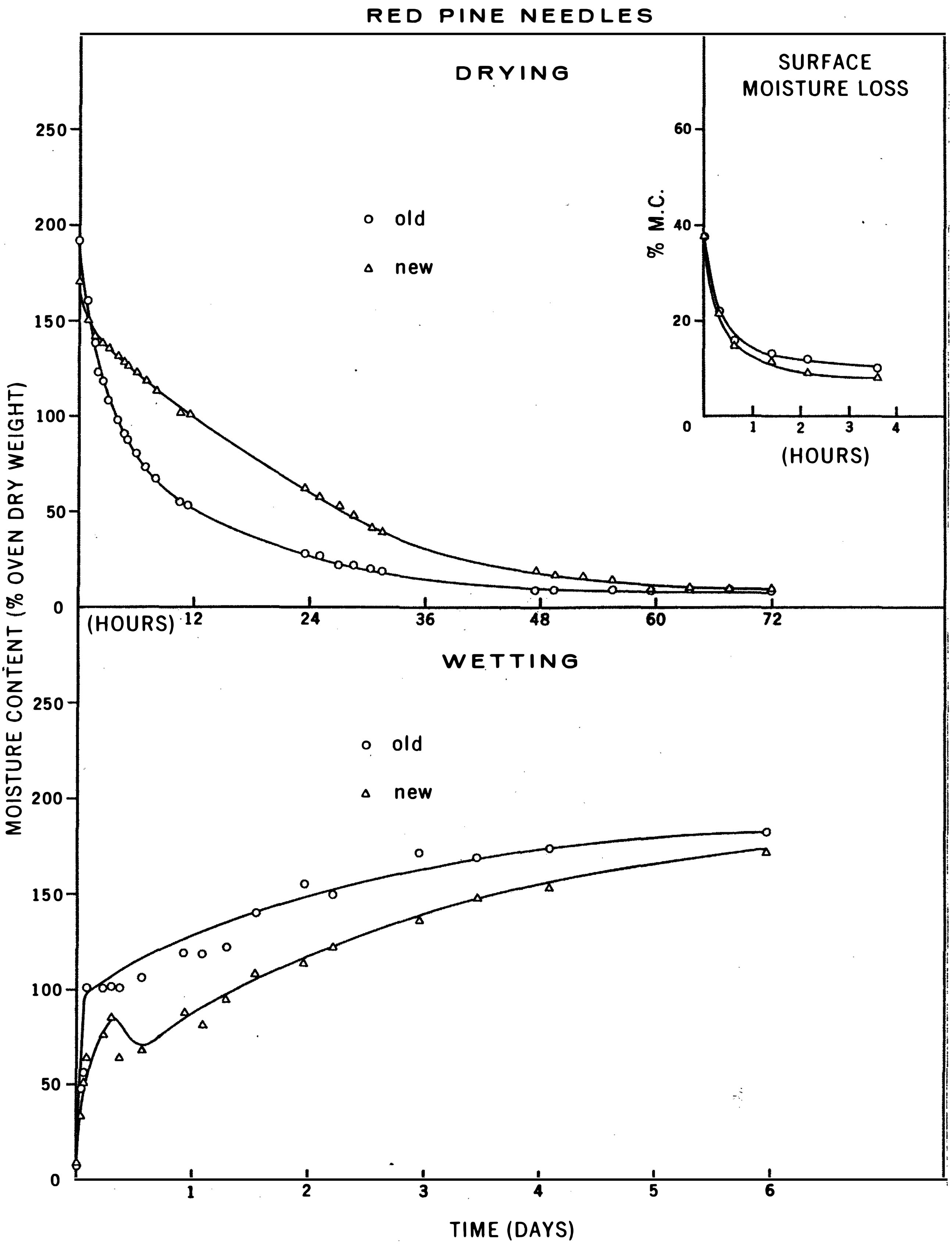
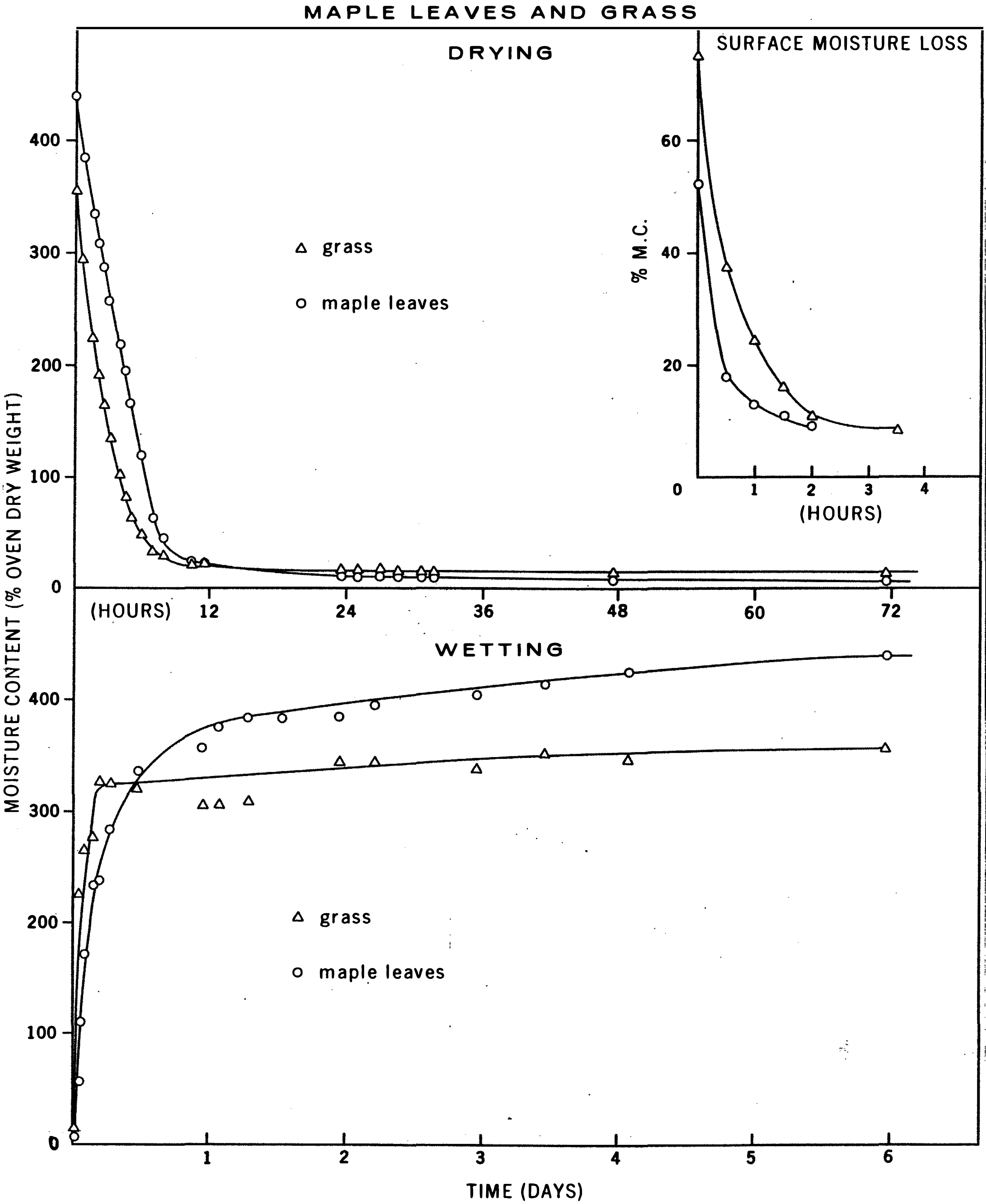


Figure 5 Moisture content as a function of time.



are about four times faster for the old material, and again the significance is greater than during the wetting phase. This indicates that once the moisture diffused into the fuel, it encountered greater resistance in getting out in the new needles. Presumably the outer wax layer on the new samples impedes the flow of moisture.

Looking at the surface moisture drying curves gives further confirmation of the above theory. In every case, the moisture content of the new material was lower than that of the old after the quick dunking tests (except Red Pine, where it was equal). It can also be noted that the old White pine needles took considerably longer to dry back to the starting moisture content than did the new. Old and new needles of Red and Jack pine took about the same time. The old White spruce needles are the only ones which dried faster than the new. This is in direct contrast to the drying time from complete saturation, where the old material dried considerably faster. Rather than being a contradiction, this is exactly what would be expected. The reasoning is as follows: In the case of complete saturation, both old and new needles have moisture inside the fuel, which has to diffuse outward. In the case of dunking, the new material has little chance to absorb water, and most of the drying is simply a matter of evaporation from the surface. The old material, on the other hand, does absorb some water, and the drying process is a combination of evaporation and diffusion, hence the difference in the ratio between old and new drying rates after a quick dunking and prolonged soaking.

In studying the drying curves, it can be seen that, in all cases, the initial rate of drying is relatively rapid. This behavior is discussed by a number of early investigators whose work is summarized by Rees and Buckman (1938) as follows:

> ". . . when the solid is very wet, the rate of moisture loss from the surface is similar to that from a free water surface; therefore, under constant drying conditions, the rate of drying remains constant. During this period, the controlling factor is the rate of evaporation through the surface air film. As drying continues, a critical point eventually is reached on the drying curve where the rate of moisture loss begins to decrease, and the range from this point to the equilibrium moisture control is called the "falling rate period"."

Rees and Buckman (1938) conducted a study of the relative rates of moisture movements in different structural directions of a number of wood samples. Using the formula for evaporation from a free water surface derived by Lurie and Michailoff (1936) Rees and Buckman computed a value of 0.0187 gms/cm/hr. for the rate of evaporation under the conditions of their experiment (81% relative humidity, and 30°C.). The actual rates of water loss which they measured in the longitudinal direction averaged 0.0128 gm/cm/hr. This difference is attributed to the necessity of maintaining a moisture gradient at the surface of the material in order for diffusion to take place.

Rees and Buckman noted that as much as 60 percent of the total water available was lost during the constant rate period, which indicates that diffusion through the material was able to keep pace with evaporation from the surface until the critical point was reached.

Detailed plotting of the first 12 hours of drying on both ordinary and semi-log paper indicates that there is an initial constant rate period or at least a rapid rate which is nearly constant for old White and Jack pine and the leaves and grass samples. These samples and also the old needles of all species but White spruce show a critical point where the rate of drying is markedly reduced.

The fact that the old material loses such a large percentage of the total water available during the constant (or very rapid) rate period indicates that diffusion through foliar material is not the most limiting factor in the initial rate of drying. Early initiation of a greatly reduced rate of drying in the new material indicates that the rate of diffusion is greatly hindered. Since the only apparent difference between the two types of sample was the outer wax layer, it is therefore concluded that this layer is much less permeable to the passage of water than the foliar material itself.

Lastly, it can be seen that the initial rate of drying for all new material, except possibly White Pine, is considerably more rapid than the average rate. This is attributed to the loss of surface water. During this period, diffusion is of little importance, as the water is already at the surface.

D. Species Differences

Some differences between the species tested are evident. Table 7 summarizes the time lags and rates of change for the various species. The significant differences between the rates of change and time lags are shown in Table 8.

