ON THE WET-HEARTWOOD OF SOME BROAD-LEAVED TREES GROWN IN JAPAN. II.[1,2]

Seasonal moisture content of Yachi-damo and Haru-nire by months.

By

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Introduction

In the first paper of this series[1)] it was reported that there were three different types of moisture distribution pattern concerning sapwood and heartwood of broad-leaved trees; the first type showed an average moisture content of sapwood higher than that of heartwood, the second was just the reverse of the first and the third was in between.

Yachi-damo (*Fraxinus mandshurica* RUPR. var. *japonica* MAXIM.), Haru-nire (*Ulmus davidiana* PLANCH var. *japonica* NAKAI) and Doro-no-ki (*Populus maximowiczii* A. HENRY) were classified into species belonging to the second type according to a survey carried out from summer to early winter 1963. Two concepts were newly proposed[1)], by the authors for describing the moisture relations in the sapwood and heartwood of broad-leaved trees; one was "wet-heartwood" for the heartwood of the tree species of which the moisture distribution pattern belonged to the second type stated above and the other was "wet-heartwood tree species" for those species which had "wet-heartwood" throughout the whole year or during most of a year.

Though Yachi-damo, Haru-nire and Doro-no-ki were known as species of the second type during a certain period of year at least, there was no enough data to prove that both were of the second type throughout the whole year, i.e., which proved both to be typical wet-heartwood tree species. Accordingly,

1 Presented at 15th Meeting of The Japan Wood Research Society, 1965.

2 The first paper of this series was reported in the Journal of the Japan Wood Research Society, 1965.

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a survey of seasonal moisture content of Yachi-damo and Haru-nire (apart from Doro-no-ki) was carried out throughout the whole year of 1964, as a part of the serial work continued from 1963.

Attention was also paid in studying some characteristics of the wet-heartwood itself, that is, on the moisture movement in it compared with sapwood, and on the internal pressure developed in the heartwood as well as sapwood tissue by the liquid and gases involved, probably mainly air.

Materials and methods

A standing tree trunk of Yachi-damo and Haru-nire, resp., was felled every month from January to December 1964 for determining its moisture content distribution. The sample trees were all growing on a flat forest area along a small river in the Tomakomai College Experiment Forest of Hokkaido University; their growing conditions seemed to be quite similar to one another.

To determine moisture content by the weight (φ) of test specimens, entirely the same procedure as that in the first paper[1] was employed. In addition to φ, moisture content by volume (U) was calculated by the use of formula $\varphi \times R$, in which R means basic specific gravity[2], Raumdichtezahl, based on ovendry weight and green volume of specimen.

An 0.5% aqueous solution of acid fuchsin and methylene blue was used as the injection medium to detect moisture movement in tree stems of Yachi-damo and Haru-nire. Methylene blue was mainly used because of its convenience in following the way of the dye solution rose, especially in the case of such dark colour as that of the both species' heartwood.. The dye solution was injected into the sapwood or heartwood of the trunks at different heights above the ground, applying 10~20 grams of pressure.

In July, many mercury manometers were connected with the sapwood and heartwood of some standing tree trunks at several heights above the ground. As connectors which led the manometers to the inside of the trunks to indicate their internal pressure, copper tubes of an outer diameter of 5 mm were hammered tightly into the guide holes which had been drilled to the sapwood or the heartwood in advance. Readings with the manometers were taken at time intervals of 4 hours and lasted for about 10 days.

Results of the study

Results obtained are summarized in table 1 and figure 1. 12 sample trees of each species surveyed are described briefly as follows: in Yachi-damo, 18~22 cm in diameter at breast height, 14.2~18.0 m in tree height above the ground

TABLE 1. Numerical values of the seasonal moisture content (by weight φ, by volume U) and basic specific gravity of sapwood and heartwood in Yachi-damo (*Fraxinus* sp.) and Haru-nire (*Ulmus* sp.) trunks

