

On the Quantitative Differences in the Water-Conductivity of the Wood in Trees and Shrubs. Part I.—The Evergreens.

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The present communication aims at presenting, in a necessarily curtailed and somewhat preliminary form, the results of an enquiry into the comparative efficiency of the wood as a water-conducting tissue in about sixty species of plants. These consisted for the most part of trees and shrubs, but a few herbaceous forms were studied as well. The investigation was undertaken in the first instance in order to find out whether the efficiency (regarded from the standpoint of its water-conductivity) of the wood could be usefully expressed for a given species in a quantitative form, and if so, what kind of deviation from the average or mean was to be expected, and to what extent separate species might differ among themselves in this respect; secondly, whether the mean conductivity can be correlated with any obvious character such as deciduous or evergreen habit; thirdly, to ascertain if possible whether definite changes of external conditions can evoke corresponding change in the water-conductivity.

It is a remarkable circumstance that, although the absorption of water by the roots and its elimination during transpiration from the leaves and other green surfaces are processes which have served as the starting-points of a vast number of investigations, the behaviour of the wood as the intervening conducting channel has been almost entirely neglected. It is true that the path actually followed by the water has long been known, and that attempts to discover an adequate physical explanation of the ascent had been repeatedly made for many years before the fine researches of Dixon and Joly showed clearly where the solution of this problem was to be sought. But the limitation which the structure of the wood may impose on the volume of water transmitted appears to have attracted no attention at all. And yet the life and habits of a plant are so closely linked up with the problem of water supply that every factor that can influence the complex adjustment of supply of and demand for water deserves serious consideration. It cannot be devoid of interest for those concerned in arboriculture and forestry, for not only may it determine whether a particular species can flourish under given natural conditions, but it also concerns the inter-relations between those

tissues in the wood which materially determine the nature and commercial value of timber.

The method adopted for securing the data required for the present investigation consists essentially in measuring the amount of water passing in a given time and at standard pressure through a definite length of twig or branch, the cross-sectional area of whose wood is carefully ascertained. From the data thus obtained, it is easy to state the result in terms of the amount of water that would pass under precisely similar conditions through a stem, the cross-sectional area of the wood of which measured 1 sq. cm. in cross-section; in other words, starting from a ratio, "absolute volume" \div observed area of wood, to state the results in such a form that "area" shall equal 1 sq. cm. The actual procedure adopted was as follows:—

A branch of a tree or shrub is immersed in and severed under water, in order to obviate the entrance of air into the vessels. Twigs from $\frac{1}{2}$ to 1 cm. in diameter are cut off, also under water, and are divided into lengths of exactly 15 cm. In the case of rod-like branches, *e.g.*, of sapling trees or coppice-shoots, it is possible to get from three to five or more lengths, and these are kept together and numbered from base to apex for purposes of subsequent identification. Any lesions consequent on trimming off side branches are well luted up with sealing-wax of low melting point, this proving the best of all the substances tried. The twigs are then put into a vessel of boiled water and subjected to vacuum treatment, in order to free the wood as far as possible of any air it might contain. This precaution has served to eliminate most of the discrepancies which appeared in the earlier stages of the investigation. The twigs are then fixed (wiring them if necessary) by their lower or basal ends into the pressure tubing at the ends of the vertical tubes below J, J₂, J₃, J₄, in the apparatus shown in fig. 1, and the amount of water, delivered at a pressure of 30 cm. of mercury, which is transmitted in exactly 15 minutes, can easily be collected and measured in the graduated glasses below. Three or four successive measurements were made for each twig in order to test the uniformity of flow, which thus lasted for about an hour or more. Only those results which showed no, or very small, deviations were accepted, but the number of those discarded as untrustworthy becomes very trifling when precaution is taken to prevent air trouble. Stems which contain resin or mucilage, however, are apt to be unsatisfactory, owing to the blocking of the ends of the water-conducting tracts. After the stems are removed and the estimation of the transmitted water is finished, the cross-sectional area of the wood is measured. The twig is bisected transversely, and a section from the surface so exposed is prepared for the microscope. The limits of the wood are accurately traced on paper by

means of a camera lucida at an exact magnification of 10 diameters. By means of a planimeter the area of the wood thus obtained can easily be determined. Inasmuch as the instrument used by me measures areas in inches a reduction to centimetres has to be made, and the result divided by 100 gives the real area in square centimetres.