Table 7 Species Differences

Species	Wetting		Drying		Average	
	Time Lag (hrs)	Rate of Increase (1)(Pct/hr)	Time Lag (Hrs)	Rate of Decrease (Pct/Hr)	Time Lag (Hrs)	Rate of Change (Pct/Hr)
Grass	2.0	106	3.0	46.7	2.5	76.4
Maple leaves	6.0	44.8	5.0	33.4	5.5	39.1
White spruce	7.0	26.6	10.0	8.6	8.5	17.6
Jack pine	13.5	25.7	10.2	8.9	11.8	17.3
White pine	16.5	23.1	10.5	9.0	13.5	16.0
Red pine	30.0	3.6	14.2	4.9	22.1	4.2
Average*	14.2	30.9	9.8	18.0		

* From individual measurements.

(1) Percent of oven dry weight per hour.

Table 8 Significance of differences between the species tested

	Grass	Maple Leaves	White Spruce	Jack Pine	White Pine	Red Pine
					Rates of change	
Grass		.40	.06	.07	.07	.02
Maple leaves	.05		.20	.30	.30	.01
White spruce	.05	.40		N.S.D.	N.S.D.	.20
Jack pine	.02	.05	.04		N.S.D.	.30
White pine	.02	.09	.40	N.S.D.		.30
Red pine	.01	.01	.01	.01	.06	
	Average time lags					

Comparing the various species, it can readily be seen that the average time lag of the fastest (grass) is about 10 times as great as the slowest (Red Pine). The rate of change for grass is about 20 times as great as for Red Pine. The grass samples used had no noticeable outer wax layer, so it is presumed that they presented little resistance to the flow of moisture, and hence the rapid rates of diffusion. The Red Pine on the other hand were the largest needles used, and appeared to have the heaviest outer wax layer - hence the slow rates of diffusion.

Due to the greater variability in the rates of change as opposed to the time lags, the significance of the differences is poorer for the former. On the basis of Table 8, it is safe to say that the rate of diffusion in grass is significantly faster than all other species tested, with the possible exception of maple leaves. Further testing with a larger sample will probably confirm this difference. The rate of diffusion in Red Pine is significantly slower than all species tested. Diffusion in Maple Leaves appears to be faster than the three remaining needle species, but the rather marginal significance of the difference between the rates suggests that further tests are needed before a definite conclusion can be reached. There appears to be little significant difference between the three remaining needle species.

E. Effects of Immersion in Water

A number of interesting observations were made on the effects of soaking the needle samples. A comparison of the moisture contents at room conditions of the soaked samples and the untreated set indicated that a change had occurred. In every case, the old needles held more moisture than the new ones at room conditions. Table 9 lists the difference between old and new for both series.

Table 9 Differences between old and new needle samples at room conditions (in Percent of Oven Dry Weight)

Species	Soaked	Untreated
White Spruce	0.8%	1.7%
Red Pine	1.2%	2.4%
White Pine	2.2%	3.7%
Jack Pine	2.1%	5.3%
Average	2.2%	4.4%

It can be seen that without exception the differences in the soaked samples are about half of those in the untreated set. This is interpreted as meaning that half of the difference between old and new needles was removed in one week of immersion in water. In other words, the new needles were aged by soaking. Rather than conclude that another week of soaking would eliminate the differences entirely, it would probably be more accurate to assume an exponential pattern for the change.

Only two samples changed their appearance during the wetting phase. The maple leaves changed from yellow to brown, while the spruce needles became a duller shade of tan. Rather than occurring gradually in the needles, the color change proceeded in an abrupt line, starting at the end where the needle had been broken from the twig. Only the spruce needles had an open end; all other samples included the entire fascicle. It was also noted that when the needles were partially waterlogged they inevitably sank with the open end down. These two observations indicate that water entered through the broken ends more readily than through the rest of the needle surface. This may be due to either increased diffusivity in a longitudinal direction, or resistance to the flow of water by the outer wax layer, or (and more likely) both.

F. Comparison of Wetting and Drying

The last question which comes to mind is whether wetting is faster or slower than drying. One would think that drying should be faster, due to the added diffusion potential of evaporation. The data gives conflicting evidence with respect to this point. The average time lag for wetting is 14.2 hours as opposed to 9.8

for drying. In contrast to this, the average rates of absorption were 30.9 and 18.0%/hr. for wetting and drying respectively. This is primarily due to the abrupt changes in the rate of wetting, which makes comparison of the curves rather difficult. Further, the average rates of change during the time lag period are of doubtful value, because as the time lags become smaller the increase in sorption rates is entirely out of proportion to the change in time lags.

Comparing a constant time period of twelve hours, the average rates of change are 19.8 and 16.9 %/hr. for drying and wetting respectively. Looking at the initial five hour period, however, the rates are 14.2 and 14.8%/hr. for drying and wetting respectively. Therefore, on the basis of this data it can only be said that there does not appear to be any consistent difference between the rates of wetting and drying of foliar material.

G. <u>Conclusions</u> - Foliage

1. There is considerable difference in the amount of water that the various species can hold. The entire range is about 250 percent. Maple leaves and grass absorb considerably more than the needle samples tested. Only Red Pine appears to be significantly different from the other needle species, in that it absorbed less during the course of the experiment.
2. There does not appear to be a significant difference in the net absorption over an extended period between old and new undecomposed needles. There is a significant difference, however, over a short period, (24 hours or less), in that the old material absorbs more (at a ratio of about 1.5:1).

3. There is a difference between the rates at which old and new material gain and lose water. In the case of absorption, the difference occurs primarily during the initial rapid increase period, which lasts for about 5 hours. In the case of drying, it starts after the surface water has been lost, and continues throughout the entire drying period. The rate of diffusion through the material does not appear to be the limiting factor. The difference is due to the reduced permeability of the outer cuticle wax layer, which is heaviest on the new material.
4. There is a difference in the rates of moisture content change between the species. Grass is significantly faster than all other species tested, and Red Pine is significantly slower. Maple leaves are probably faster than the needle species. Little difference could be found between the three remaining needle species, White Spruce, White, and Jack Pine.
5. The dissolving of solubles within the material is one of the important processes governing initial decomposition of dead foliage material.

2. Twig Samples

A. Total Absorption

Preliminary examination of the results indicated that there was a considerable difference in the total amount of water which various sized twigs of a particular species would absorb. The range was as much as 195% for maple. The results are summarized in Table 10, with a complete listing available in the appendix.

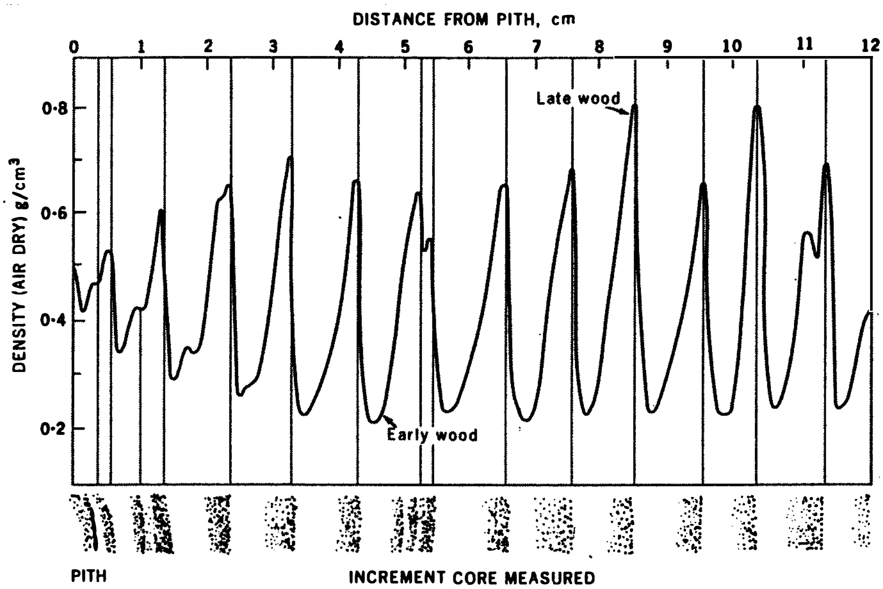
Table 10 Total Absorbed Water (in Percent of Oven Dry Weight)

Size Class (Dia. in mm)	With Bark	Without Bark	Average
1.0-3.0	196%	198%	197%
3.1-5.0	148%	210%	179%
5.1-7.0	150%	183%	166%
7.1-9.0	124%	151%	144%
9.1 +	75%	138%	117%
Average	139%	176%	158%

Kuebler (1957) found that the rates of response for equal sized samples of a single species of wood vary by one order of magnitude. Although he was working with water vapor only, the emphasis here is that there is considerable variation within a single species, despite the apparent uniformity of samples. In all cases (except Red Pine which was discarded because of considerable variability) the smaller twigs absorbed more than the larger ones. The average difference between the largest and smallest classes of twigs was 80% for all species.

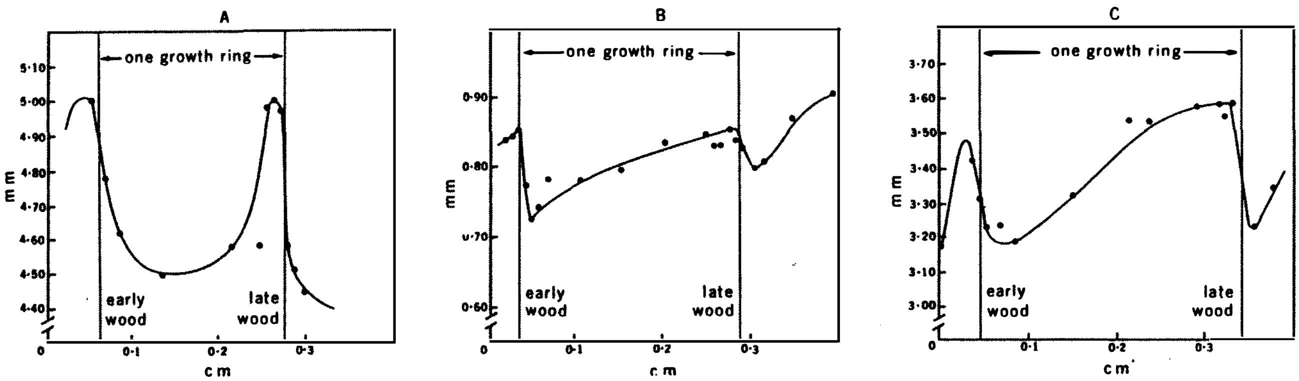
In looking for an explanation for the difference in absorptivity the question of the density of the samples suggested itself. Phillips, et al., (1962) found that the late wood within a growth ring zone of Longleaf Pine was about three times as dense as the early wood of the same ring (Fig. 6). Further, the pattern of density corresponds closely to the fiber length variation in a number of species where growth rings were apparent, as determined by Bisset and Dodswell (1956), three of which are shown in Fig. 7. They found that fibers in late wood were invariably longer than those in early wood, when growth rings were present. Examination of a graph of density across a number of growth rings of Douglas-fir, as determined by Phillips, et al. (1955), indicates the following trends: 1. The early wood decreases in density across the first five rings from the pith and then maintains a fairly constant level. The drop is from about 0.4 to 0.2. 2. The late wood increases in density across the first 8-10 rings and then is fairly constant. The range for late wood is 0.5 to 0.8. Measuring the area under the curves indicates that the average density is fairly constant across the growth rings.

