THE RELATION BETWEEN THE OSMOTIC STRENGTH OF CELL SAP IN PLANTS AND THEIR PHYSICAL ENVIRONMENT

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The literature relating to methods of determining the osmotic strength of the cell sap in plants is voluminous. Foremost amongst writers on the subject have been De Vries (1, 2, 3, 4, 5), Pfeffer (6), Stange (7), Janse (8 and 9); and many other authors have contributed to our knowledge. But in spite of the attention which has been directed to this line of investigation, few authors have given the results of comparative work on a series of plants, though scattered throughout the literature are many isolated instances which, if brought together, would tell us something of the real range of osmotic strength met with. The results obtained seem to show that in general the osmotic strength of sap in land plants ranges between strengths equivalent to 1·3 and 2 per cent. potassium nitrate. It is unfortunate that in the majority of cases the equivalents have been given in percentages of the salt used, for this has greatly obscured the true significance of the results. At the present time it is customary to quote the strengths as equivalent to fractions of gram-molecular solutions; but even stated in this way the results obtained with different electrolytes are not strictly comparable. The best way is to give the osmotic pressures as equal to that of so many millimetres of mercury.

In 1905 a short preliminary statement of the results of our work on the osmotic strengths of sap in plants growing under different

conditions was published (10). In this note determinations for nine plants were described. The number of plants investigated has now been brought up to forty-eight. They have been collected from many very different sources, and the relation between external environment and strength of cell sap has been clearly established.

METHOD

The method of plasmolysis employed by de Vries has been used throughout, the plasmolysing agent employed being sodium chloride. Solutions differing by a unit in the second place of decimals were made up from 0.10 to 0.60 gram-molecular strength.

The epidermis, stripped from the surface of the leaf as described by de Vries (3 and 5), is the easiest tissue to work with when it contains a coloured sap as in *Tradescantia* or *Saxifraga sarmentosa*, but in the large majority of cases the epidermis is devoid of such coloured sap, and, moreover, it can only be removed from the leaf with difficulty. On this account the mesophyll has been used in nearly every case, and owing to the presence of chlorophyll corpuscles in these cells, the first appearance of plasmolysis could very certainly be detected after considerable experience of the method. A small portion of the leaf was teased on the slide in water, and was then carefully examined for comparison with the same tissue in the different strengths of solution, commencing with the lowest, 0.10. At a certain concentration, plasmolysis just commences. The strength of solution which just fails to plasmolyse is then taken as the osmotic equivalent of the cell sap. The solutions were allowed to remain on the tissue for from five to ten minutes, and it is important to note that if the cells showed no sign of plasmolysis at the end of this time no plasmolysis could be induced by lengthened exposure to this strength of solution. Hence any objection to the method based on the supposition that treatment with the solutions was not sufficiently long-continued would appear to be without foundation. The mesophyll cells have very thin, readily-permeable cellulose walls, through which the solutions penetrate very rapidly. Penetration through the walls of the epi-

dermal cells is frequently not nearly so rapid, and this is another disadvantage in using the epidermis for making the determinations.

The choice of sodium chloride as the plasmolysing agent is justified from several points of view. In dilute solutions it has only a very slightly toxic action if any, even when exposure to its action is prolonged. It is a salt of which the plant has much experience in nature, sodium chloride being a constituent of cell sap, and also present, often in considerable quantity, in the soil water. Experiment has shown that cells may be plasmolysed with quite strong solutions of this salt, as much as 1-gram-molecular, without losing the power of recovery when again placed in water. Our experience has been in full accord with the statement made by Livingston (11) that sodium chloride penetrates the cells of most plants very slowly if at all, since cells placed in a solution of this salt just strong enough to cause plasmolysis will not recover even after several hours.

True (12) states that a 0.1 gram-molecular solution of sodium chloride will kill *Spirogyra* in twenty-four hours; our own experience, however, does not support this statement. In any case, sodium chloride may be used with confidence as the agent of plasmolysis, especially in view of the fact that the cells are exposed to its action for a short time only.