Species	Month	Moisture content (%)						Basic specific gravity***			Diameter b.h. (cm)	Tree height (m)	Tree age (year)
		by weight (φ)*			by volume (U)**								
		sap	heart	h/s	sap	heart	h/s	sap	heart	h/s			
Yachi-damo	Jan	46.2	90.2	1.65	23.1	50.5	2.19	0.50	0.55	1.09	21	16.5	48
	Feb	47.0	87.4	1.86	24.8	46.3	1.87	0.53	0.55	1.05	20	16.0	51
	Mar	42.3	74.8	1.77	26.3	44.9	1.71	0.62	0.61	0.99	22	14.2	60
	Apr	43.8	82.6	1.89	24.4	46.1	1.89	0.56	0.56	1.00	22	15.7	79
	May	45.0	89.3	1.98	24.7	50.4	2.04	0.55	0.56	1.03	20	16.5	43
	June	46.3	83.3	1.80	21.5	47.2	2.20	0.47	0.58	1.24	22	18.0	72
	July	46.3	73.3	1.57	26.0	44.1	1.70	0.59	0.60	1.01	18	15.7	65
	Aug	51.7	93.3	1.81	29.3	50.5	1.72	0.55	0.54	1.00	21	16.5	51
	Sept	47.4	93.7	1.98	21.7	52.1	2.40	0.44	0.56	1.26	20	17.9	67
	Oct	49.7	99.6	2.00	27.7	44.0	1.59	0.55	0.52	0.96	20	17.8	46
	Nov	43.1	84.3	1.96	25.0	50.0	2.00	0.58	0.59	1.02	20	16.6	44
	Dec	50.7	80.5	1.59	22.3	45.4	2.04	0.44	0.57	1.28	22	16.8	66
	Avg	46.5	86.1	1.85	24.7	47.6	1.93	0.53	0.57	1.07	21	16.5	58
Haru-nire	Jan	65.4	98.4	1.51	38.0	56.7	1.49	0.59	0.58	0.98	21	14.5	39
	Feb	70.3	107.1	1.52	39.3	57.5	1.46	0.56	0.54	0.96	18	12.5	34
	Mar	62.9	95.6	1.52	36.9	53.5	1.45	0.59	0.56	0.95	24	13.0	33
	Apr	65.2	98.9	1.52	35.8	53.9	1.51	0.55	0.54	0.97	22	14.3	33
	May	67.9	97.5	1.44	38.9	54.2	1.39	0.57	0.56	0.98	19	15.7	45
	June	69.9	103.7	1.48	36.1	55.9	1.55	0.52	0.55	1.05	20	15.8	38
	July	76.9	112.7	1.47	39.1	57.6	1.47	0.51	0.52	1.01	17	15.3	61
	Aug	64.5	105.7	1.64	31.8	55.9	1.76	0.50	0.52	1.05	21	16.5	52
	Sept	63.7	102.9	1.62	32.1	55.9	1.74	0.51	0.55	1.08	21	16.5	60
	Oct	59.6	97.3	1.63	33.4	55.5	1.66	0.56	0.57	1.02	22	16.5	42
	Nov	59.0	94.4	1.60	32.9	52.2	1.59	0.52	0.58	1.11	19	15.0	38
	Dec	66.6	109.4	1.64	35.8	56.7	1.58	0.54	0.54	0.99	20	15.0	42
	Avg	65.9	102.0	1.55	35.8	55.5	1.55	0.54	0.55	1.01	20	15.1	43

* Moisture content φ (%) $= \dfrac{\text{weight of water in wood}}{\text{ovendry weight of wood}} \times 100.$

** " " U (%) $= \dfrac{\text{volume of water in wood}}{\text{volume of wood}} \times 100$

$= \varphi \times$ basic sp. gravity, in this work.