Figure 6 Fiber length variation across a number of growth rings of Douglas fir



From: Phillips, (1959), The measurement of density variation within the growth rings in thin sections of wood, using beta particles, Plate 1, Forest Products Research 1959, (London: H.M.S.O. 1960). By permission of H.M. Stationery Office

Figure 7 Fiber length variation across a single growth ring



Douglas fir | Hard Maple | Monterey pine

From: Bisset and Dadswell (1950), Variations in cell length within one growth ring of certain angiosperms and gymnosperms

A more detailed examination of Fig. 7a discloses that the late wood in Douglas-fir is only 1/4 to 1/3 of the total ring width, with a rather abrupt transition. In the case of Sugar Maple, and Monterey Pine, the late wood is 50% to 75% of the total ring width, and the transition is much more gradual. Characteristics of the species tested in the present experiment, as given by Panshin and DeZeeuw (1964) are summarized in Table 11.

Table 11 Visible Characteristics of Selected Ring Porous Woods

Species	Late Wood Zone *(1)*	Difference	Transition
H. Maple	narrow	fairly distinct	gradual *(2)*
R. Pine	narrow-to-wide	distinct	fairly abrupt
W. Pine	wide	distinct	gradual
J. Pine	narrow-to-wide	distinct	abrupt
W. Spruce	moderate	distinct	gradual
Douglas-fir	narrow	very distinct	abrupt

1. Young growth where a difference exists
2. From Fig. 7.

It can be seen that in White Spruce, White Pine, and Hard Maple, the transition to the denser wood zone is gradual, while for Jack Pine it is fairly abrupt, and Red Pine and Douglas-fir have marked changes. Comparing Fig. 7a with 7b, it can be seen that if we decrease the minimum values and increase the maximum values by equal amounts over a number of growth rings, the effect on the area under the curve or average fiber length will be quite different. For Douglas-fir, where the curve is concave, it will have little effect. In fact, had the upper portion not gone up faster than the lower, the density might have decreased. For Maple, on the other hand, the average value should increase over a number of rings because the curve is convex. Therefore, if the density of the late wood increases as fast (or even faster as in the case of Douglas-fir), the average density of those species with more gradual transitions will increase also. From this discussion it appears possible that the density of a number of the species tested actually increased as the diameter of the twig increased.

Since the difference in absorption had not been anticipated, no volume or density measurements were made prior to the experiment. In an effort to determine the degree of uniformity of the material from which the samples had been selected, the density of a number of different sized twigs of all species tested was determined separately. The results were stratified, and class averages were determined. The density averages are plotted in Fig. 8. Average values for absorption are also plotted in Fig. 8.

Figure 8 Relationship between average total absorption and average twig density as a function of average twig size.

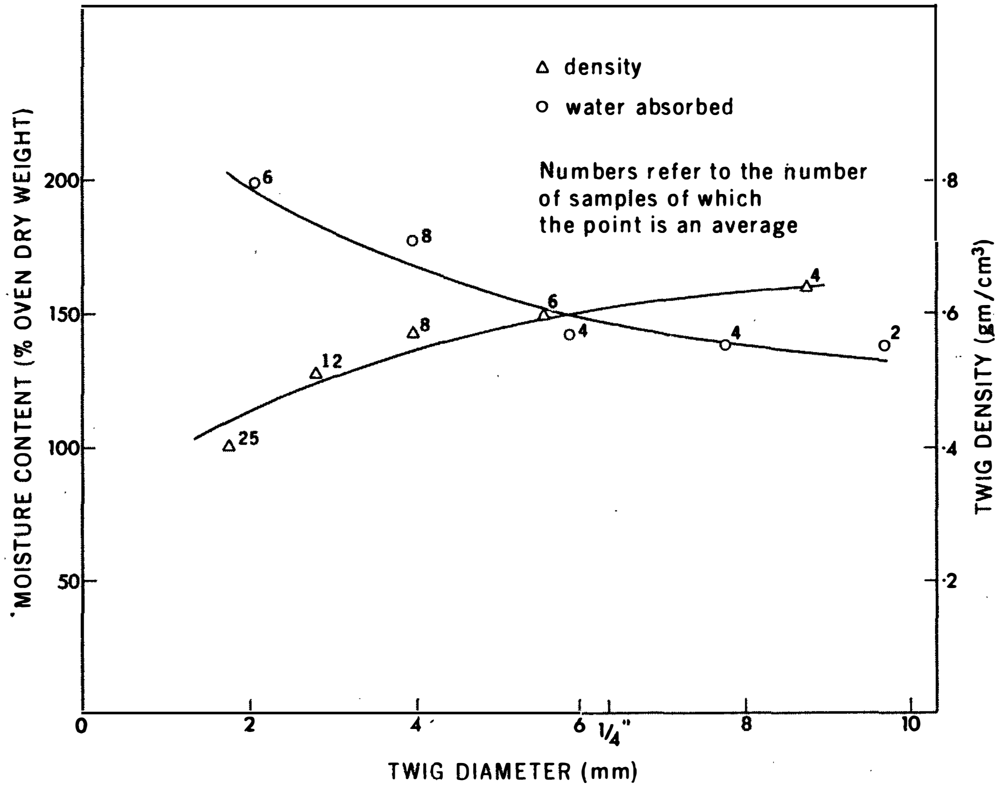
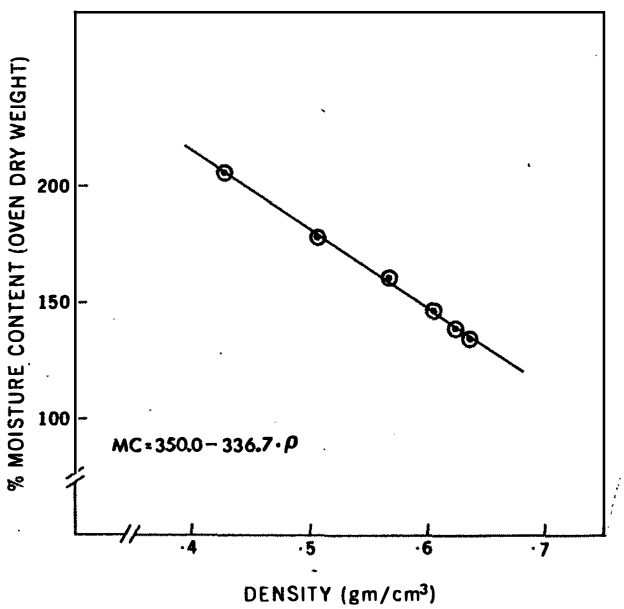


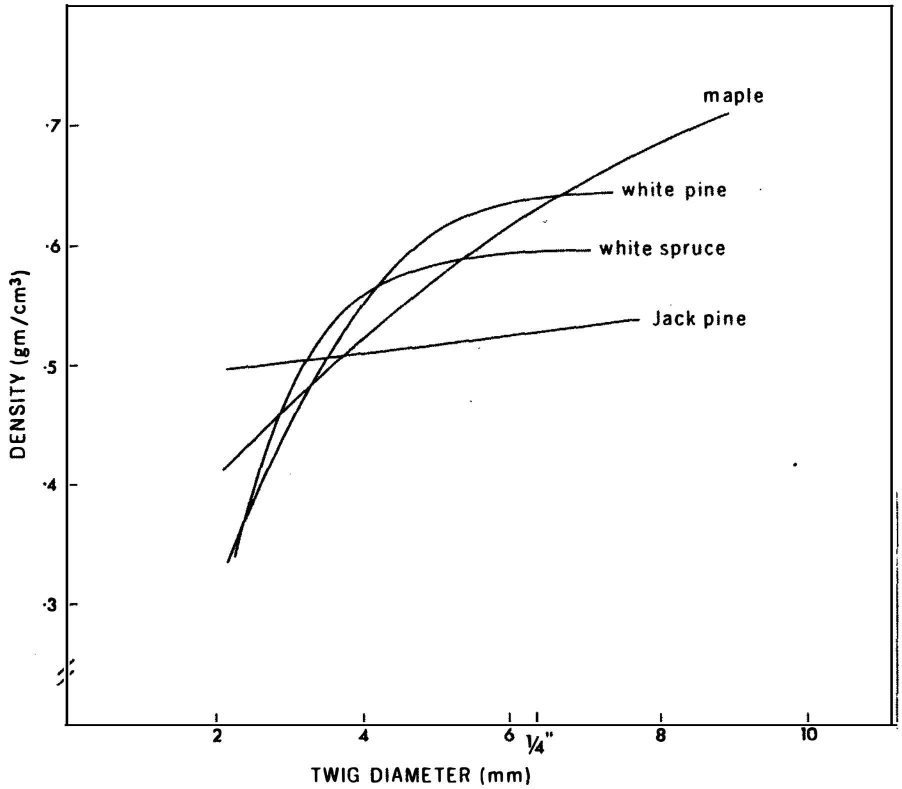
Figure 9 Relationship between average moisture content and average twig density.



The assumption was made that the density of the soaked samples was the same as that for comparable sized twigs used for density determination. Average values for absorption and density for comparable size twigs were then determined from Fig. 8, and plotted in Fig. 9. The values obtained closely approximate a straight line, with a negative slope, which suggests that adsorption is inversely proportional to the density of the wood. This seems to be reasonable, since the denser wood would have fewer air spaces, and therefore could hold less water, (assuming that the intake of liquid water is proportional to the air space present). A review of the literature failed to disclose any evidence which supports or contradicts the premise. Therefore, additional research will be necessary, involving a greater number of samples, with greater uniformity, and more accurate measurements before any definite conclusion can be drawn with respect to the relationship between absorption and density.

A breakdown of the average density by species and size class can be seen in Fig. 10. It is interesting to compare the slope of the curves with the verbal descriptions listed in Table 11. The three species with gradual transitions between early and late wood (Maple, Spruce, White Pine) have the greatest differences, while Jack Pine has considerably less. Red Pine (not shown) was highly variable (as was the amount of water absorbed) but showed no tendency to increase with increasing size. It should be mentioned, however, that the amount of deterioration of the Red Pine samples appeared to be less uniform than the other species.

Figure 10 Relationship between wood density and average twig size by species.



Further examination of Table 10 may lead one to believe that the samples with bark absorbed less than those without. The average for all samples was 139% and 176% for those with and without bark, repsectively. This is further compounded by the fact that the average diameter of the samples with bark was 2.0 mm smaller. The values were 4.1 mm and 6.1 mm for twigs with and without bark, respectively. From the previous discussion, the smaller twigs would be expected to absorb more water. One factor which cannot be overlooked, however, is that all samples were picked from the field. It is to be expected that a twig which has lost its bark would be more deteriorated than one which has not, and therefore it would have a lower density. This cannot be overlooked, and if this difference does exist, it probably would account for a large proportion of the difference between the samples with and without bark.

B. Rate of Water Absorption

The twigs did not behave as did the foliage samples. For the foliage, the rates of water absorption differed, but the final values reached were not too far apart. In the case of the twigs, the final values reached were considerably different. Figs. 11 through 14 show the adjusted values. The numbers adjacent to the symbols refer to the sample numbers listed in the appendix. The problem which presents itself is one of determining what proportion of the differences in rates are due to the factors which are being measured (twig size and bark) and how much is simply a function of the differences in total absorption.

The nature of the results are such that the effect of size on rate of diffusion cannot be easily separated from the effect of size on total absorption. Naturally, the rates of absorption in the smaller twigs are faster than those in the larger ones. The question is whether they are even faster than what would be expected due to the different amounts absorbed. Rates of absorption for the various size classes were determined for a number of periods, and are presented in the appendix. What is more pertinent for the present discussion, these rates were divided by the total amount of water absorbed by each class. Comparison of the relative rates of absorption as a percent of the total moisture gained indicates a slight downward trend as

Figure 11 Moisture content as a function of time.