It may be objected that a section taken from the middle of the stem will not give absolutely accurate data for estimating the flow per square centimetre through the twig. But, having regard to the natural taper of the stem and the fluctuating area of the wood, it is probably as near an approximation as it is possible to reach. Furthermore, as all the specimens are treated in the same way, the error, in so far as it affects the value of comparative results, will in any case be very small, and well within the limit of unavoidable experimental error. From the data obtained as above, the volume transmitted by a stem 15 cm. in length per 1 sq. cm. of wood (in cross-section) is calculated, and this ratio constitutes what is hereafter termed the "specific volume," and it expresses quantitatively the "specific conductivity" of the wood of any given twig. Comparison can be made with other branches, whether of the same or another species, thus enabling a very precise estimate to be made of the range of variation occurring in a particular species, and this again serves as the basis for comparing the behaviour of different species with one another.

The apparatus employed in this research is shown in the accompanying illustration (fig. 1), for which I am indebted to Miss Reeks, Technical Artist. It consists, essentially, of a tube which conveys the water, under any desired pressure, to the twigs figured as dipping into the four measuring glasses. A special arrangement also renders it possible to suck water up through the twigs from the measuring glasses, and to determine the amount so transmitted by means of the burette marked P in the figure.

The water is supplied from the main supply by means of the tap A; it passes through a glass wool filter D_1 to a T-piece, and thence in the direction of the arrow through the tap E, and a second glass wool filter D_2 to the three-way tap F, which connects with the manometer. The water rises in the tube leading to the latter, but is prevented from passing into the manometer head by the two pairs of bulbs G_1 and G_2 . The three-way tap F further carries the water through H to the four twigs through the three-way taps J_1, J_2, J_3, J_4 . Any or all of these twigs can, of course, be disconnected at pleasure from the water in the horizontal tube leading to the three-way tap K, which ordinarily serves as a cut-off, and thus all the water is delivered through the twigs, and the amount from any or all of them is severally collected in the measuring glasses. Any air bubbles that may occur in the system are easily washed out by opening the taps K and O, and drawing the water through the apparatus by means of the filter pump B attached to the middle of the three main taps. For this purpose the bottle of water N is specially useful, as a means of completely washing out the whole of the horizontal tube.

The pressure of water from the main is kept nearly constant by the device of connecting the limb of the T-piece beyond D_1 with a filter pump attached to the main tap A. The negative pressure thus produced is roughly adjusted to carry off a part of

the water that enters from A, and a screw pinch-cock C serves as a very delicate fine adjustment. The desired pressure within the apparatus, registered by the manometer shown in the figure as graduated in centimetres (but actually each centimetre is subdivided into millimetres), is thus easily obtained, while the sort of differential pressure in the T-piece secures steadiness, since any sudden increase in A is largely met by an increased outflow in A, and thus is prevented from effecting sudden change in the body of the apparatus. But, although the manometer level may remain constant for a considerable period, any unusual demand on the main supply naturally becomes