*** Basic specific gravity[2] was determined based on green volume and ovendry weight.

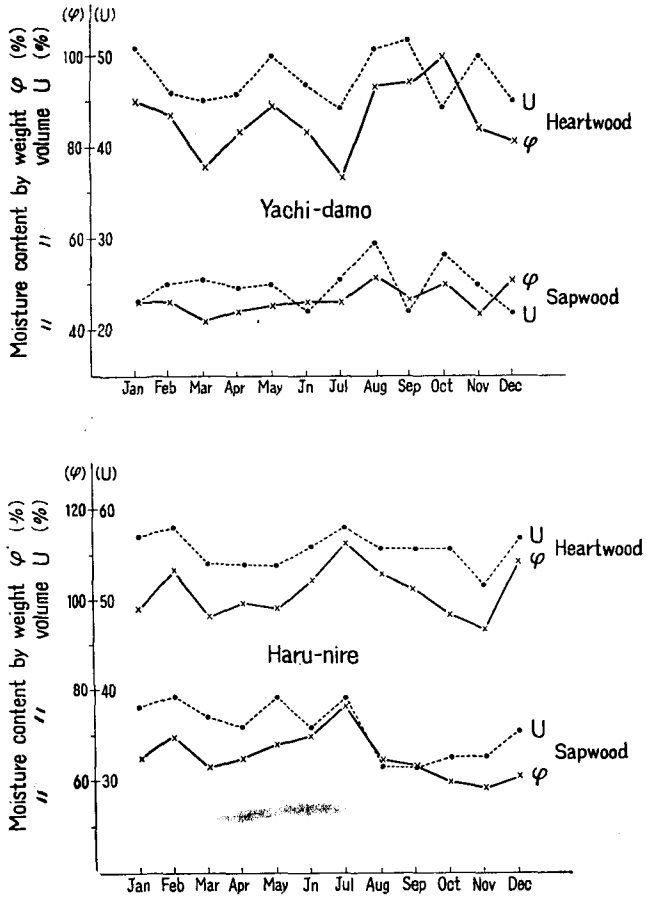

Figure 1. Graphical representation of the seasonal moisture content (φ, U) of sapwood and heartwood in Yachi-damo and Haru-nire trunks.

and 43～79 years of age, while in Haru-nire 17～24 cm diameter, 12.5～16.5 m tree height and 33～61 years of age.

In Yachi-damo, moisture content by weight (φ) of 12 sample trees which were taken by a ratio of one per month for the seasonal moisture survey, ranged from 42.3 to 51.7% in sapwood, 73.3～99.6% in heartwood and averaged for all 12 sample trees 46.5% in sapwood, 86.1% in heartwood. Showing a higher value of moisture content in heartwood than sapwood, the ratio of the value of heartwood to that of sapwood was 1.85 on the average for 12 trunks surveyed. On the other hand, moisture content by volume (U) ranged

from 21.5～29.3% in sapwood, 44.0～52.1% in heartwood and averaged 24.7% in sapwood, 47.6% in heartwood. The ratio of the average heartwood U to the sapwood was 1.93, a little higher than that for φ because of a little higher value of R in heartwood than sapwood.

In Haru-nire, φ of 12 sample trees ranged from 59.0 to 76.9% in sapwood, 95.6～112.7% in heartwood; and averaged for all sample trees 65.9% in sapwood, 102.0% in heartwood, and the ratio was 1.55 on the average. Moisture content U of the species was 31.8～39.3% in sapwood, 52.2～57.6% in heartwood; and the ratio of the heartwood U to the sapwood was just the same as that of φ because there was no difference between the sap- and heartwood R of Haru-nire, showing a little difference from Yachi-damo.

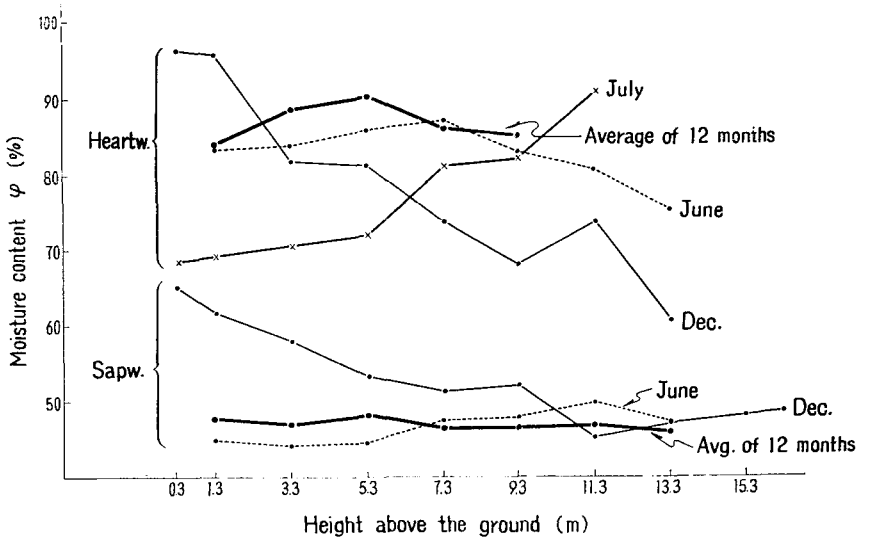

Figure 2-1. Average moisture content of sapwood and heartwood at different heights above the ground, of Yachi-damo sample trees (June, July, Dec. and average of the year).

Comparing the Yachi-damo moisture content (φ, U) with Haru-nire, the former was lower than the latter in both sapwood and heartwood as stated above. The relation between the average moisture content for whole sapwood and that of whole heartwood of each individual trunk was also observed at various different heights above the ground, as shown in figures 2-1 and 2-2 where some examples are illustrated.