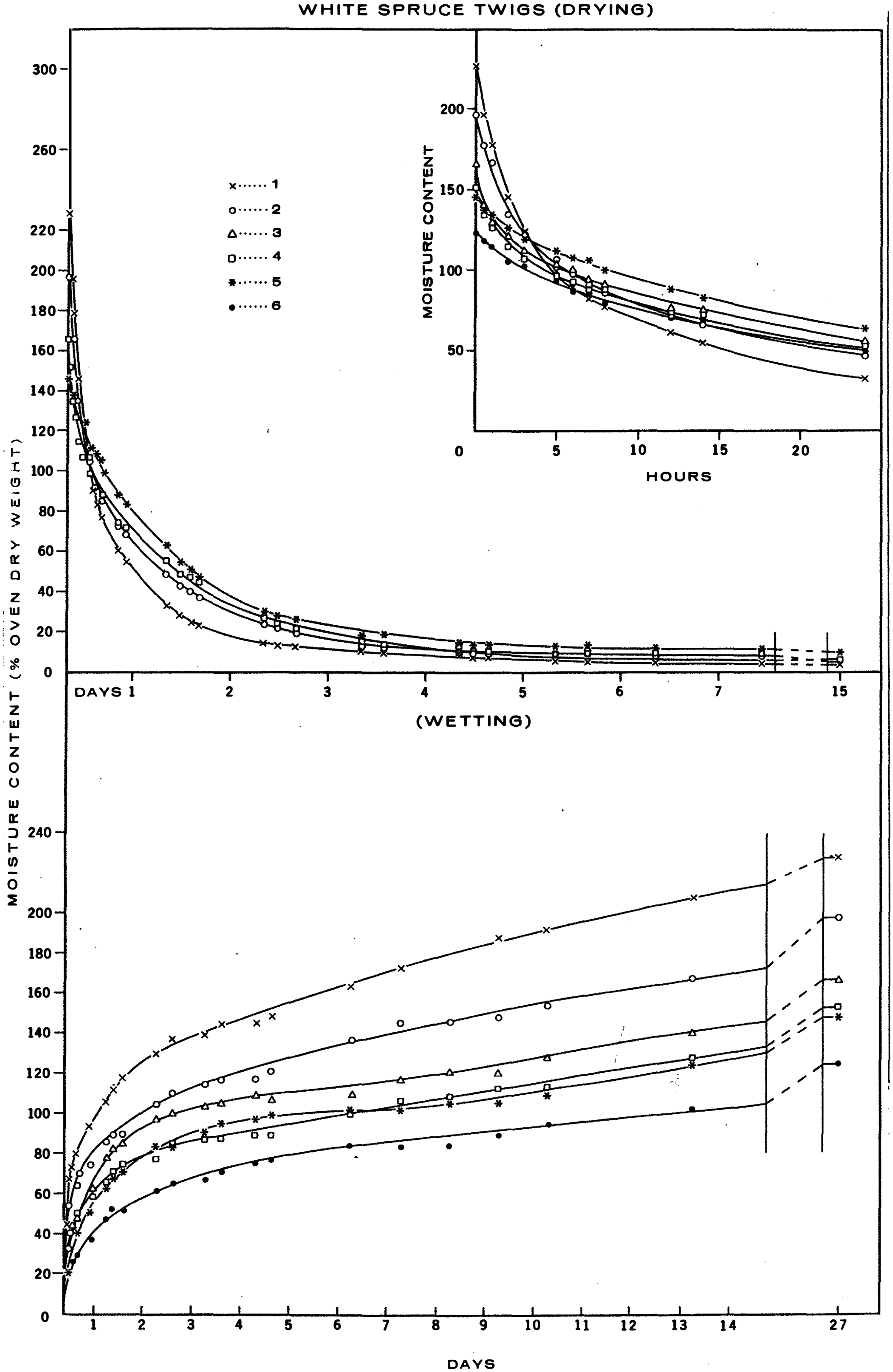


Figure 12 Moisture content as a function of time.

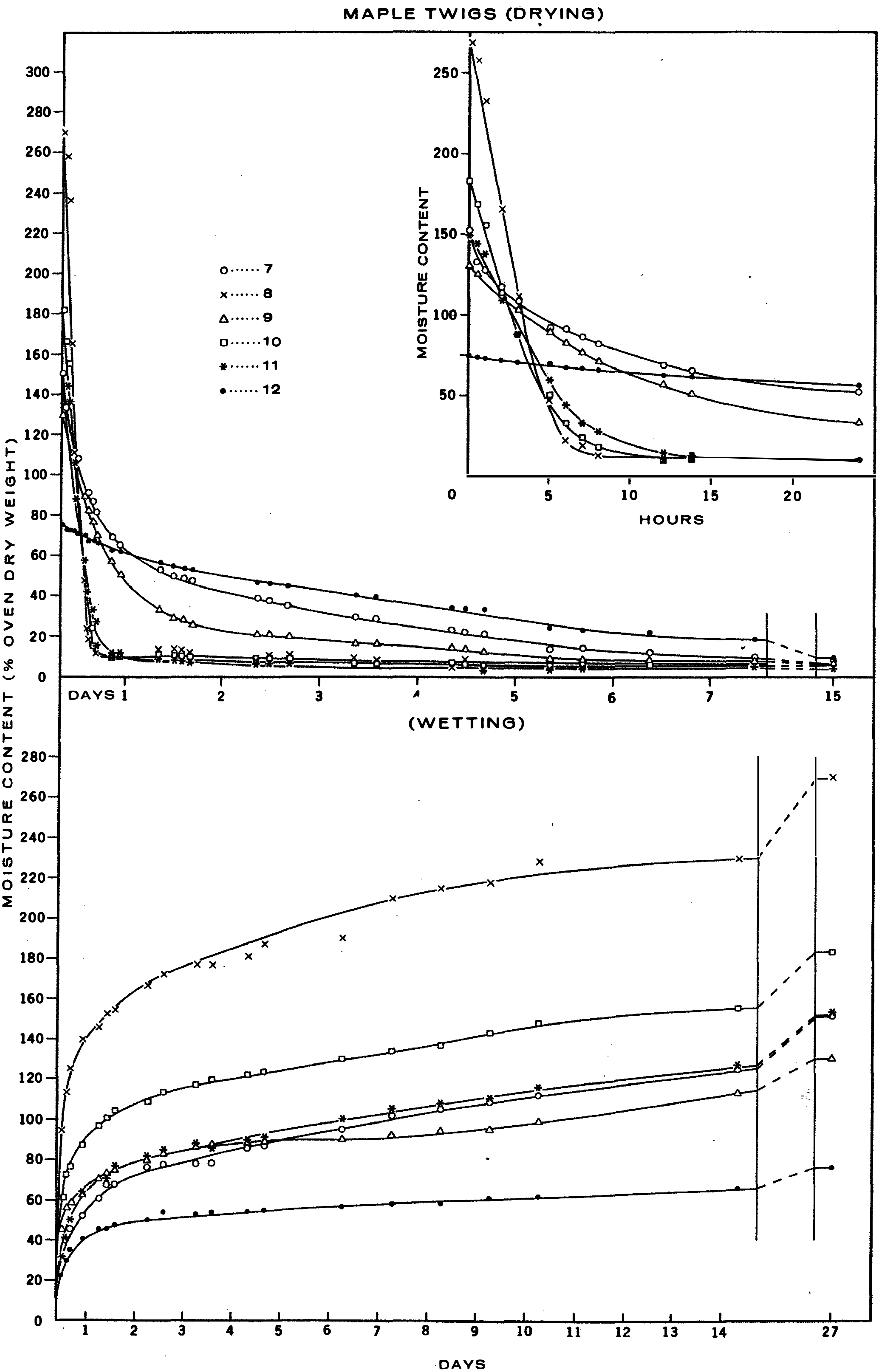


Figure 15 Moisture content as a function of time.