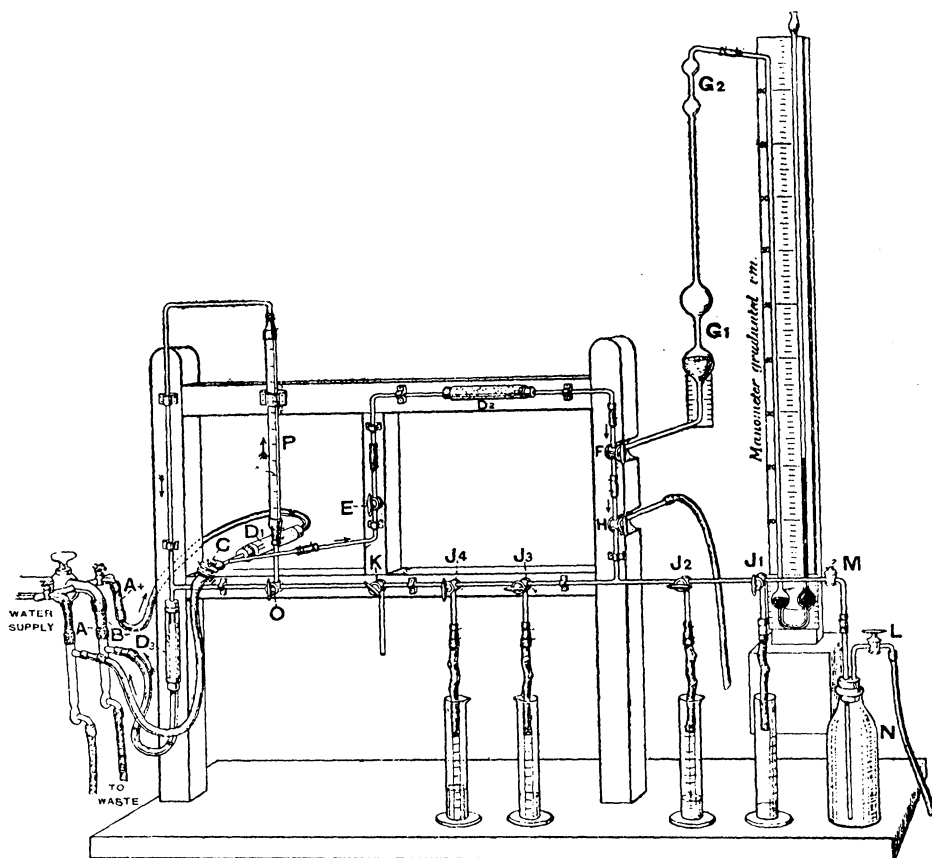


FIG. 1.

reflected in a change in pressure, but this can instantly be remedied by means of the pinch-cock C. It need hardly be added that the height of the water from the bulb G_1 to the twigs must be taken into account in determining the height of the mercury required to indicate the particular pressure desired.

When the apparatus is used to measure the amount of water sucked up through a twig from a glass, under given conditions of negative pressure, the procedure is somewhat different. For this purpose all the twigs are first cut out of the water circuit by the three-way taps. The water supply is then cut off at the tap F, which at the same time places the manometer in communication solely with the part of the tube below it.

The negative pressure is obtained by connecting the horizontal tube with the filter pump B through the taps O and K. Any air bubbles that may be formed are easily washed out by temporarily admitting water either through H or M. Practice enables one to judge how much water is needed in the system to correspond with any desired pressure, and, having once obtained this amount, the tap O is turned to direct part of the water into the burette P; finally, any additional water required to bring the water-level therein to the zero mark is drawn in through K. Only one twig can, of course, be connected up during a single experiment, and care must be taken that the height of the water column on the scale G is always brought to the same level when readings of the burette are to be taken.

In practice, the results obtained under negative pressure merely confirm those more easily and economically (since four twigs can be used simultaneously) reached under positive pressure. This fact indicates that, as might be expected, the water is transmitted with equal facility from base to apex and in the reverse direction, having regard to differences of thickness of the two ends. It serves as a useful check on results where there is reason to suspect air bubbles as the cause of unexpected irregularities in consecutive readings, for the alternate application of positive and negative pressure may be used to dislodge them without otherwise interfering with the experiment. At other times also it affords a useful means of testing a reading of unanticipated value.

The subjoined Table indicates how the records were made, and the degree of uniformity to be expected. It may be noted that the doubled pressure (60 cm. mercury) is only applied for $7\frac{1}{2}$ minutes, that being equivalent to 30 cm. for 15 minutes. The readings are taken to the nearest tenth of a cubic centimetre in well-made measuring glasses, graduated in cubic centimetres and tenths of a cubic centimetre. The stem in question happens to be that of a deciduous tree, but it has an advantage in this respect over that of an evergreen, in that the larger actual values given afford a better illustration of the method as a whole.

Table I.—Apple, Cox's Orange Pippin, September 27, 1917. Length of Stems, 15 cm.

Time.	Stem No. 1.	Stem No. 2.	Stem No. 3.	Stem No. 4.	Pressure.
4.3 to 4.18 P.M.	11.4	10.6	7.6	4.8	+ 30 cm. mercury
4.19½ to 4.27 P.M.	11.2	10.6	7.2	4.6	+ 60 cm. "
4.28 to 4.43 P.M.	11.6	10.6	7.4	4.8	+ 30 cm. "
Average absolute volume	11.4	10.6	7.4	4.8	
Area of wood in middle zone of twig (Planimeter reading)	2.68	2.91	2.06	1.47	

The area of the wood is given in inches, as measured by the planimeter on a drawing to scale ($\times 10$) from a section. It is reduced to cm. at magn. ($\times 1$) in calculating the specific volume.