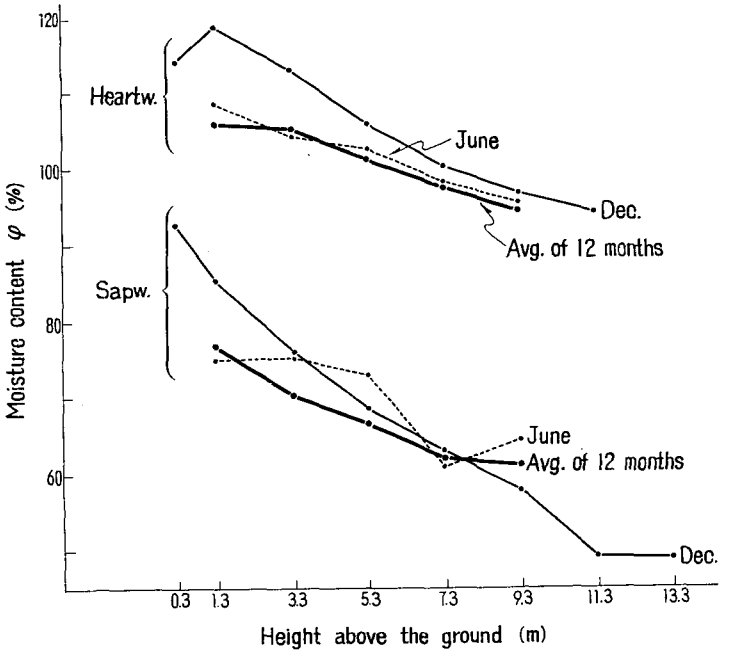

Figure 2-2. Average moisture content of sapwood and heartwood at different heights above the ground, of Haru-nire sample trees (June, Dec. and average of the year).

Lateral distribution of moisture at different heights above the ground in regard to the sapwood and heartwood of a Yachi-damo trunk felled in September and a Haru-nire trunk in August is shown in figures 3–1 and 3–2 with a particular analysis of the top portin of the tree trunk where the heartwood disappears. The same pattern of lateral moisture distribution as that of Yachi-damo in the first paper will be seen from these figures; low moisture content in sapwood, sudden increase of the content on entering the heartwood, and a slight decrease or even distribution from the outer part of heartwood to the pith are shown. Near the top of the trunk where the heartwood ends it was also found that heartwood had a higher moisture content than the sapwood surrounding the heartwood in both species.

In Haru-nire, the heartwood in the root extended deeply under the ground, while in Yachi-damo the heartwood reached only to 2～3 decimeters below the border of the stem and the root. Even in the root of both species, higher moisture content in the heartwood than in the sapwood was obtained (in June),

