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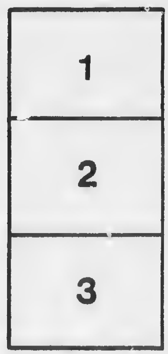
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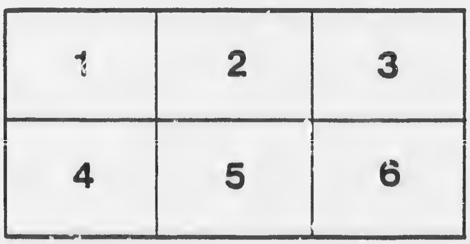
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[From the CANADIAN RECORD OF SCIENCE, Vol. II., No. 2, April, 1886.]

VARIATION OF WATER IN TREES AND SHRUBS.

BY D. P. PENHALLOW.

The amount of water which highly lignified plants contain, particularly as influenced by season and condition of growth, obviously bears a more or less important relation to physiological processes incident to growth, and most conspicuously to those which embrace the movement of sap. Studies relating to the mechanical movement of sap in early spring, at once suggest the question as to how far this is correlated to greater hydration of the tissues at the time when this movement is strongest. It was with a view to exhibiting this relation more clearly, that determinations of moisture in a large number of woods, representing growth of one and also of two years, collected at different seasons, were made by me in 1874.[1] The range of seasons was not as complete as could have been desired, and no attempt was made to formulate a general law applicable to this question. With a view to extension of data in this direction, I undertook additional determinations in 1882. The final determinations were made in most cases by Mr. W. E. Stone, then acting as assistant. It is the object of the present paper to combine all the results thus obtained, together with such other facts

[1] W. S. Clark: Agriculture of Massachusetts, p. 289.

as have come to hand, and to see how far they indicate a general law.

Theoretical considerations lead us to infer that if there is any variation at all, the hydration of the structure must be greatest during the period of active growth, and least during the period of rest. How far this is supported by the facts, will appear in the following.

HYDRATION OF DEAD WOOD.

Incidentally to the main question, specimens of dead wood, devoid of the bark, and representing an age of four to six or eight years, were collected and the moisture determined. While the branches were dead, none of them were in advanced stages of decay, so that the contained water could not be regarded as that of active decomposition, but simply that which would be readily retained in the lifeless, air-dried substance as exposed on the tree. The results obtained from fifteen species of trees showed an extreme variation of 6.4 per cent., the range being from 12.9 per cent to 19.0 per cent. of water. The mean hydration obtained from these determinations, was 15.1 per cent. The results appear in the following table:—

HYDRATION OF DEAD WOODS.

Determined at 100° C.

SPECIES.	PER CENT. WATER.
Acer saccharinum	18.8
Amelanchier canadensis	19.0
Betula alba	15.1
" excelsa	15.9
" lenta	13.7
Carpinus americana	13.8
Castanea vesca	14.0
Cydonia vulgaris	12.9
Cornus sericea	13.6
Pinus strobus	11.9
Pirus malus	12.9
Prunus serotina	17.4
Quercus alba	15.5
Tsuga canadensis	18.6
Ulmus americana	13.5
MEAN.	15.1

HYDRATION OF WOOD FROM LIVING TREES.

The specimens, upon which the principal facts of this paper are based, were collected as sections of living trees, representing on the one hand, branches of two years growth, and on the other, branches from two to four years old. For the obvious reason that the bark could not be properly separated from the wood with any degree of uniformity, it was left on in every case, so that in all the determinations here given, the results show the combined percentage of water in wood and bark. Obviously, this gives a result which differs materially from that which would be obtained if bark and wood were considered separately. Also, while care was taken not to collect specimens in which the dead bark was strongly developed, thus securing as great uniformity as possible, the very fact that the bark was present, as well as the certainty of its being variable in structural character and thus also in hydration, as collected even from the same species at different seasons, rendered variations in the results unavoidable. This will doubtless appear upon examining individual cases, but the error from this source is reduced in the aggregate, so that the mean results, in view of all the precautions taken, may doubtless be accepted as correct.