Perhaps the most clearly defined result which has emerged from this investigation is that the evergreens, as a class, possess wood of markedly lower efficiency than that of the broad-leaved deciduous trees. In other words the specific conductivity is lower. Furthermore the absolute range of

variation in an individual species is far narrower than in the deciduous forms. The Holly affords a good example of this character. The specimens used for the experiments were cut from trees and bushes of the most diverse habitat, some growing in wet soil near a brook, others in woodland shade, others again were hedgerow trees on well-drained sandy soil, fully exposed to wind and sun. No constant difference was observed between shoots bearing prickly leaves, and those with laurel-like foliage. The subjoined Table will illustrate the points just mentioned, and it also shows that the uniformity of the wood is independent of its cross-sectional area and the age of the twig. Of course, in this, as in all the other examples, only the sap wood is under consideration. No branches with functionless heart wood were used. Naturally also, properly ripened wood must be taken. Young or immature wood always gives a relatively low reading and of quite uncertain value.

Table II.—Twenty-eight Twigs of Holly from Different Trees Growing in Diverse Situations.

Age in years.	Area of wood in inches ($\times 10$).	Absolute vol. in c.c. per $\frac{1}{4}$ hour.	Specific vol. in c.c. per $\frac{1}{4}$ hour.
1	1.60	1.1	10.8
1	1.45	1.0	10.5
1	1.19	0.6	7.8
1	1.36	0.7	8.0
2	2.74	1.6	9.0
2	3.48	1.7	7.7
2	6.19	3.0	7.5
2	4.84	2.6	7.0
3	6.36	5.0	12.2
2	1.93	1.4	11.3
1	2.56	1.5	8.9
3	3.74	1.9	7.8
1	2.49	1.3	8.1
1	1.59	1.2	9.8
1	1.77	0.9	7.9
1	1.24	0.7	8.6
2	4.75	3.3	8.6
2	3.30	1.8	7.4
2	3.28	2.0	9.4
2	2.60	1.6	7.9
2	1.98	1.2	9.4
2	2.47	1.4	8.6
2	2.49	1.2	7.9
1	1.52	0.8	6.8
2	4.73	2.3	7.6
2	4.23	2.7	10.0
2	4.34	2.2	7.8
2	2.72	1.9	8.6
	82.94	46.6	242.4
	(= 5.35 sq. cm., actual size)	$\frac{46.6}{5.35} = 8.7$	Average = 8.7

The value for the wood of the Yew (*Taxus*) was also low, but slightly higher than that of Holly, with specific conductivity of 12 ± 2 in the rather small number (6) of twigs examined, but the ages of these ranged from three to eight years, and I think the result may be taken as fairly accurate. *Podocarpus Milanjiana* grown in a plant-house in the Physic Garden at Chelsea was also examined. The plant was a well-grown one, and the branches were each divided into a basal and apical half. The average of the specific value of each pair thus obtained was also strikingly uniform, and it illustrates the desirability, in work of this kind, of getting fair averages to use as a basis of comparison. There are often considerable fluctuations in the conductivity of different regions of lateral branches, but when the average of the whole length is taken a figure is reached which is very near the mean for the particular species. This is much more obvious in deciduous than in evergreen trees, as in the former the fluctuation is considerably greater. It will be seen that in eight branches of *Podocarpus* the mean is 9·3 with an extreme variation of only 1·1 if the weak fourth shoot (at 7·1) be omitted. The Pine (*P. sylvestris*) and Larch (*L. europæus*) presented difficulties, owing to the presence of resin, but the figure for their specific conductivity is respectively about 14 and 16. Such uniformity as that indicated for the species hitherto mentioned is by no means universal even in the evergreens. Thus 15 stems of *Garreya elliptica*, with an average of 14·6, showed a

Table III.—*Podocarpus Milanjiana*. Each branch is divided into a basal (L) and an apical (U) half, and the results of each pair are bracketed.

Order of segment.	Age in years.	Absolute vol. in c.c. per $\frac{1}{4}$ hour.	Specific vol. in c.c. per $\frac{1}{4}$ hour.	Averages.
L	3	0·9	8·8	} = 8·90
U	3	0·7	9·0	
L	5	1·4	8·9	} = 9·65
U	5	1·4	10·4	
L	7	2·0	10·3	} = 9·65
U	4	1·1	9·0	
L	4	0·7	7·2	} = 7·10
U	4	0·5	7·0	
L	4	1·8	9·9	} = 8·55
U	4	1·2	7·2	
L	4	1·2	9·2	} = 10·35
U	4	1·3	11·5	
L	6	3·4	9·9	} = 10·30
U	5	3·2	10·7	
L	4	1·0	8·9	} = 9·70
U	4	0·9	10·5	
Total				74·10
Average				= 9·27

\pm variation of 5, whilst 50 stems of *Rhododendron ponticum* taken from different localities chiefly varied from 10 to 25, with a large proportion grouped about 18. But some were lower than 10, and a few were much higher than 25. Such variation is to be expected in a plant which is so freely branched, and with so wide a difference in the development of the branches, extending almost from abortion to extreme luxuriance.