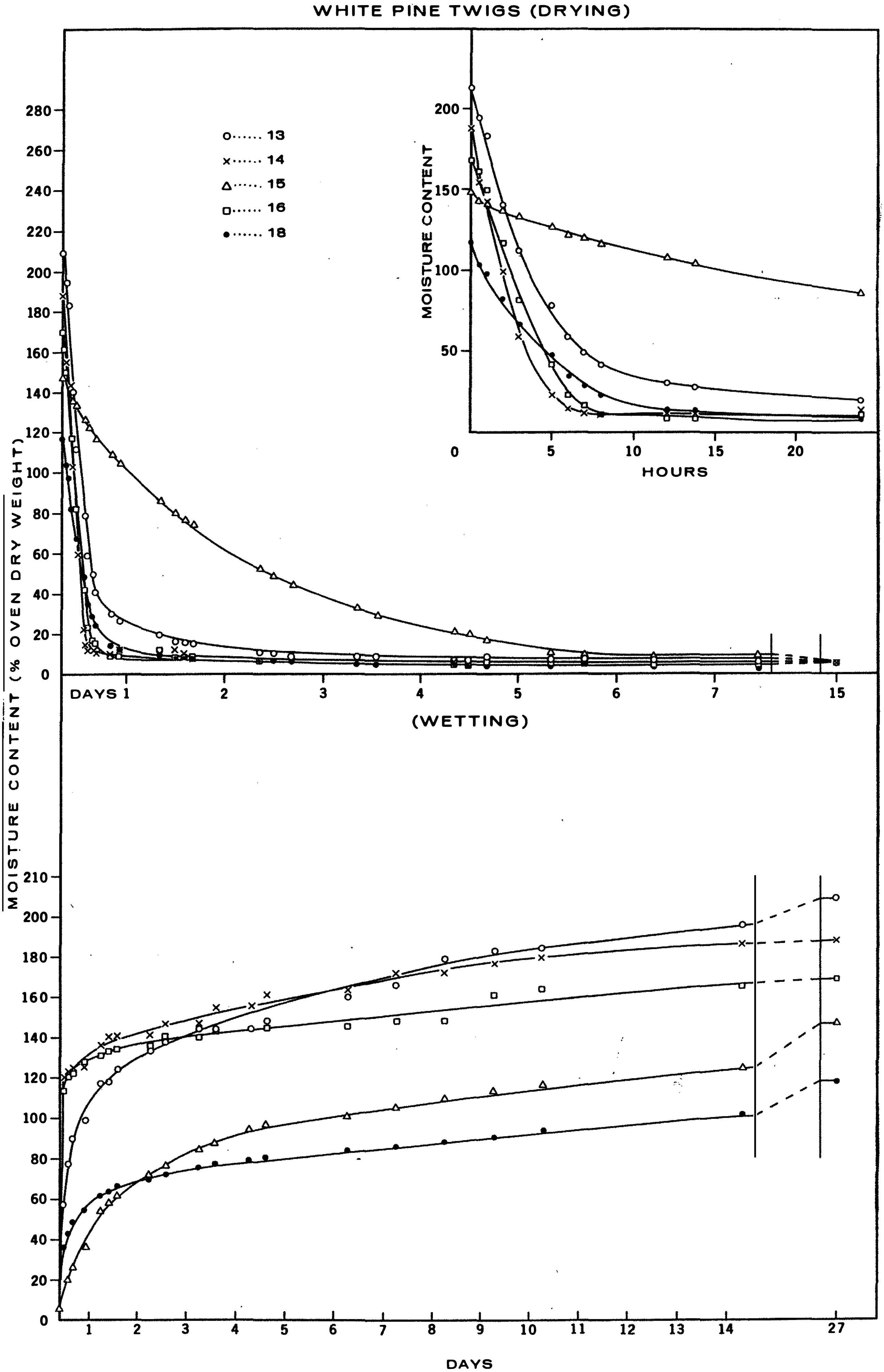
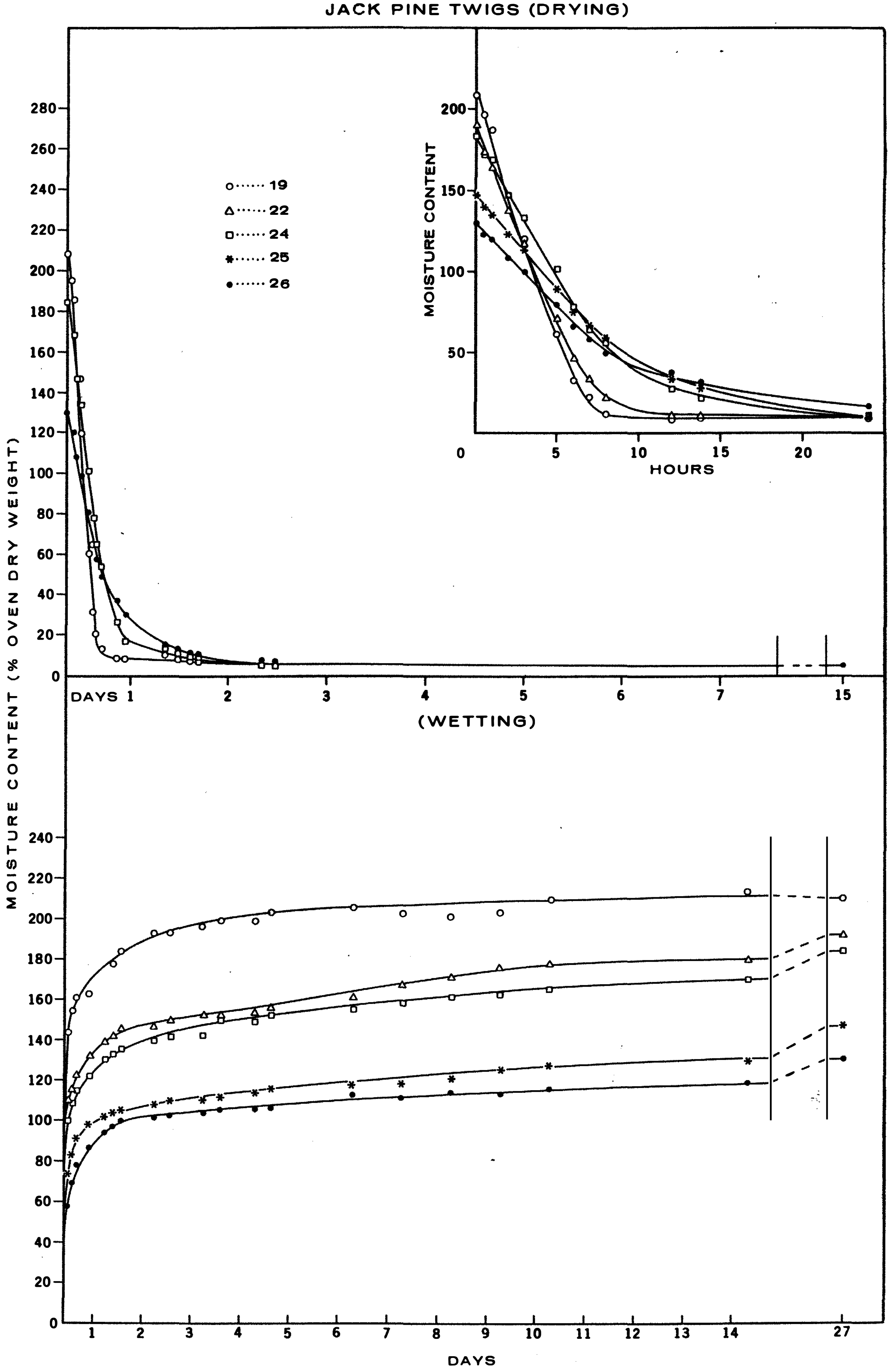


Figure 14 Moisture content as a function of time.



size increases in the smaller sizes, but this does not continue through the larger size classes. Sample variation and a small sample size may be the reasons for this. Comparing the magnitude of the difference between fastest and slowest rates, we can see that during all three periods, (5, 12 and 48 hours), the fastest absolute rate is about twice as fast as the slowest. The difference between the relative rates is about one and a half to one during the five and twelve hour periods, and decreases to almost no difference at 48 hours. This suggests that, initially, the slower absolute rate of absorption for larger sized twigs is due to both slower diffusion rates and lower total water gain. Under prolonged soaking the difference in amounts absorbed seems to become more important.

Further compounding the problem, Rees (1938) found that the rate of liquid water loss increased with decreasing density. Presumably the same relationship holds for moisture gain. Linton (1962) found that response time (below the fiber saturation point) increases with increasing thickness of wood, although not in proportion to the square of the thickness as Kuebler (1957) suggests. Byram (1963) suggests that for fine material it may be more on the order of the first power of the thickness. The present experiment indicates that for twigs less than 6 mm in diameter a fourfold increase in diameter makes a difference of only 50 percent in the rate of diffusion. Diffusion does not appear to be the limiting factor in fine twigs as it may be in larger material.

The difference with and without bark is slightly easier to demonstrate. Comparing the relative ratios between the two, we see that during the first five hours the twigs without bark gain water almost twice as fast as those with bark. During the twelve hour period, the ratio drops to 1.6:1, and during the 48 hour period it is 1.3:1. From the present study it can be concluded that the presence of bark on small twigs reduces the rate of water absorption by about one half. This is less than what would be expected from the work of Reifsnyder (1967), who gives values for moisture diffusivity through bark of 1/4 to 1/8 that of wood. It should be noted that the single bark thickness of all samples was only about 0.4 mm, so that a reduction of 1/2 may not be out of line. No doubt thicker bark would be more effective in reducing diffusion.

C. Rate of Water Loss

Prior to processing the data, certain samples had to be eliminated due to the fact that the bark had cracked or separated from the wood during soaking. Examination of the drying curves indicated that Maple No. 9, and White Pine No. 13 did not behave as did the other samples with tight bark. The samples were examined and found to have loose bark. The curves indicate, as would be expected, that loose bark modifies the rate of diffusion so that it lies between what would be expected with tight bark and no bark at all.

Considering the effect of twig size on the rate of drying, about the same results are obtained as with the wetting portion. A summary of the drying data can be found in the appendix. While the actual rates of change of the smallest twigs is about five times as fast as the largest during the first five hours, the rates as a percent of the total change are just about double. We can, therefore, conclude again that a fourfold increase in size halves the rate of loss (in relative terms). The ratio is reduced by the end of the twelve hour period, because many of the twigs are approaching their equilibrium values. By the end of the 48 hour period, all twigs except the larger ones with bark have reached equilibrium with room conditions.

The effect of bark is clearly seen. Initially, the twigs without bark dry almost three times as fast as those with bark (when the rate is measured as a percent of the total ultimate change). During the twelve hour period, the difference is reduced only slightly. By the end of the 48 hour period, however, there is very little difference in the average rates, as most of the twigs have nearly completed drying.

Looking at the percent of the total change completed, it can be seen that all but the largest twigs without bark are close to the equilibrium moisture content within twelve hours. Even after 48 hours, the fastest twig with bark has only completed 90% of the total change, and the slowest 39%.

The fact that all but the larger twigs without bark approach a constant rate of loss initially indicates that diffusion is not the main limiting factor in the smallest twig sizes (6 mm and less). It must be concluded, therefore, that the difference in the rate of loss in the smaller twigs is due entirely to the presence of bark.

The effect of bark does not appear to be constant, but rather it seems to be of increasing importance with increasing twig size. In the smallest sizes, the ratio of rates of loss of the twigs without bark to those with was 1.7:1, while for the largest size it was 4.7:1. It appears that as twig size (and hence bark thickness) increases, bark becomes more effective in reducing the passage of water.

The fact that most of the twigs with bark and the larger ones without bark did not dry at a rapid and constant rate initially is attributed to the fact that most of the surface water was removed prior to drying.

Comparing the average rates of wetting and drying for all twig samples given in the appendix, it can be seen that, on the average, drying is about 1.4 times as fast as wetting. As previously mentioned, this is what one would expect, considering the added diffusion potential of evaporation during the drying process.

D. Effects of Immersion in Water

The loss of weight during the experiment is summarized by size classes in Table 12.

Table 12 Loss of Weight by Size Class

Size Class (Dia. in mm)	Average Loss (in Percent of Oven Dry Weight)
1.0 - 3.0	17.8%
3.1 - 5.0	11.6%
5.1 - 7.0	11.7%
7.1 - 9.0	9.4%
9.1 +	5.1%

It can be seen that the smallest twigs lost 3.5 times as much material (in terms of percent of oven dry weight) as the largest size. This is reasonable, considering that the cambial region contains most of the young material, and is most actively involved in the translocation of the various nutrients required by the tree. These substances are generally soluble, hence - the greater is the proportion of cambial tissue in relation to the entire twig, the greater will be the amount of material dissolved.

E. Comparison of Twigs with Foliage

There does not appear to be a valid basis for comparing twigs with foliage. Every method used leads to a different conclusion. There are so many complicating factors involved that such a comparison would be of questionable value, if it were attempted. However, a few general comments would be appropriate at this time.

The smallest twigs, (3 mm and less), without bark lose water at about the same rate as the old needles. The time lags for both are short, (5 hours or less), and the drying rates are rapid. The sorption rates of even the smallest twigs with bark are slower, and the time lags are longer than any of the foliage samples. Lastly, the twigs show a greater difference between wetting and drying than the foliage samples.

F. Conclusions - Twigs

1. There is a considerable difference in the amount of water that can be absorbed by different sized twigs of a single species for twigs 6 mm or less in diameter. The smallest twigs absorb the most. The amount of water absorbed may be a function of the density of the material.

2. Small twigs without bark will gain water about twice as fast as those with bark. They will lose it two to five times as fast.

3. With respect to twigs 6 mm or less in diameter, a fourfold increase in size reduces the relative moisture content change by a ratio of about 1.5 to 1, irrespective of the absolute amount of water absorbed. The actual rate of change is reduced by about two to one. The difference between the two is primarily a function of the difference in total water absorbed.

4. As bark thickness increases, its effectiveness in retarding the diffusion of water also increases during the drying process. This is not apparent during the wetting phase.

SUMMARY

To investigate moisture content changes above the fiber saturation point a number of foliage and twig samples were soaked for an extended period and then dried. The most important problem encountered was loss of weight by the samples during soaking. A number of possible reasons for the weight loss are discussed. The most likely answer appears to be the dissolving of soluble substances within the samples.

The results indicate that there is a difference in total water retention and sorption rates between the various foliage samples. Grass and Maple leaves absorb considerably more than the other samples tested, and the sorption rate is faster. Red pine absorbed less than the other samples, and the sorption rate was much slower. Weathered needles absorb water faster than freshly fallen material. This is thought to be due to the outer cuticle wax layer.

With respect to the twig samples, the major problem encountered was the large range in total water absorption by a number of twigs of the same species. The smallest twigs absorbed the most water in terms of percent of oven dry weight. This difference is tentatively attributed to a difference in twig density, with density increasing as twig size increases.