From an examination of the results that follow, it will appear that, comparing the younger with the older wood, the percentage of water is sometimes greater in one, sometimes greater in the other, apparently conforming to structural peculiarities of the species. The mean results, however, show clearly what we might infer upon theoretical grounds, viz., that in the youngest growth, as also in the sap wood, the percentage of water is higher by two per cent. than in the older growth where the heart-wood is in relative excess. This is found to hold true in the mean results, not only for each season, but also for all seasons; in the former case, however, this difference shows a variation of from 0.8 per cent. to 3.3 per cent. of water.

Species.	English Name.	February. 1st Year	February. 2nd Year	March. 1st Year	March. 2nd Year	April. 1st Year	April. 2nd Year	September. 1st Year	September. 2nd Year	December. 1st Year	December. 2nd Year
MAGNOLIACEÆ.											
Liriodendron tulipifera, L.	Tulip tree	......	55.8	52.7	54.9	......	......	......	......	......	59.30
TILIACEÆ.											
Tilia americana, L.	Bass wood	55.1	53.9	......	55.6	......	......	48.6	55.9	53.20	58.1
RUTACEÆ.											
Ailanthus glandulosus, *Desf.*	Tree of heaven	48.6	46.0	......	......	......	......	......	......	......	......
ANACARDIACEÆ.											
Rhus glabra, *L.*	Smooth sumach	......	......	45.6	41.1	......	......	......	......	41.2	36.4
" typhina, *L.*	Staghorn sumach	......	......	51.3	33.3	......	......	......	......	......	......
VITACEÆ.											
Vitis cordifolia, *Michx.*	Frost grape	42.1	41.7	48.3	48.0	......	......	......	......	48.8	43.7
Ampelopsis quinquifolia, *Michx.*	Virginia creeper	......	......	59.2	60.7	......	......	......	......	76.4	62.4
ILICINEÆ,											
Ilex verticellata, *Gray*	Black alder	......	......	46.2	46.4	......	......	......	......	48.0	49.4
CELASTRACEÆ.											
Celastrus scandens, *L.*	Bitter sweet	......	......	47 7	49.4	......	......	......	......	52.3	52.4
RHAMNACEÆ.											
Ceanothus americanus, *L.*	New Jersey tea	......	......	17.3	37.6	......	......	......	......	19.5	41.4
SAPINDACEÆ.											
Acer saccharinum, *Wang.*	Rock maple	46.5	47.1	47.5	42.9	......	......	48.1	44.0	42.6	42.7
" rubrum, L.	Soft maple	44.9	44.7	50.8	45.4	......	48.7	......	......	53.0	55.1
Æsculus hippocastanum, *L*	Horse chestnut	49.1	46.1	......	......	......	......	......	......	......	......
" flava, *Ait.*	Sweet buckeye	......	......	......	......	......	......	64.9	65.4	......	......

LEGUMINOSÆ.											
Gleditschia triacanthos, *L.*	Honey locust	34.9									
Robinia pseudacacia, *L.*	Locust			44.0	38.3					51.3	
ROSACEÆ.											
Amygdalus persica, *L*	Peach	46.1	40.4	50.9	49.4	56.0	43.7			55.3	42.0
Prunus domestica, *L.*	Plum			48.7	41.2					53.9	46.2
" serotina, *Ehrhart*	Black cherry			52.7	50.8			50.6	50.3	47.3	46.0
" cerasus, *L.*	Cherry			49.9						50.6	47.7
Cydonia vulgaris, *L.*	Quince	45.5	39.6					56.3	52.6		
Pirus communis, *L*	Pear	49.9	47.7	49.7	43.1	55.4	54.0	54.0	51.5	53.7	50.0
" malus, *L.*	Apple	49.5	44.8	55.7	41.5	49.0	46.4	56.2	54.5	48.3	51.9
Amelanchier canadensis, *Torr & Gr.*	Shad bush	44.3	38.6		44.6					47.4	45.1
Cratægus tomentosa, *L*	Thorn			43.1	40.4					55.9	43.4
HAMAMELACEÆ.											
Hamamelis virginica, *L*	Witch hazel	41.7	41.1	48.2	54.2					48.7	51.3
CORNACEÆ.											
Cornus florida, *L.*	Flower'g dogwood			55.1	43.2					53.6	52.8
" sericea, *L.*	Silky dogwood			50.6	49.2			55.4		51.2	
Nyssa multiflora, *Wang*	Tupelo	50.9	49.0	48.0	49.3			51.1	50.9	50.8	58.7
CAPRIFOLIACEÆ.											
Sambucus canadensis, *L.*	Elder			58.2	48.2					56.3	55.1
" pubens, *Michx*	Red-berried elder	54.5	55.7								
Viburnum opulus, *L.*	Cranberry tree	44.7	47.7								
RUBIACEÆ.											
Cephalanthus occidentalis, *L.*	Button bush			54.1	42.8					42.8	
ERICACEÆ.											
Andromeda ligustrina, *Muhl.*				46.7	45.9					38.0	59.0
Kalmia latifolia, *L*	Calico bush		42.5	50.7	44.4					49.4	42.3
Azalea nudiflora, *L.*	Azalea			41.8	43.8					45.8	49.9