Euonymus japonicus is also worth considering in this connection, and especially so because it will subsequently be convenient to compare it with the deciduous *E. europæus*. The branches of which the results are given in the annexed Table were taken from four sets of bushes, one lot growing in sandy soil in Surrey, the others from good fertile garden soil in Buckinghamshire, the last one growing in well-manured ground under the shade of trees. Although the plant indicates considerable responsiveness to the influence of the environment, it still is well within what might be called the evergreen limits, and in this respect contrasts with the deciduous species. Taking the mean for *E. japonicus* to be 12, it is seen that of 18 stems, 12 fall within 12 ± 3 , while three are above and three below these limits.

Table IV.—*Euonymus japonicus*.

Age in years.	Absolute vol. in c.c. per $\frac{1}{4}$ hour.	Specific vol. in c.c. per $\frac{1}{4}$ hour.
1	0.6	12.5
1	0.5	7.5
1	0.5	10.2
2	1.4	9.0
2	1.0	8.9
1	0.6	9.5
1	0.4	8.6
1	1.4	13.4
2	0.7	11.6
2	0.8	11.3
1	0.8	13.4
1	0.6	10.9
1	0.3	9.8
2	5.2	19.1
3	4.2	17.0
2	3.9	17.1
3	3.1	14.9
1	1.5	13.9
Total		218.4
Average		= 12.1

The heaths are, as might be expected, rather low in the scale. The large heath (*Erica arborea*) is the highest with an average of 15 and a range of ± 5 . This may possibly be connected with ease with the lesions that often

occur in the wood of this plant. *Pernettya*, on the other hand, gave an average (six observations) of 5 with scarcely any deviation.

Escallonia macrantha, as might be expected from its habit, is higher up in the scale with an average of 24, and 6 of the 7 stems investigated were inside the range of ± 2 . The deciduous *Azalea mollis* averaged 30.5 with a range in 8 of the 9 stems examined of ± 3.5 .

The species of the genus *Daphne* are of somewhat special interest as regards their relations to water. They are slow-growing plants, and include both evergreen and deciduous species. Among the latter the common *D. Mezereum* shows a near approach to evergreen habit, and lacks the abundant foliage of ordinary deciduous shrubs. In short it belongs to the class of plants often termed xerophytes, because they are supposed to be adapted to a dry environment, and yet it is a matter of common experience that the plant does not really thrive under xerophytic conditions, and this is even more true of actual evergreen species such as *D. Blagayana*, *D. Laureola*, etc. It is true that these will live in soil that is well drained, but they are by no means tolerant of drought. *D. Laureola* is commonly a woodland plant, and it grows best by the side of water. *D. Blagayana*, a plant that is sometimes difficult to grow, often refuses to succeed when exposed to sun and drought in the drier climate of the Home Counties. It requires to have its stems layered and to be earthed up with stones and leaf mould. If this is not done the shoots are apt to die back by reason of the inadequate supply of water which reaches the terminal cluster of rather large leaves. When earthed up, however, adventitious roots spring from the stem and make good the deficient water supply. For not only is the supply more copious, but it is also more immediately at the service of the leaves by reason of the shorter distance to be traversed through the wood.

All the species I have examined possess a wood of very low conductivity. *D. Mezereum*, as might be expected, is the highest, at about 7.

The low conductivity is clearly connected with the slow growth, and, like the latter feature, is a strongly marked and inherent character of the whole group. Nevertheless, the plants can hardly be, with propriety, termed xerophytes. The rather large leaves of the evergreen species are badly fitted to resist transpiration. They are reduced in number, it is true, but those present actually transpire rather freely. It is unquestionable that the limiting effect of the wood materially influences the reduced leaf area, although questions as to root efficiency are also bound up with the matter, at any rate in terrestrial plants. Those leaves that *are* present require supplies enabling them to transpire somewhat freely. Hence it becomes intelligible why a plant apparently xerophytic may yet be restricted to

localities in which it is never really subjected to drought. The wood is capable of transmitting a limited amount of water, the leaves are fitted just to utilise this amount with very little margin; in other words, though the plant requires little, it can hardly do with less. Furthermore, the roots are able at all times to supply the small amount of water needed by the relatively small, or else slowly transpiring, leaf surface, and this circumstance is doubtless the prime factor both in determining the evergreen habit, and also in limiting the situations in which the plants can flourish. The subject of the interrelation of root, stem, and leaf is a very complex one, and obviously cannot be dealt with here. It must suffice to have indicated that the stem structure may exert an influence in the whole problem which is by no means negligible.