The results indicated that the small twigs without bark gain and lose water two to five times as fast as those with bark. A fourfold increase in twig size reduces the average sorption rate by about 1.5:1, (when the effects of the differences in total absorption are eliminated).

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APPENDIX

This appendix contains lists of all data from the soaking experiment. It also contains the summaries of wetting and drying information over a number of periods referred to in the paper.

List of Tables

TABLE 1

LIST OF FOLIAGE SAMPLES

No.	Name
1	Maple Leaves
2	Spruce (old)
3	Spruce (new)
4	Jack Pine (old)
5	Jack Pine (new)
6	Grass
7	Red Pine (old)
8	Red Pine (new)
9	White Pine (old)
10	White Pine (new)

TABLE 2

FOLIAGE SAMPLE WEIGHTS - WETTING PHASE (UNADJUSTED)

Time	1	2	3	4	5	6	7	8	9	10
0.0	2.00	1.90	1.85	1.90	1.90	2.08	1.78	1.61	1.57	1.80
1.0	2.58	3.03	2.53	3.01	2.48	5.60	2.40	1.99	2.87	2.17
1.5	3.17	3.30	2.60	3.45	2.72	5.60	2.54	2.25	3.38	2.46
2.0	3.86	3.41	2.71	3.51	2.55	6.25	3.26	2.41	3.28	2.38
3.5	4.59	3.93	2.91	4.12	3.15	6.40	3.20	2.60	4.41	3.35
4.5	4.61	4.06	3.10	4.20	3.24	7.29	3.22	2.74	4.10	3.17
6.5	5.13	3.99	3.06	4.20	3.21	7.21	3.17	2.39	4.30	3.29
11.5	5.71	3.99	3.45	4.31	3.39	7.09	3.26	2.45	4.84	3.00
23.0	5.86	4.07	3.80	4.29	3.60	6.80	3.45	2.70	4.80	3.03
26.0	6.00	3.96	3.90	4.60	3.87	6.88	3.43	2.62	4.73	3.30
31.0	6.14	4.27	4.00	4.74	3.91	6.88	3.50	2.81	4.79	3.43
37.0	6.05	4.47	4.24	5.09	4.20	7.23	3.79	3.00	5.12	3.50
47.0	6.01	4.42	4.07	4.95	4.28	7.42	4.02	3.07	5.04	3.76
53.0	6.11	4.32	4.32	5.08	4.38	7.39	3.93	3.20	5.10	3.72
71.0	6.07	4.57	4.31	5.14	4.48	7.30	4.29	3.40	4.87	4.17
83.0	6.15	4.70	4.39	5.18	4.62	7.49	4.20	3.56	5.02	4.19
98.0	6.17	4.69	4.40	5.24	4.76	7.40	4.30	3.63	5.08	4.33
143.0	6.10	4.77	4.49	5.13	4.91	7.50	4.41	3.88	5.02	4.50

Oven Dry Weights

1.13	1.51	1.42	1.52	1.53	1.64	1.57	1.43	1.29	1.58

Weight Lost During Experiment

0.78	0.25	0.31	0.19	0.21	0.23	0.06	0.06	0.13	0.07

TABLE 3

FOLIAGE SAMPLE WEIGHTS - DRYING PHASE

Time	1	2	3	4	5	6	7	8	9	10
0.0	6.10	4.77	4.49	5.13	4.91	7.50	4.41	3.88	5.02	4.50
0.75	5.51	4.40	4.19	4.68	4.57	6.45	4.00	3.58	4.53	4.21
1.5	4.92	4.01	3.98	4.08	4.34	5.31	3.75	3.44	3.92	4.00
2.0	4.62	3.83	3.91	3.86	4.27	4.77	3.51	3.41	3.66	3.91
2.5	4.39	3.62	3.85	3.60	4.15	4.32	3.41	3.39	3.38	3.87
3.0	4.05	3.40	3.75	3.33	4.06	3.87	3.26	3.35	3.02	3.79
4.0	3.62	3.16	3.63	2.97	3.94	3.32	3.10	3.32	2.64	3.70
4.5	3.35	2.98	3.57	2.72	3.86	2.98	3.00	3.24	2.44	3.67
5.0	3.02	2.84	3.52	2.52	3.80	2.72	2.93	3.23	2.28	3.60
6.0	2.48	2.64	3.43	2.27	3.70	2.46	2.82	3.17	2.05	3.53
7.0	1.88	2.39	3.30	2.00	3.59	2.20	2.72	3.11	1.81	3.43
8.0	1.65	2.27	3.20	1.90	3.50	2.13	2.62	3.04	1.69	3.33
10.5	1.40	2.06	2.95	1.81	3.26	2.00	2.44	2.89	1.58	3.10
11.5	1.39	2.01	2.90	1.80	3.21	2.00	2.41	2.86	1.57	3.08
23.5	1.26	1.73	2.13	1.74	2.52	1.90	2.00	2.30	1.50	2.42
25.0	1.25	1.73	2.07	1.74	2.45	1.90	1.98	2.24	1.49	2.38
27.0	1.25	1.70	1.97	1.73	2.38	1.90	1.92	2.17	1.49	2.29
28.5	1.24	1.70	1.91	1.71	2.30	1.88	1.91	2.10	1.48	2.23
30.5	1.23	1.70	1.83	1.71	2.22	1.88	1.88	2.02	1.47	2.18
31.5	1.22	1.69	1.81	1.71	2.20	1.88	1.86	2.01	1.47	2.14
47.5	1.22	1.67	1.59	1.71	1.87	1.88	1.77	1.71	1.47	1.84
49.5	1.22	1.66	1.59	1.71	1.84	1.88	1.75	1.68	1.47	1.83
52.5	1.22	1.65	1.59	1.71	1.83	1.88	1.75	1.68	1.47	1.82
55.5	1.22	1.65	1.54	1.71	1.81	1.88	1.75	1.63	1.47	1.82
71.5	1.22	1.65	1.54	1.71	1.71	1.85	1.72	1.58	1.44	1.73
75.0	1.22	1.65	1.54	1.71	1.71	1.85	1.72	1.58	1.44	1.73
79.5	1.22	1.65	1.54	1.71	1.71	1.85	1.72	1.58	1.44	1.73
95.5	1.22	1.65	1.54	1.71	1.69	1.85	1.72	1.55	1.44	1.73

TABLE 4

SUMMARY OF FOLIAGE WETTING MEASUREMENTS

	Maple		White Spruce			White Pine			Red Pine			Jack Pine		
	Leaves	Grass	Ave.	New	Old	Ave.	New	Old	Ave.	New	Old	Ave.	New	Old
Total Water Absorbed[1]	440%	357%	216%	216%	216%	237%	185%	289%	176%	171%	181%	229%	221%	238%
Surface Water	52%	75%	30%	29%	50%	63%	47%	78%	37%	37%	37%	42%	30%	54%
Net Total Water	388%	282%	177%	187%	166%	175%	138%	211%	139%	134%	144%	188%	191%	184%
Time of Rate Change (Hrs. from Start)	13	4	4.5	4	5	7	4	10	5	7	3	5	6	4
M.C. at Rate of Change[2]														
Actual	350%	320%	119%	96%	143%	186%	106%	265%	92%	85%	98%	132%	107%	157%
As Fraction of Total	.80	.89	.55	.44	.66	.75	.57	.92	.52	.50	.54	.57	.48	.66
Rate of Increase (%/hr) Rapid Rate Period														
Actual	26.3	77.0	24.4	22.0	26.8	24.8	24.2	25.3	20.2	11.0	29.3	27.5	16.2	38.8
As Fraction of Total	.062	.222	.122	.110	.132	.107	.142	.092	.104	.071	.180	.114	.080	.165
Time Lag (hrs)	6	2	7	11	3	16.5	29	4	30	37	23	13.5	24	3
Rate of Increase (%/hr) Time Lag Period														
Actual	44.8	106	26.6	11.6	41.6	23.1	3.7	42.5	3.6	2.7	4.5	25.7	5.4	46.0
As Fraction of Total	.105	.315	.090	.057	.210	.038	.022	.158	.021	.017	.027	.047	.028	.210
Moisture Content at End of Time Lag Period	277%	225%	136%	136%	136%	145%	116%	182%	111%	108%	114%	111%	139%	150%

[1] All moisture contents are in % oven dry weight.

[2] Moisture Content

TABLE 5

SUMMARY OF FOLIAGE MEASUREMENTS DURING SELECTED TIME INTERVALS

	Maple		White Spruce			White Pine			Red Pine			Jack Pine		
	Leaves	Grass	Ave.	New	Old	Ave.	New	Old	Ave.	New	Old	Ave.	New	Old
Moisture Content Change End of First 5 hrs.														
Drying	275%	285%	98%	68%	128%	130%	57%	204%	73%	43%	103%	120%	71%	168%
Wetting	249%	317%	115%	95%	135%	142%	96%	188%	81%	67%	95%	118%	151%	86%
Rate of Change (%/hr) During First 5 Hours														
Drying	55.0	57.0	19.6	13.6	25.6	26.0	11.4	40.8	14.6	8.6	20.6	24.0	14.2	33.6
Wetting	49.8	63.4	23.0	19.0	27.0	28.4	19.2	37.6	16.2	13.4	19.0	23.6	17.2	30.2
Moisture Content Change End of First 12 hrs.														
Drying	429%	345%	152%	116%	187%	178%	91%	264%	106%	71%	140%	166%	113%	219%
Wetting	331%	325%	130%	117%	142%	171%	86%	256%	85%	64%	106%	138%	109%	167%
Rate of Change (%/hr) During First 12 hrs.														
Drying	35.8	28.8	12.7	9.7	15.6	14.8	7.6	22.0	8.8	5.9	11.7	13.8	9.4	18.2
Wetting	27.6	27.1	10.8	9.8	11.8	14.2	7.2	21.3	7.1	5.3	8.8	11.5	9.1	13.9
Moisture Content at End of 2nd 48 hrs.														
Actual	400%	340%	182%	180%	184%	210%	135%	285%	140%	122%	158%	202%	179%	225%
As Fraction of Total	.91	.95	.84	.83	.85	.86	.73	.99	.79	.71	.87	.88	.81	.95
Rate of Increase (%/hr) During 2nd 48 hrs.														
Actual	1.04	0.42	1.31	1.75	0.85	0.50	0.60	0.42	1.00	0.77	1.25	1.46	1.50	1.42
As Fraction of Total	.0022	.0012	.0060	.0081	.0039	.0022	.0033	.0014	.0056	.0044	.0069	.0064	.0069	.0060

TABLE 6

SUMMARY OF DRYING MEASUREMENTS FOR FOLIAGE SAMPLES

Species	Time Lag (hrs)	Water Lost at Time Lag	Moisture Content at Time Lag	Rate of Loss (%/hr) as % Total	Rate of Loss (%/hr) of moisture Content
Maple Leaves	5.0	272%	168%	12.6%	33.4%
Grass	3.0	217%	140%	31.0%	46.7%
White Spruce	10.0	130%	86%	6.3%	8.6%
(new)	15.0	131%	85%	4.2%	5.7%
(old)	5.0	130%	86%	12.6%	17.2%
White Pine	10.5	142%	95%	6.0%	9.0%
(new)	17.5	111%	74%	3.6%	4.2%
(old)	3.5	174%	115%	18.0%	32.8%
Red Pine	14.2	106%	70%	4.4%	4.9%
(new)	21.5	103%	68%	2.9%	3.2%
(old)	7.0	108%	73%	9.0%	10.4%
Jack Pine	10.2	138%	91%	6.2%	8.9%
(new)	16.5	133%	88%	3.8%	5.3%
(old)	4.0	142%	96%	15.8%	21.0%

TABLE 7

LIST OF TWIG SAMPLES

No.	Species	Bark	Average Diameter (mm)
1	White Spruce	x	1.6
2	" "	x	2.9
3	" "	x	3.5
4	" "	x	4.8
5	" "	x	4.6
6	" "	x	6.4
7	Maple		2.8
8	"	x	4.0
9	"	x	4.0
10	"		5.3
11	"		7.6
12	"	x	8.2
13	White Pine	x	2.2
14	" "		3.1
15	" "	x	5.2
16	" "		4.5
18	" "		6.7
19	Jack Pine		2.4
22	" "		4.2
24	" "		7.1
25	" "		9.1
26	" "		14.4

Data for White Pine No. 17, Jack Pine No. 21, and all Red Pine are not included in this appendix because the data for these samples was variable. They are touched upon only briefly in Table 3.3. Jack Pine No. 20 was eliminated prior to the start of the experiment.