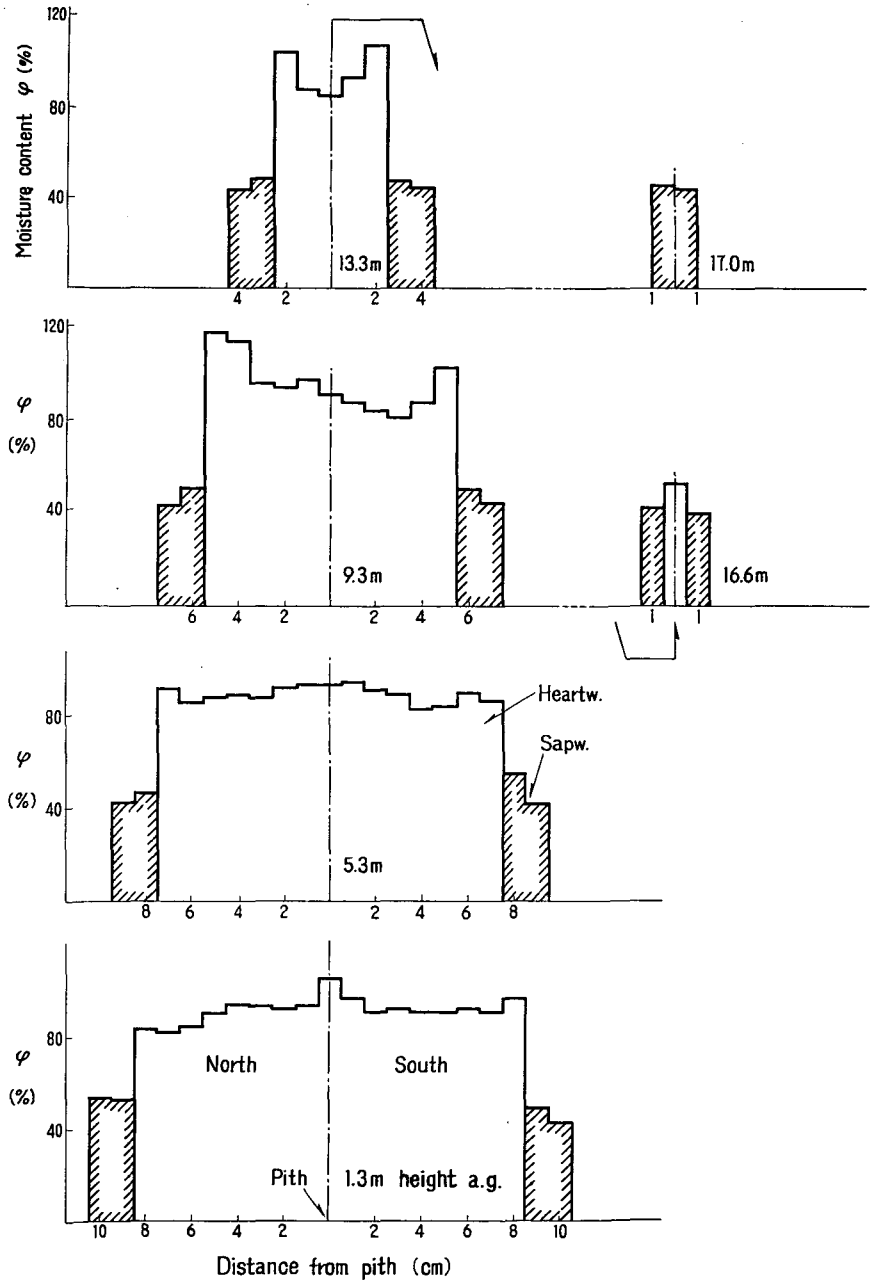

Figure 3-1. Lateral distribution of moisture at different heights above the ground of a Yachi-damo trunk felled in August '64.

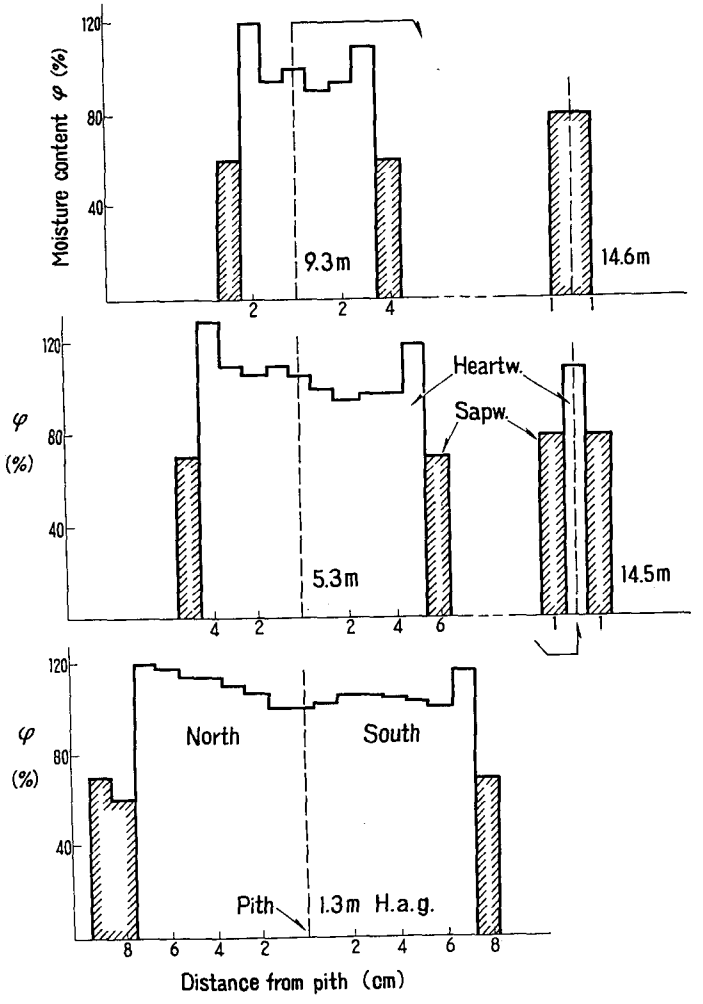

Figure 3-2. Lateral distribution of moisture at different heights above the ground of a Haru-nire trunk felled in September '64.

as shown in figures 4-1 and 4-2.