It may be mentioned, also, that the creeping habit, combined with rooting at the nodes, so often to be seen among herbaceous plants, is also commonly connected with a wood of defective conductivity. It is not improbable that this correlation, which experience indicates very generally to exist between the creeping habit on the one hand, and with badly conducting wood on the other, is not merely a coincidence. Plants differ widely in the degree of variability in this or that character, and creeping plants would certainly repay experimental treatment from the point of view here under consideration.

Another plant of special interest in the present connection is the Butcher's Broom (*Ruscus aculeatus*). Attention must be called in the first place to the fact that it belongs to the class of monocotyledons, and the structure of its stem is unlike that of the plants hitherto considered. Owing to the circumstance that there is no clear demarcation between the wood and the cortex without and the pith within, it is not easy to get a well-defined area for measurement. The plan adopted was to include all the tissue within the cortex as wood. This doubtless (as in the case of other monocotyledons) means that the figure arrived at as representing the specific conductivity is somewhat low. But it seems the best that can be done, and having regard to the low absolute conductivity it is probable that it is not so far from the correct figure as might be supposed. At all events the monocotyledons themselves are fairly comparable *inter se* on such a basis.

The Butcher's Broom is certainly one of the most striking examples of a xerophyte, so far as habit goes, among all our native plants. And yet it avoids habitats which might be regarded as consonant with its appearance. Like the Daphnes, it requires very little water—far less, relatively speaking, than they do. But it flourishes best in woodlands, and thrives in damp ground, soon disappearing when really dry conditions set in, even though these may

endure for short periods of time. There is no question of invoking the facile "explanation" that it is adapted to "physiological drought." Its associates are mainly ordinary mesophytic, often almost hygrophytic, plants, and no assumption of sour soil, or of unavailable or peaty water will satisfy the facts.

Suggestions as to the supposed influence of "sour" soil have often been advanced to account for the supposed xerophytic habit of rushes and sedges. Nearer examination tends to show that such "explanations," however attractive, are apt to be illusory. Neither rushes nor sedges are for the most part at all adapted to endure real shortage of water.* It is true that some of them use relatively little, but they are commonly extremely intolerant of any diminution beyond their actual modest requirements. It is quite possible to grow rushes in apparently dry garden soil, provided the water table is not so far down that the capillary action of the soil is not at all times able to supply the roots with the amount the plants normally utilise. The small amount of water actually rendered available is to be attributed to the defective conductive capacity of the wood, which in all such plants as Butcher's Broom, Rushes, etc., so materially hampers a free supply. The same is true of the aquatic *Scirpus lacustris*, with its green wand-like stems, and also of the *Equiseta*. None of these plants are able to endure even short periods of complete deprivation of water without wilting.

It appears then that the xerophytic habit of the plants just mentioned is to be correlated very directly with the inherent structure of their own wood, and not with any special feature in their external surroundings, or in imperfect water absorption.

An inspection of the figures given for *Ruscus* will readily serve to make clear the points alluded to above. Indeed so little water is transmitted per $\frac{1}{4}$ hour, that it was necessary to continue each measurement for an hour, or else to double the pressure for half-an-hour (which yields the same result) in order to collect enough water for a reliable estimate to be made.

The climbing plant *R. (Semele) androgynus* is strictly comparable with *R. aculeatus* in respect of its stem, and as might be anticipated it is found to possess a vastly superior vascular tissue, regarded from the point of view of its conductivity. Like the climbing species of *Asparagus*, which have also unquestionably sprung from xerophytic ancestors, it has largely increased its green water-transpiring surface and it is freely branched. Its specific conductivity varies within rather irregular limits, but the mean is about 40 in

* In an interesting paper, by Dr. M. Delf, the point is made that the leaves of halophytes are not specially adapted to restrict transpiration. It would be of interest to examine the wood of some of these plants. See Delf, "The Meaning of Xerophily," 'Journ. Ecol.,' III.

Table V.—*Ruscus aculeatus*. Eight stems, of which seven are divided into a lower and upper half.