TABLE 8

TWIG SAMPLE WEIGHTS - WETTING PHASE (UNADJUSTED)

(grams)

Elapsed Time Days	Hours	1	2	3	4	5	6	7	8	9	10	11
	0.0	2.00	2.00	0.72	1.38	0.88	0.78	1.77	1.00	1.91	1.25	2.40
	1.0	2.75	3.00	0.95	1.80	1.00	0.89	2.18	1.73	2.56	1.85	3.00
	3.0	2.88	3.10	0.91	1.81	1.05	0.93	2.26	1.89	2.74	1.97	3.15
	4.5	2.95	3.22	0.93	1.90	1.10	0.95	2.36	1.99	2.77	2.01	3.38
	9.5	3.10	3.44	1.00	1.98	1.19	1.00	2.44	2.10	2.83	2.12	3.65
	22.0	3.33	3.62	1.10	2.07	1.29	1.07	2.57	2.15	2.95	2.24	3.78
1	1.0	3.34	3.74	1.13	2.13	1.31	1.10	2.67	2.21	3.00	2.28	3.79
1	6.0	3.35	3.83	1.15	2.17	1.32	1.10	2.67	2.23	3.03	2.32	3.90
1	22.5	3.57	4.02	1.21	2.20	1.42	1.16	2.81	2.32	3.10	2.36	4.00
2	5.0	3.68	4.13	1.22	2.28	1.39	1.18	2.83	2.37	3.16	2.41	4.05
2	22.0	3.73	4.15	1.24	2.31	1.43	1.20	2.83	2.40	3.20	2.45	4.12
3	4.5	3.77	4.23	1.25	2.31	1.46	1.22	2.80	2.40	3.22	2.48	4.13
3	23.0	3.73	4.22	1.27	2.32	1.48	1.25	2.90	2.43	3.22	2.50	4.16
4	7.0	3.80	4.30	1.26	2.31	1.49	1.26	2.93	2.48	3.27	2.52	4.20
5	22.0	4.03	4.52	1.27	2.43	1.49	1.30	3.03	2.52	3.27	2.58	4.39
6	23.0	4.17	4.69	1.31	2.50	1.50	1.30	3.13	2.68	3.29	2.62	4.49
7	22.0	4.17	4.79	1.33	2.51	1.53	1.30	3.18	2.71	3.31	2.66	4.53
8	23.0	4.20	4.90	1.33	2.55	1.53	1.34	3.23	2.73	3.33	2.71	4.61
9	22.0	4.27	4.96	1.36	2.56	1.55	1.36	3.27	2.81	3.38	2.78	4.72
13	23.0	4.47	5.16	1.42	2.72	1.65	1.40	3.43	2.81	3.60	2.83	4.87
14	22.0	4.44	5.11	1.42	2.70	1.65	1.42	3.44	2.93	3.62	2.90	4.93
15	23.0	4.52	5.15	1.48	2.73	1.67	1.42	3.53	2.95	3.62	2.90	5.00
16	22.0	4.53	5.15	1.47	2.73	1.67	1.42	3.53	2.95	3.65	2.92	5.03
19	23.0	4.70	5.27	1.48	2.80	1.71	1.48	3.69	3.00	3.72	2.99	5.15
21	22.0	4.78	5.12	1.48	2.81	1.73	1.50	3.74	3.05	3.78	3.03	5.27
24	1.0	4.67	5.23	1.50	2.87	1.77	1.51	3.72	3.00	3.79	3.08	5.31
26	22.0	4.81	5.32	1.55	2.93	1.78	1.52	3.62	3.07	3.80	3.11	5.36

Oven Dry Weights

1.62	1.62	0.58	1.16	0.72	0.68	1.50	0.83	1.65	1.10	2.13

Weight Lost During Experiment

0.27	0.28	0.10	0.16	0.09	0.07	0.17	0.11	0.16	0.08	0.18

TABLE 8 (cont'd)

TWIG SAMPLE WEIGHTS - WETTING PHASE (UNADJUSTED)

(grams)

Elapsed Time Days	Hours	12	13	14	15	16	18	19	22	24	25	26
	0.0	3.10	1.76	1.41	2.03	1.48	2.75	1.25	2.03	1.74	3.46	4.26
	1.0	3.41	2.45	2.71	2.20	2.93	3.53	2.71	3.80	3.18	5.60	6.27
	3.0	3.64	2.73	2.76	2.27	3.00	3.70	2.83	3.90	3.31	5.88	6.72
	4.5	3.75	2.89	2.80	2.36	3.05	3.83	2.89	4.01	3.43	6.13	7.10
	9.5	3.89	3.00	2.80	2.53	3.11	4.00	2.91	4.17	3.51	6.34	7.40
	22.0	4.03	3.24	2.91	2.83	3.16	4.15	3.05	4.30	3.63	6.43	7.66
1	1.0	4.03	3.26	2.95	2.91	3.19	4.21	3.05	4.36	3.67	6.51	7.78
1	6.0	4.05	3.34	2.96	2.98	3.20	4.27	3.11	4.42	3.71	6.53	7.90
1	22.5	4.13	3.45	2.98	3.15	3.21	4.38	3.20	4.44	3.78	6.61	7.97
2	5.0	4.15	3.52	3.04	3.20	3.28	4.41	3.16	4.50	3.80	6.67	8.02
2	22.0	4.20	3.58	3.00	3.35	3.23	4.49	3.19	4.53	3.83	6.71	8.06
3	4.5	4.22	3.53	3.09	3.38	3.25	4.50	3.21	4.54	3.87	6.72	8.08
3	23.0	4.25	3.52	3.04	3.50	3.29	4.57	3.19	4.58	3.91	6.79	8.08
4	7.0	4.25	3.57	3.10	3.54	3.29	4.60	3.23	4.64	3.96	6.80	8.13
5	22.0	4.30	3.71	3.12	3.61	3.29	4.69	3.25	4.70	4.00	6.87	8.27
6	23.0	4.33	3.78	3.22	3.67	3.32	4.74	3.22	4.80	4.05	6.90	8.31
7	22.0	4.35	3.94	3.21	3.73	3.34	4.82	3.11	4.88	4.10	6.99	8.38
8	23.0	4.39	3.98	3.25	3.80	3.49	4.87	3.13	4.97	4.11	7.12	8.41
9	22.0	4.41	4.01	3.28	3.84	3.53	4.94	3.19	5.00	4.13	7.18	8.45
13	23.0	4.50	4.09	3.34	3.95	3.54	5.06	3.21	5.02	4.21	7.23	8.54
14	22.0	4.51	4.14	3.31	4.00	3.58	5.10	3.12	5.10	4.20	7.24	8.61
15	23.0	4.55	4.12	3.37	4.03	3.58	5.18	3.10	5.10	4.22	7.37	8.68
16	22.0	4.55	4.11	3.30	4.10	3.58	5.19	3.11	5.12	4.22	7.38	8.70
19	23.0	4.60	4.23	3.30	4.16	3.58	5.27	3.11	5.19	4.29	7.45	8.75
21	22.0	4.67	4.19	3.30	4.22	3.60	5.32	3.16	5.20	4.32	7.51	8.82
24	1.0	4.69	4.14	3.29	4.25	3.59	5.40	3.09	5.24	4.34	7.59	8.86
26	22.0	4.72	4.11	3.28	4.25	3.55	5.41	3.09	5.25	4.34	7.68	8.92

Oven Dry Weights

2.69	1.33	1.14	1.72	1.32	2.49	1.00	1.86	1.53	3.11	3.87

Weight Lost During Experiment

0.13	0.34	0.20	0.20	0.09	0.14	0.20	0.13	0.12	0.16	0.17

TABLE 9

TWIG SAMPLE WEIGHTS - DRYING PHASE

(grams)

Elapsed Time Days	Hours	1	2	3	4	5	6	7	8	9	10	11
	0.0	4.81	5.32	1.55	2.93	1.78	1.52	3.76	3.07	3.80	3.11	5.36
	0.5	4.51	4.79	1.40	2.73	1.71	1.48	3.49	2.97	3.71	2.93	5.19
	1.0	4.32	4.50	1.33	2.63	1.69	1.46	3.41	2.79	3.68	2.81	5.03
	2.0	3.80	3.99	1.28	2.49	1.63	1.40	2.20	3.48	3.48	2.35	4.43
	3.0	3.62	3.62	1.24	2.40	1.60	1.38	3.13	1.75	3.33	2.06	4.00
	5.0	3.35	3.26	1.19	2.31	1.53	1.32	2.86	1.22	3.13	1.63	3.36
	6.0	3.21	3.08	1.16	2.24	1.50	1.28	2.87	1.02	3.00	1.45	3.05
	7.0	3.11	2.97	1.13	2.20	1.48	1.27	2.89	0.98	2.91	1.36	2.83
	8.9	3.02	2.87	1.11	2.17	1.44	1.23	2.72	0.92	2.82	1.29	2.70
	12.0	2.79	2.61	1.03	2.03	1.35	1.17	2.53	0.91	2.59	1.20	2.43
	14.0	2.72	2.51	1.02	1.99	1.32	1.14	2.47	0.91	2.49	1.20	2.39
1	0.0	2.41	2.15	0.91	1.80	1.18	1.02	2.30	0.93	2.19	1.22	2.35
1	3.5	2.32	2.08	0.88	1.73	1.11	0.98	2.25	0.93	2.13	1.21	2.33
1	6.0	2.27	2.03	0.83	1.70	1.08	0.93	2.23	0.93	2.11	1.21	2.32
1	8.0	2.22	2.00	0.82	1.68	1.05	0.91	2.20	0.92	2.08	1.21	2.31
2	0.0	2.01	1.84	0.73	1.49	0.92	0.81	2.08	0.90	2.00	1.19	2.28
2	3.5	1.98	1.83	0.72	1.44	0.92	0.80	2.05	0.91	1.99	1.19	2.28
2	8.0	1.92	1.80	0.72	1.42	0.91	0.80	2.03	0.91	1.97	1.19	2.28
3	0.0	1.83	1.78	0.68	1.35	0.85	0.78	1.95	0.89	1.92	1.18	2.25
3	3.5	1.83	1.78	0.68	1.34	0.85	0.77	1.93	0.90	1.91	1.18	2.25
4	0.0	1.79	1.73	0.64	1.31	0.83	0.73	1.85	0.89	1.88	1.18	2.25
4	3.0	1.79	1.73	0.64	1.31	0.83	0.74	1.83	0.90	1.87	1.16	2.25
4	8.0	1.79	1.73	0.64	1.29	0.82	0.73	1.83	0.89	1.85	1.16	2.25
7	0.0	1.75	1.73	0.62	1.26	0.80	0.72	1.70	0.89	1.80	1.18	2.23
7	8.0	1.77	1.73	0.62	1.26	0.80	0.72	1.70	0.89	1.80	1.17	2.25
8	0.0	1.75	1.73	0.62	1.26	0.80	0.72	1.68	0.89	1.79	1.17	2.25
9	2.0	1.75	1.73	0.62	1.26	0.80	0.72	1.65	0.89	1.78	1.17	2.25
11	0.0	1.75	1.73	0.62	1.26	0.80	0.72	1.62	0.89	1.77	1.17	2.25
13	0.0	1.74	1.72	0.62	1.22	0.79	0.71	1.60	0.89	1.75	1.17	2.22
14	0.0	1.73	1.72	0.62	1.22	0.79	0.71	1.60	0.89	1.75	1.17	2.22