Species.	English Name.	February.		March.		April.		September.		December.	
		1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year
Oleaceæ.											
Fraxinus americana, *L*	White ash	32.0	29.6	38.3	34.4	......	......	......	......	35.2	29.5
Thymeleaceæ.											
Dirca palustris, *L*	Leatherwood	51.8	......	......	......	......	......	......	......	......	......
Lauraceæ.											
Sassafras officinalis, *Nees*	Sassafras	34.9	33.9	40.7	38.1	......	......	......	......	......	41.4
Solanaceæ.											
Lycium barbarum, *L*	Matrimony	......	......	......	......	......	......	......	......	65.4	58.0
Urticaceæ.											
Ulmus fulva, *Michx*	Red elm	......	......	52.1	44.0	......	......	......	......	51.5	36.3
" americana, *L*	White elm	41.4	39.8	45.6	36.8	......	......	57.1	52.3	43.0	43.9
Morus alba, *L*	White mulberry	52.1	43.0	......	......	......	......	......	......	......	......
" rubra, *L*	Red mulberry	......	......	47.0	42.8	......	......	......	......	56.2	40.9
Platanaceæ.											
Platanus occidentalis, *L*	Plane tree	44.5	51.6	50.2	52.1	52.5	53.8	......	......	48.2	50.6
Juglandaceæ.											
Juglans nigra, *L*	Black walnut	45.5	46.1	50.2	56.1	......	......	......	......	50.6	53.8
" cinerea, *L*	Butternut	......	......	50.5	52.2	......	......	54.2	54.1	49.5	50.4
Carya alba, *Nutt*	Hickory	......	......	39.2	40.2	......	......	45.7	45.1	38.4	37.8
" porcina, *Nutt*	Pig nut	......	......	40.8	38.0	......	......	......	......	38.1	35.4
" amara, *Nutt*	Bitter nut	33.3	31.2	......	......	......	......	......	......	......	......