The osmotic pressures determined by the method thus described can be stated in fractions of a gram-molecular solution of sodium chloride. But this salt is an electrolyte, dissociating in different degree for each stage of dilution. Not only do the undissociated molecules in the solution act osmotically, but the ions play a similar part. A bare statement of osmotic strengths in fractions of a gram-molecular solution does not take into account the fact of ionization, and hence results obtained by using different plasmolysing agents, stated thus, are no more comparable with one another than if they were expressed in percentages.

We have made a calculation of the dissociation-constant $\alpha = \frac{\lambda_v}{\lambda_\infty}$ for every strength of solution used. From this the osmotic

pressure reckoned in millimetres of mercury can be calculated for any solution. Expressed in this way the results obtained are quite comparable with those obtained by any other method.

The size of the mature mesophyll cells does not diminish sensibly when they are placed in the solutions of sodium chloride. Had there been any great decrease in size it would have been necessary to allow for this in calculating the osmotic strength of sap in the turgid cell, as was pointed out by Jost for merismatic cells from the apices of plants. Free cells such as yeast and *Protococcus* sensibly diminish with increasing strength of the solution in which they are placed, as will shortly be shown.

RESULTS

The osmotic pressures determined in the plants examined are expressed in the following table :—

Plant	Situation	Grm. mol. of NaCl	Pressure in mm. mercury °C. & 760 mi
<i>Callitriche</i> sp.	Submerged in bog, Cathole, Derbyshire	0·11	3389·60
<i>Myosotis palustris</i> , Relh.	Partially submerged in bog, Cathole, Derbyshire	0·11	3389·60
<i>Nasturtium officinale</i> , R. Br.	Partially submerged in bog, Cathole, Derbyshire	0·11	3389·60
<i>Ranunculus repens</i> , L. ...	On saturated mossy tufts in bog, Cathole, Derbyshire	0·11	3389·60
<i>Taraxacum officinale</i> , Web.	Damp grass near ditch by Thames, Kew	0·11	3389·60
<i>Angelica sylvestris</i> , L. ...	On mossy tufts in bog, Cathole, Derbyshire	0·12	3728·56
<i>Taraxacum officinale</i> , Web.	Garden, Upper Brighton, Cheshire...	0·12	3728·56
<i>Hydrocotyle vulgaris</i> , L.	Dryer part of bog, Cathole, Derbyshire	0·13	4067·52
<i>Cnicus palustris</i> , Willd.	Dryer part of bog, Cathole, Derbyshire	0·13	4067·52
<i>Prunella vulgaris</i> , L. ...	Dryer part of bog, Cathole, Derbyshire	0·13	4067·52
<i>Spiraea</i> sp.	Shrubbery on sandy soil, Sunningdale	0·13	4067·52
<i>Mahonia</i> sp.	Shrubbery on sandy soil, Sunningdale	0·13	4067·52
<i>Saxifraga sarmentosa</i> , L.	Cool-house, Chelsea Physic Gardens	0·13	4067·52
<i>Brassica oleraceae</i> , L. (Cabbage)	Garden, Upper Brighton, Cheshire...	0·13	4067·52
<i>Athyrium Filix-foemina</i> , Roth.	Exposed wood on Bidston Hill, Cheshire, overlooking sea	0·14	4406·48
<i>Taraxacum officinale</i> , Web.	Exposed wood on Bidston Hill, Cheshire, overlooking sea	0·15	4406·48