TABLE 9 (cont'd)

TWIG SAMPLE WEIGHTS - DRYING PHASE

(grams)

Elapsed Time Days	Hours	12	13	14	15	16	18	19	22	24	25	26
	0.0	4.72	4.11	3.28	4.25	3.55	5.41	3.09	5.25	4.34	7.68	8.92
	0.5	4.68	3.92	2.91	4.20	3.44	5.08	2.96	4.91	4.18	7.43	8.62
	1.0	4.68	3.76	2.78	4.15	3.29	4.94	2.86	4.75	4.11	7.32	8.50
	2.0	4.62	3.20	2.30	4.07	2.87	4.52	2.47	4.28	3.79	6.92	8.05
	3.0	4.59	2.82	1.81	4.00	2.40	4.17	2.20	3.92	3.58	6.67	7.71
	5.0	4.56	2.38	1.39	3.91	1.88	3.68	1.61	3.08	3.08	5.92	6.48
	6.0	4.50	2.11	1.31	3.82	1.63	3.37	1.32	2.63	2.73	5.48	6.41
	7.0	4.49	1.99	1.28	3.79	1.53	3.22	1.21	2.42	2.52	5.19	6.12
	8.9	4.47	1.88	1.28	3.72	1.48	3.08	1.13	2.20	2.37	4.88	5.80
	12.0	4.39	1.73	1.26	3.59	1.44	2.85	1.09	2.00	1.95	4.19	5.27
	14.0	4.36	1.69	1.26	3.52	1.44	2.79	1.09	1.99	1.79	3.98	5.08
1	0.0	4.21	1.59	1.28	3.20	1.47	2.74	1.11	1.99	1.71	3.48	4.46
1	3.5	4.18	1.55	1.26	3.10	1.44	2.72	1.10	1.97	1.70	3.43	4.37
1	6.0	4.15	1.54	1.28	3.03	1.44	2.72	1.10	1.97	1.69	3.42	4.30
1	8.0	4.12	1.53	1.26	3.00	1.44	2.71	1.09	1.97	1.69	3.41	4.30
2	0.0	3.95	1.48	1.22	2.61	1.41	2.68	1.07	1.94	1.63	3.34	4.18
2	3.5	3.92	1.47	1.22	2.55	1.41	2.68	1.08	1.94	1.64	3.34	4.18
2	8.0	3.89	1.45	1.22	2.48	1.41	2.68	1.08	1.92	1.64	3.33	4.18
3	0.0	3.78	1.45	1.22	2.28	1.41	2.63	1.07	1.91	1.63	3.31	4.11
3	3.5	3.73	1.45	1.22	2.22	1.41	2.63	1.06	1.91	1.64	3.31	4.11
4	0.0	3.60	1.42	1.22	2.08	1.41	2.63	1.06	1.91	1.64	3.29	4.09
4	3.0	3.60	1.42	1.22	2.05	1.40	2.63	1.05	1.91	1.62	3.30	4.10
4	8.0	3.58	1.45	1.22	2.02	1.39	2.62	1.06	1.91	1.63	3.30	4.09
7	0.0	3.34	1.43	1.22	1.90	1.40	2.62	1.06	1.91	1.63	3.30	4.09
7	8.0	3.32	1.44	1.22	1.90	1.40	2.63	1.06	1.91	1.63	3.30	4.09
8	0.0	3.28	1.43	1.22	1.88	1.40	2.62	1.06	1.91	1.63	3.30	4.09
9	2.0	3.21	1.43	1.21	1.87	1.40	2.62	1.06	1.91	1.63	3.30	4.09
11	0.0	3.10	1.43	1.21	1.85	1.40	2.62	1.06	1.91	1.63	3.30	4.09
13	0.0	3.00	1.42	1.21	1.84	1.39	2.61	1.05	1.90	1.62	3.27	4.06
14	0.0	2.97	1.42	1.21	1.83	1.39	2.61	1.05	1.90	1.62	3.30	4.09

TABLE 10

SUMMARY OF TWIG WETTING MEASUREMENTS

INITIAL 5-HOUR PERIOD

Moisture Content Change (%)[1/]

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	66	139	90	34	70	46	2.1
3	45	118	82	30	56	46	1.9
5	35	74	48	23	40	30	1.7
7	26	68	57	21	45	40	2.5
9+	29	80	63	39	58	54	1.5

Rate of Change (%/hr.)[2/]

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	13.2	27.8	18.0	6.7	14.0	9.1	2.1
3	9.1	23.6	16.4	6.1	11.2	9.2	1.8
5	6.9	14.8	9.5	4.6	8.1	5.9	1.8
7	5.2	13.5	11.4	4.2	8.9	7.9	2.1
9+	5.8	15.9	12.5	7.7	11.5	10.7	1.5

INITIAL 12-HOUR PERIOD

Moisture Content Change

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	82	149	104	42	75	53	1.8
3	60	132	96	40	63	53	1.6
5	50	88	63	33	48	39	1.4
7	40	80	70	32	53	49	1.6
9+	40	92	74	53	67	63	1.3

Rate of Change

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	6.3	11.9	8.2	3.2	6.0	4.2	1.9
3	4.4	10.5	7.5	3.0	5.0	4.2	1.7
5	3.7	6.8	4.7	2.5	3.7	2.9	1.5
7	3.8	6.3	5.6	3.1	4.1	3.9	1.3
9+	2.5	7.2	5.6	3.3	5.2	4.8	1.6

INITIAL 48-HOUR PERIOD

Moisture Content Change

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	111	168	130	57	85	66	1.5
3	87	152	120	59	72	67	1.2
5	72	111	85	48	61	53	1.3
7	61	98	89	49	65	62	1.3
9+	56	106	97	67	77	74	1.2

Rate of Change

Size Class (mm)	Actual With Bark	Actual Without Bark	Actual Average	Relative With Bark	Relative Without Bark	Relative Average*	No Bark/Bark
1	2.3	3.5	2.7	1.2	1.8	1.4	1.5
3	1.8	3.2	2.5	1.2	1.5	1.4	1.2
5	1.5	2.3	1.8	1.0	1.3	1.1	1.3
7	1.3	2.0	1.8	1.0	1.2	1.3	1.2
9+	1.0	2.2	1.8	1.4	1.6	1.5	1.3

[1] Values are in % oven dry weight

[2] Values are in % oven dry weight change per hour

*From individual values

TABLE 11

SUMMARY OF TWIG DRYING MEASUREMENTS

INITIAL 5-HOUR PERIOD

Size Class (mm)	Actual: With Bark	Actual: Without Bark	Actual: Average	Relative: With Bark	Relative: Without Bark	Relative: Average*	No Bark/Bark
			Moisture Content Change (%)[1]				
1	93	161	120	49	84	63	1.7
3	50	158	115	35	77	66	2.2
5	38	136	70	26	77	45	3.0
7	31	82	69	26	56	50	2.2
9+	6	54	38	8.6	41	32	4.8
			Rate of Change (%/hr.)[2]				
1	18.5	32.2	24.0	9.7	16.7	12.5	1.7
3	10.0	31.7	23.0	7.0	15.5	13.2	2.2
5	7.5	27.2	14.1	5.1	15.3	9.0	3.0
7	6.2	16.5	13.9	5.2	11.3	10.0	2.2
9+	1.2	10.7	7.5	1.7	8.0	6.4	4.7

INITIAL 12-HOUR PERIOD

Size Class (mm)	Actual: With Bark	Actual: Without Bark	Actual: Average	Relative: With Bark	Relative: Without Bark	Relative: Average*	No Bark/Bark
			Moisture Content Change				
1	123	188	149	65	98	78	1.5
3	77	197	147	54	96	85	1.8
5	58	172	96	38	97	62	2.6
7	52	133	113	44	92	82	2.1
9+	12	110	78	17	83	67	4.9
			Rate of Change				
1	10.3	15.6	12.4	5.4	8.1	6.4	1.5
3	6.0	16.4	12.3	4.2	8.0	7.1	1.9
5	4.8	14.3	8.0	3.2	8.0	5.1	2.5
7	4.3	11.1	9.4	3.6	7.6	6.8	2.1
9+	1.0	9.2	6.5	1.4	6.9	5.5	4.9

INITIAL 48-HOUR PERIOD

Size Class (mm)	Actual: With Bark	Actual: Without Bark	Actual: Average	Relative: With Bark	Relative: Without Bark	Relative: Average*	No Bark/Bark
			Moisture Content Change				
1	163	191	174	86	99	91	1.1
3	128	201	172	90	98	99	1.1
5	130	173	145	89	98	94	1.1
7	104	143	133	85	99	96	1.2
9+	27	133	97	39	99	83	2.5
			Rate of Change				
1	3.4	4.0	3.6	1.7	2.0	1.8	1.2
3	2.6	4.2	3.6	1.8	2.0	2.0	1.1
5	2.7	3.6	3.0	1.8	2.0	1.9	1.1
7	2.2	3.0	2.8	1.8	2.0	2.0	1.1
9+	0.6	2.8	2.0	0.9	2.1	1.7	2.3

[1] Values are in % oven dry weight

[2] Values are in % oven dry weight change per hour

*From individual values

TABLE 12

SUMMARY OF TWIG TIME LAG MEASUREMENTS

Sample No.	% Change at Time Lag	Wetting Time Lag (hrs)	Wetting Rate of Increase (%/hr)	Drying Time Lag (hrs)	Drying Rate of Decrease (%/hr)
1	140	96	1.46	6.0	23.4
2	120	112	1.07	10.5	11.4
3	105			21.0	5.0
4	93	144	0.64	19.5	4.8
5	87	96	0.91	26.0	3.3
6	75	112	0.67	23.5	3.2
7	91	152	0.60	16.0	5.7
8	166	46	3.61	3.3	50.4
9	78	56	1.39	-	-
10	111	68	1.63	3.2	34.7
11	93	130	0.72	5.0	18.6
12	41	60	0.68	94.0	0.44
13	128	58	2.21	-	-
14	114	4	28.5	2.7	42.3
15	89	112	0.79	43.0	2.1
16	103	2	51.5	3.9	26.4
18	71	80	0.89	5.2	13.7
19	128	2	64.0	4.2	30.5
22	117	13	9.00	4.7	24.9
24	112	10	11.2	6.5	17.2
25	89	10	8.90	8.0	11.1
26	79	12	6.58	8.0	9.9