CUPULIFERÆ.											
Quercus alba, *L.*	White oak	38.0	35.2	40.6	58.7	41.2	36.7	43.1	39.5	45.0	41.9
" bicolor, *Willd.*	Swamp oak	......	......	45.0	......	......	......	......	......	46.9	......
" coccinea, *var.* tinctoria, *Wang*	Scarlet oak	......	......	42.5	38.0	......	......	......	......	44.9	39.3
" ilicifolia, *Wang*	Scrub oak	......	......	40.6	39.4	......	......	......	......	42.2	38.4
" palustris, *DuRoi*	Pin oak	......	......	43.2	39.8	......	......	......	......	44.8	39.9
" prinus, *L.*	Chestnut oak	......	......	42.4	37.9	......	......	......	......	42.4	......
" rubra, *L*	Red oak	......	34.3	42.6	38.6	......	......	......	......	41.7	39.9
Castanea vesca, *L.*	Chestnut	......	......	47.4	45.6	......	......	......	......	45.1	44.5
Fagus ferruginea, *Ait*	Beech	44.2	44.7	45.4	45.7	......	......	......	......	45.2	45.8
" sylvatica, *var.* purpurea	Purple beech	......	......	43.8	43.3	......	......	......	......	43.7	43.5
Corylus americana, *Walt*	Hazel	......	......	49.8	48.6	......	......	......	......	50.9	52.8
Ostrya virginica, *Willd*	Lever wood	37.6	38.6	43.0	36.5	......	......	......	......	44.4	41.5
Carpinus americana, *Michx.*	Iron wood	38.7	39.4	45.6	42.8	......	......	51.7	48.7	44.5	43.9
MYRICACEÆ.											
Comptonia asplenifolia, *Ait*	Sweet fern	40.6	40.0	......	......	......	......	......	......	......	......
BETULACEÆ.											
Betula lenta, *L.*	Cherry birch	......	......	44.9	38.9	......	......	......	......	44.7	41.5
" lutea, *Michx*	Yellow birch	42.4	43.6	......	38.2	......	......	49.7	49.4	44.4	42.5
" alba, *var.* populifolia, *Spach*	White birch	46 2	42.0	41.1	37.7	......	......	53.9	48.5	45.0	39.1
Alnus viridis, *D.C.*	Green alder	......	......	47.9	43.2	......	......	......	......	48.9	55.0
" incana, *Willd*	Speckled alder	50.4	51.5	......	......	......				......	......
SALICACEÆ.											
Salix alba, *var.* vitellina, *L*	White willow	49.9	51.7	55.5	55.5	......	......	53.1	49.7	55.4	55.5
Populus tremuloides, *Michx*	Aspen	49.8	50.9	47.9	52.5	......	......	53.3	51.0	52.8	51.5
CONIFERÆ.											
Larix europea, *L*	Larch	40.9	47.8	......	......	......	......	......	......	......	......
Juniperus virginiana, *L*	Red cedar	......	......	57.6	45.9	......	......	......	......	56.2	45.1
Tsuga canadensis, *Carriere*	Hemlock	48.7	49.6	46.8	49.9	......	......	......	......	44.1	45.6
Pinus rigida, *Miller*	Pitch pine	......	......	54.2	54.3	......	......	......	......	53.8	57.6
" strobus, *L*	White pine	......	......	58.8	52.1	56.3	55.5	62.9	58.3	63.1	51.6

If we next inquire into the relation which seasons bear to the contained water, we shall observe that the percentage continually rises from the midwinter period until spring, and that it again falls from the close of summer to the midwinter period. The extreme variations as exhibited in our figures, show, between February and September, a difference of 8.4 p. c. for the youngest growth, and 7.1 p. c. for that which is older.

MEAN HYDRATION OF WOODS.

MONTHS.	Per Cent. Water.		No. for Average.	
	1st Year.	2nd Year.	1st Year.	2nd Year.
February	44.7	43.9	37.0	38.0
March	47.2	44.8	59.0	60.0
April	51.7	48.4	6.0	7.0
September	53.1	51.0	19.0	18.0
December	48.3	47.2	61.0	58.0
MEAN	49.0	47.1	36.4	36.2

Our figures also indicate that the maximum hydration of the tissues must occur either in September, or at some period intermediate to this month and April. By graphic representation of these results, it will become possible to determine with approximate accuracy the true period at which this maximum is reached. The figures show that, from February to April, the rate of percentage increase is much more rapid than the rate of percentage decrease from September to December. A curve which will show this, should also show the period of maximum percentage. By reference to the chart, it will be seen that the curves for both young and old wood run nearly parallel, but that they tend to approach at their greatest depression, and to separate more widely at their greatest elevation. It is also seen that, from midwinter to spring, the curve rises rapidly and reaches its greatest elevation about May 18th for the youngest wood, while that for the older wood attains its maximum a few days later, or about the 22nd. From this time on, the curve descends at a more gradual rate until December, when it suddenly drops to its minimum depression, which evidently occurs in January.

PERIODS OF CESSATION OF GROWTH.

As, upon theoretical grounds, the tissues contain most water when the growth is most active, data which will enable us to fix accurately the limiting periods for the season's growth, will have an important bearing upon this question. Mr. W. E. Stone, [1] accepting the completion of terminal buds as marking completion of the longitudinal growth for the entire year, has obtained the following data, as establishing periods limiting growth in trees for the latitude of West Point, New York, 41° 23′ N.:—

JUNE 1ST.