According to the preliminary work on moisture movement inside the trunk of Yachi-damo and Haru-nire, it was shown that a dilute aqueous solution of methylene blue rose quickly through the sapwood from the place where the solution was injected, and reached to the leaves at a hight of 20 meters above the ground about two days later when the sample trees were cut to be observed. On the other hand, in heartwood, in general, the moisture movement was

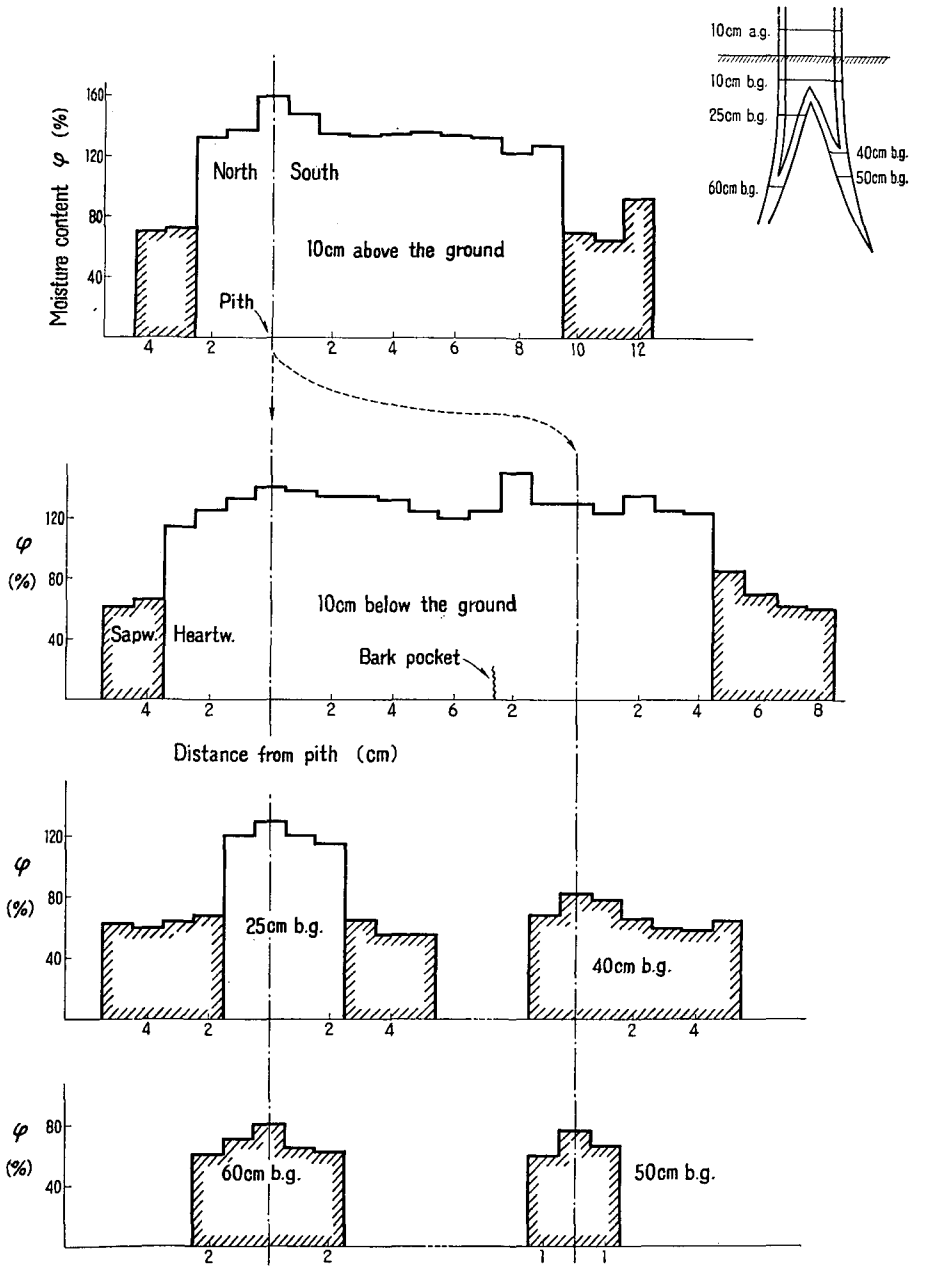

Figure 4-1. Moisture distribution in Yachi-damo root wood obtained in June '64.