	Absolute vol. in c.c. per $\frac{1}{4}$ hour.	Specific vol. in c.c. per $\frac{1}{4}$ hour.	Average.
1. Entire	0·2	0·77	0·77
2. { Lower	0·2	0·76	} 0·65
{ Upper	0·1	0·49	
3. { Lower	0·3	1·15	} 1·06
{ Upper	0·2	0·96	
4. { Lower	0·15	0·81	} 0·93
{ Upper	0·15	1·04	
5. { Lower	0·2	0·85	} 0·82
{ Upper	0·1	0·78	
6. { Lower	0·15	0·75	} 0·77
{ Upper	0·15	0·78	
7. { Lower	0·2	1·10	} 0·88
{ Upper	0·1	0·74	
8. { Lower	0·2	0·85	} 0·94
{ Upper	0·2	1·12	
Mean			= 0·86 (nearly)

the material at my disposal, the stems of which were about 0·4 cm. in diameter. Although very much greater than that of its shrubby relatives, its conductivity still falls far below that of the common dicotyledonous climbers. It is probable that the rather clumsy and characteristic appearance of most arborescent monocotyledons is to be associated with a defective water conductivity. The Palms, for example, commonly have leathery leaves and unbranched stems. There are, however, some exceptions amongst the palms, and it would be of great interest to know more about the efficiency of their wood.

Among dicotyledonous climbers the Ivy deserves notice, since it illustrates a feature that is very characteristic of climbers in general. The wood of its creeping youth-form has a low conductivity value, ranging round 25, but as the plant reaches the freely branching large-leaved adult form ("Tree Ivy"), the vascular tissue undergoes a change, and the conductivity increases to at least twice the value of that characteristic of the juvenile stage. But the relatively inadequate water supply is seen in the inability of the plant to succeed in exposed dry situations, and by the reduction in the size of its leaves plainly to be observed in Ivy that is freely open to sun and wind.

The common Privet (*Ligustrum vulgare*) stands high among the evergreens as regards conductivity. It often sheds its leaves in winter, and may, therefore, be regarded as approaching the deciduous class. Its principal range, as determined from an examination of 50 stems, extends from 30 to 42,

Table VI.—Twenty-three Branches of Privet.

Age in years.	Absolute vol. in c.c. per $\frac{1}{4}$ hour.	Specific vol. in c.c. per $\frac{1}{4}$ hour.
1	6.0	37.5
1	7.4	35.5
1	7.2	34.5
1	5.2	35.5
1	6.4	39.0
1	6.5	34.5
1	6.2	41.5
1	6.3	29.2
2	9.0	31.0
2	8.0	40.0
1	7.6	37.5
1	7.6	39.0
2	11.4	33.5
2	7.6	42.0
2	14.8	37.0
4	14.6	32.0
2	14.6	40.5
2	4.0	32.5
4	8.0	27.5
2	11.2	37.5
2	16.2	38.0
2	9.4	37.5
2	15.0	34.0
Total		826.7
Average		= 35.9

with a few outliers on either side, but a large proportion falling close to the mean, 37.3, with a P.E. of 3.6 for the whole lot.

The curve is a very regular one, but not more so than that furnished by

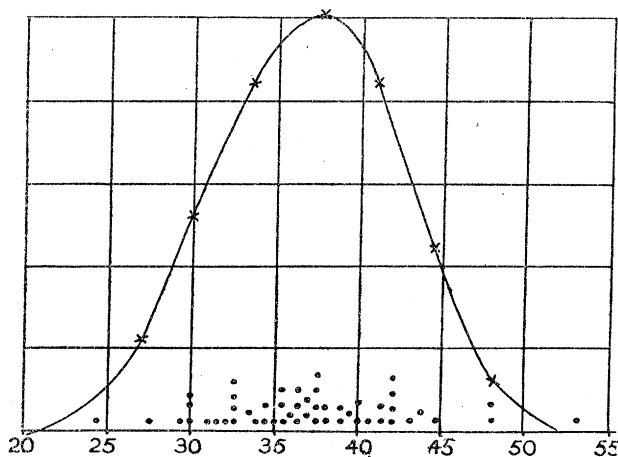


FIG. 2.—Results for Privet. Arithmetic mean = 37.3 and the P.E. = 3.6.

Summary of Observations on Evergreens, Trees and Shrubs, etc.