Acer saccharinum. *Wang.*
" rubrum. *L.*
Amelanchier canadensis. *Torr & Gr.*
Carya alba. *Nutt.*
Fagus ferruginea. *Ait.*
Fraxinus americana. *L.*
Hamamelis virginica. *L.*
Kalmia latifolia. *L.*
Populus tremuloides. *Michx.*
Quercus alba. *L.*
" bicolor. *Willd.*
" coccinea. *Wang.*
" prinus. *L.*
Sambucus pubens. *Michx.*
Tilia americana. *L.*
Ulmus americana. *L.*
" fulva. *Michx.*

JUNE 15TH.

Betula lenta. *L.*
Carpinus americana. *Michx.*
Castanea vesca. *L.*
Juglans nigra. *L.*
Lindera benzoin. *Meissner.*
Morus rubra. *L.*
Ostrya virginica. *Willd.*
Prunus cerasus. *L.*

[1] Bull. Torrey Bot. Club., xii. 8, 83.

JULY 19TH.

Andromeda ligustrina. *Muhl.*
Alnus incan . *Willd.*
Nyssa multiflora. *Wang.*
Staphylea trifolia. *L.*

INDETERMINATE PERIOD.

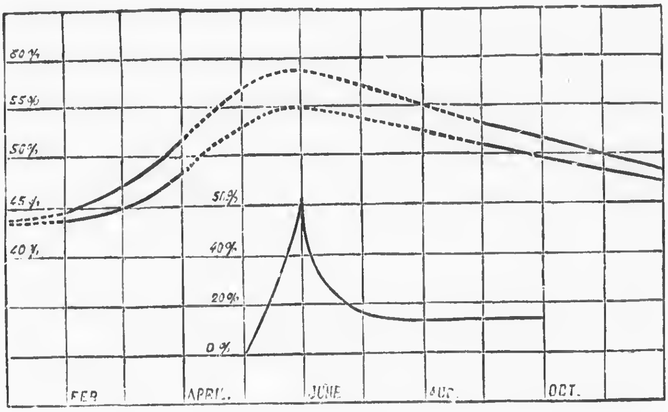
Ampelopsis quinquifolia. *Michx.*
Celastrus scandens. *L.*
Rhus. *Sp.*
Vitis. *Sp.*

This, therefore, gives us the following percentage quantities, showing cessation of growth at different periods :—

May 1st, commencement of growth.			
June 1st, cessation of growth in		51.5	p. c.
June 15th,	" "	24.2	"
July 19th,	" "	12.1	"
Indeterminate period	"	12.1	"

Growth in length having ceased at these periods, the energy of the plant then becomes directed to the lignification of tissues and the deposition of reserve material for growth the following year. These changes, however, involve of necessity, a continual decrease in the contained water. The data above, also, show that the majority of plants complete their longitudinal growth within the first six weeks of the growing season; that most of these complete their growth in from three to four weeks; and that, as the season advances, the number of plants still growing rapidly diminishes until the middle of July, after which there are left but few, those being plants like the grape, which continue to grow to the very end of the season.

A graphic representation of these changes will enable us to institute a comparison with the relations of seasons to hydration of the structure. The lower figure of the chart is the curve expressing this decrease of growth with advancing season. A comparison of both curves will show most conspicuously, that that period, during which growth for the season is most rapid is coincident with the period of maximum hydration of the tissues.



It is evident from the facts stated, that the amount of water contained in trees can have no direct relation to their bleeding when punctured. Indeed, it is a well-known fact that the bleeding of trees, such as enables us to collect maple sugar, is a purely physical process, wholly dependent upon the effect of external temperature in producing variable internal tension, hence in no sense connected with physiological processes; that this bleeding may occur at any time during the rest period, provided the conditions of temperature are favorable; hence, that it is most pronounced when there is the least water in the tissues: that during the seasons of most active growth, when the plant contains most water, no bleeding occurs.

CONCLUSIONS.

From the foregoing facts, we are justified in the conclusions which follow:—

(1.) The hydration of woody plants is not constant for all seasons, and depends upon conditions of growth.

(2.) The hydration reaches its maximum during the latter part of May or early June, and its minimum during the month of January.

(3.) Hydration is greatest in the sap wood; least in the heart wood.

(4.) Greatest hydration is directly correlated to most active growth of the plant,—lignification, and storage of starch and other products, being correlated to diminishing hydration.

These conclusions are to be understood as applying only to latitudes lying between New York and Boston. For other latitudes, certain modifications might be necessary.