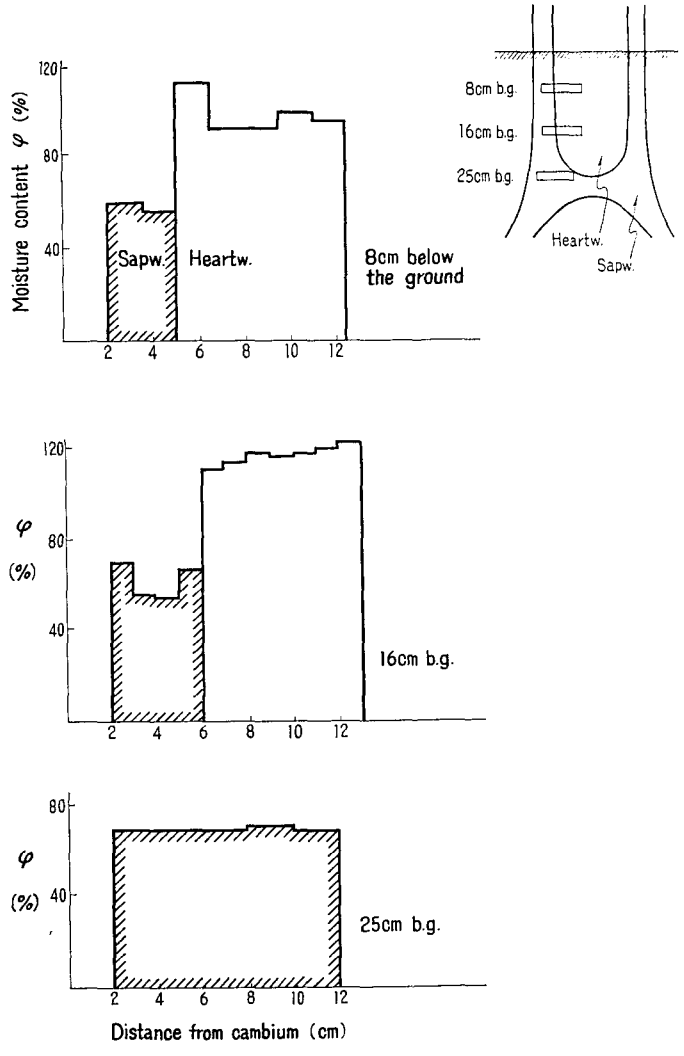

Figure 4-2. Moisture distribution in Haru-nire root wood obtained in June '64.

extremely slow with an exception in the case of a Haru-nire trunk whose bark and sapwood had been girdled[3] at about 30 cm above the place injected. In the outer growth layers of the both species sapwood the dye solution tended to rise through the earlywood vessels but only through the latewood vessels in the inner part of sapwood.

Two Yachi-damo trunks showed slightly negative liquid pressure in both

sapwood and heartwood below the height of 4 meters above the ground in June when the experiment was carried out. Of Haru-nire, however, only in sapwood was a slightly negative pressure similar to Yachi-damo observed. The pressure of heartwood near the pith of Haru-nire was complicated by the different individual trees surveyed; No 1 sample tree showed nearly normal atmospheric pressure at 0.3 m, 1.2 m and 4.0 m height above the ground. On the contrary, No 2 showed 64 cm, 58 cm and 48 cmHg (in positive pressure) on the average during the period of the experiment, while No 3 showed 20 cm, 44 cm and 0.4 cmHg in the same order of height as that described above.

Discussion of the results

The pattern of moisture distribution indicates firmly that both Yachi-damo and Haru-nire have a moisture-content relationship between sapwood and heartwood in which the latter exceeds the former, at all parts of the trunk (as well as root) in all seasons of the year. According to the writer's thesis[1], therefore, both species are typical wet-heartwood tree species because they have typical wet-heartwood. It should be noted here that the fact can be seen not only in moisture content by weight but also in that by volume; this means there is more air (gases) in sapwood than in heartwood even if a slight difference of R exists.

Although insufficient measurements were obtained to discuss seasonal trends of sapwood moisture or heartwood moisture as GIBBS did[4], Yachi-damo sapwood seems to have a constantly low moisture content by weight, having fourties % for all seasons; and its heartwood has large and complex deviations from the average value of 86.1% for the whole year (figure 1). This is comparable with *Carya* spp. in the U.S.A.[5] In Haru-nire two minima of the moisture content were obtained in early spring and late autumn showing a good correspondence of both sapwood and heartwood as shown in figure 1.