Name of plant.	Range within which fluctuation is probably normal.		Results falling outside range. Highest and lowest deviations are included in brackets.			Ratio of number falling within normal range to those outside it.	Totals.
	Range.	Number included.	Below normal range.		Above normal range.		
Larch	14.5±2	10	1	(9)	2	10:3	13
Scots Pine	13±2	2	—	—	—	2:0	2
Yew	12±2	4	—	—	1	4:1	5
<i>Podocarpus Milanjianus</i>	9±2	18	—	—	1	18:1	19
<i>Elaeagnus macrophylla</i>	15±5	6	1	(8)	—	6:1	7
Privet	37±8	46	2	(24)	3	46:5	51
<i>Daphne Laureola</i>	3±1.5	17	1	(1)	2	17:3	20
" <i>Mezereum</i>	6.5±1.5	13	1	(3.5)	1	13:2	15
" <i>Blagayana</i>	7.5±1.0	2	—	—	—	2:0	2
<i>Veronica Traversii</i>	11±1.5	3	1	(9)	1	3:2	5
<i>Euonymus japonicus</i>	12±6	31	1	(4)	—	31:1	32
* <i>Rhododendron ponticum</i> ..	18±10	67	9	(5)	19	67:26	93
Holly9±2	35	3	(5)	—	35:3	38
<i>Garrya elliptica</i>	13±3	10	—	(8)	5	10:5	15
* <i>Quercus Ilex</i>	32±12	14	5	(8)	3	14:8	22
<i>Prunus Laurocerasus</i>	10±2	6	2	(7)	1	6:3	9
<i>P. lusitanica</i>	18.5±4	10	2	(10)	2	10:4	14
Common Broom	25±5	6	2	(13)	2	6:4	10
† <i>Azalea mollis</i>	30±5	8	—	—	—	8:0	8
† <i>Lilium Martagon</i>	17±7	7	—	—	—	7:0	7
Arborescent Heath	8±4	6	—	—	1	6:1	7
<i>Pernettya mucronata</i>	5±0.5	4	—	—	1	4:1	5
<i>Escallonia macrantha</i>	23±3	5	1	(18)	1	5:2	7
<i>Ruscus aculeatus</i>	1±0.3	18	—	—	—	18:0	18
<i>Senecio androgynus</i>	Irregular	—	—	—	—	—	—
Climbing Asparagus	Irregular	2	—	—	1	2:1	3
<i>Aucuba japonica</i>	11±1	2	1	(9)	—	2:1	3
<i>Olearia Haastii</i>	14±1	24	4	(6)	3	24:7	31
<i>Chotsya ternata</i>	11±3	6	—	—	—	6:0	6
Ivy, youth	25±5	3	1	(37)	1	3:2	11
" adult	60±10	—	—	—	—	—	—

* This is heterogeneous material, including very strong and very weak shoots.

† Not an evergreen.

observations on some of the other plants, *e.g.*, Plum "Belgian Purple." On the other hand, many species of both evergreen and deciduous plants do not admit of the water conductivity results being grouped in so satisfactory a frequency curve as that of the Privet.

The Evergreen Oak (*Quercus Ilex*) also stands high, at about 28. Its wood is far less close than that of most evergreens, and contains wide vessels resembling those of the common Oak. It shares with the latter species a considerable degree of plasticity, and in this respect it also departs from the evergreen type.

The relatively freely transpiring evergreen Portugal Laurel (*Prunus lusitanica*) has a specific conductivity of about 18.5; of 14 specimens examined 10 were within ± 4 of this amount. The Common Laurel (*P. Lauro-cerasus*), as might have been expected, ranks much lower, and of 9 specimens 6 fell within the limits of 10 ± 2 .

A number of other evergreens were examined, but those here mentioned will suffice to indicate the general character of the group. The preceding Table will, however, sufficiently indicate the range of the investigation on evergreens; it will be more fully referred to in a second paper dealing with the deciduous species of trees and shrubs.

On the Quantitative Differences in the Water-Conductivity of the Wood in Trees and Shrubs. Part II.—The Deciduous Plants.

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If the broad-leaved deciduous trees and shrubs be contrasted with the evergreens, it is found that they are marked by a specific conductivity which in the free-growing and foliage-bearing shoots is far greater than in the class hitherto considered.

This is well brought out by contrasting the results obtained on comparing an evergreen with a deciduous species of the same genus. The subjoined Table (I) for *Euonymus japonica* (evergreen) and *E. europæus* (deciduous) will serve to illustrate the point. It will presently become apparent, however, that there are certain exceptions to be reckoned with amongst the deciduous trees, especially in the case of young sapling trees and coppice stool-shoots (*e.g.* of ash or hazel).