In Haru-nire, generally speaking, the average moisture content of the sapwood and the heartwood, resp., decreased with increase of the height above the ground as shown in figure 2–2. As a result of this fact, the average sapwood moisture content in some lower parts of the trunk sometimes overcame, or closely approached that of the heartwood of some higher parts of the trunk, e.g., in May, April, November and December. In no sample trees, however, did the average sapwood moisture content exceed the heartwood at a given height of each individual tree trunk. In Yachi-damo, there were found some differences from Haru-nire concerning the relation between moisture content and the height above the ground, as will be seen in figure 2–1. The moisture

content of sapwood in every sample tree tended, to be independent of the height, showing a parallel line to the abscissa, with a good correspondence of φ and U. Although the sapwood moisture content in most of the sample trees gives roughly a similar curve to that in the sapwood, there were two or three dissimilar curves in the trend: in July, e.g., there was apparently a increasing tendency of moisture with an increase of the height, while in December a decreasing tendency of the moisture was shown.

It seemed clear that the butt sapwood of Haru-nire gave so high average of moisture content (above 90%) that there was hardly any difference between the sap- and heartwood moisture late in May. There was a vigorous water exudation through the outermost growth layers of the sapwood. In the heartwood, on the other hand, especially in summer season, there existed nearly enough water to fill up the lumina of the tissue.

As stated above, preliminary work on the moisture movement in both species showed that there was almost no heartwood-moisture movement in intact trees. In a Haru-nire standing tree trunk, however, of which the bark and sapwood were girdled at a height of 1.0 meter above the ground, moisture behaved in a little different way from the intact trees above. As will be seen from figure 5, there is a marked difference between the moisture content above

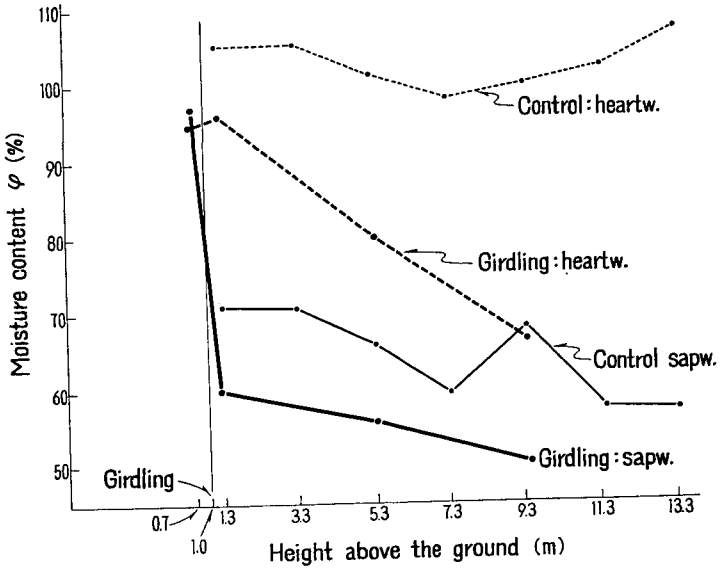

Figure 5. Effect of girdling of bark and sapwood upon the moisture movement of a Haru-nire standing tree trunk measured in August.

and below the girdling; the moisture content at 1.3 m height, 30 cm above the girdling, showed a rather lower value (60%) than that (70%) of an intact tree trunk as control, while at 0.7 meter height, 30 cm below it, the moisture content showed a markedly higher value (97%). Although there was no gap in the moisture of the heartwood above and below the place girdled, the value of the content decreased rapidly with the increase of the height compared to the control heartwood. Here it might be noted that moisture in the heartwood of Haru-nire rises to evaporate from the surfaces of leaves when the sapwood moisture supply is stopped or lowered from one cause or another and shortage of moisture occurs in the physiological organs.

Summary

From January to December 1964 a study was carried out by the authors to determine seasonal moisture content of living tree trunks of Yachi-damo (*Fraxinus* sp.) and Haru-nire (*Ulmus* sp.) in Hokkaido, Japan.

Results of this work establish firmly that both are typical wet-heartwood tree species because of their typical wet-heartwood[1]; the green heartwood moisture content by weight of both species is higher than that of sapwood surrounding the heartwood in any part of trunk at all seasons. The average moisture content by weight of all 12 sample trees was 46.5% for sapwood, 86.1% for heartwood of Yachi-damo, 65.9% for sapwood and 102.0% for heartwood of Haru-nire. Studies were begun on the moisture movement and on the liquid pressure within heartwood as well as sapwood of living tree trunks of Yachi-damo and Haru-nire as wet-heartwood species. According to preliminary work in this study there was almost no moisture movement in heartwood compared with sapwood, where the outer growth layers showed a rapid rise of moisture in intact trees of both species. It was also observed that the living tree stems of both species behaved in widely different ways in terms of liquid pressure.

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