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Plant	Situation	Grm. mol. of NaCl	Pressure in mm. mercury at 0°C. & 760 mm.
<i>Oxalis acetosa</i> , L. ...	Exposed wood on Bidston Hill, Cheshire, overlooking sea	0·17	5253·88
<i>Rubus fruticosus</i> , L. ...	Exposed wood on Bidston Hill, Cheshire, overlooking sea	0·17	5253·88
<i>Zygnema</i> sp. ...	Submerged in brackish ditch, Leasowe, Cheshire	0·17	5253·88
<i>Geranium Robertianum</i> , L.	Near, but not in, salt marsh, North- fleet	0·17	5253·88
<i>Chenopodium urbicum</i> , L.	Sand in garden, Upper Brighton, Cheshire	0·18	5541·99
<i>Stellaria media</i> , Cyr. ...	Sand in garden, Upper Brighton, Cheshire	0·19	5830·11
<i>Rumex crispus</i> , L. ...	Holymoor, Derbyshire ...	0·21	6440·24
<i>Glaucium flavum</i> , Crantz	Near salt marsh, Burton Point, Cheshire	0·22	6745·30
<i>Geranium Robertianum</i> , L.	Damp rocks below Cwm Idwal ...	0·23	7033·42
<i>Rubus fruticosus</i> , L. ...	Sandhills, Wallasey, Cheshire ...	0·24	7287·64
<i>Senecio Jacobaea</i> , L. ...	Sandhills, Wallasey, Cheshire ...	0·24	7287·64
<i>Cotula coronopifolia</i> , L.	Partially submerged in brackish ditch, Leasowe, Cheshire	0·25	7626·64
<i>Rubus fruticosus</i> , L. ...	Holymoor, Derbyshire ...	0·25	7626·64
<i>Pteris aquilina</i> , L. ...	Holymoor, Derbyshire ...	0·25	7626·64
<i>Cnicus lanceolatus</i> , Willd.	Holymoor, Derbyshire ...	0·25	7626·64
<i>Sedum acre</i> , L. ...	Sandhills, Wallasey, Cheshire ...	0·26	7880·82
<i>Calluna Erica</i> , DC. ...	Holymoor, Derbyshire ...	0·26	7880·82
<i>Galium saxatile</i> , L. ...	Holymoor, Derbyshire ...	0·26	7880·82
<i>Vaccinium Myrtillus</i> , L.	Holymoor, Derbyshire ...	0·27	7916·40
<i>Hieracium</i> sp. ...	Rocks above Cwm Idwal ...	0·28	8474·00
<i>Vaccinium Myrtillus</i> , L.	Rocks above Cwm Idwal ...	0·28	8474·00
<i>Taraxacum officinale</i> , Web.	Sandhills, Wallasey, Cheshire ...	0·28	8474·00
<i>Hypochaeris radicata</i> , L.	Sandhills, Wallasey, Cheshire ...	0·28	8474·00
<i>Potentilla reptans</i> , L. ...	Bare burnt patch, Holymoor, Derbyshire	0·28	8474·00
<i>Glaux maritima</i> , L. ...	Edge brackish ditch, Leasowe, Cheshire	0·29	8812·96
<i>Brassica monensis</i> , Huds.	Sandhills, Wallasey, Cheshire ...	0·29	8812·96
<i>Anthyllis Vulneraria</i> , L....	Sandhills, Wallasey, Cheshire ...	0·29	8812·96
<i>Plantago lanceolata</i> , L. ...	Sandhills, Wallasey, Cheshire ...	0·29	8812·96
<i>Galium verum</i> , L. ...	Sandhills, Wallasey, Cheshire ...	0·29	8812·96
<i>Festuca ovina</i> , L. ...	Salt marsh, Burton Point, Cheshire...	0·50	14660·02
<i>Aster Tripolium</i> , L. ...	Salt marsh, Burton Point, Cheshire...	0·51	14958·13
<i>Plantago maritima</i> , L. ...	Salt marsh, Burton Point, Cheshire...	0·51	14958·13

A point which has come out very clearly in the results summarised in the preceding table is the striking relation between external conditions and the strength of cell sap. In all cases plants growing in situations in which they are subjected to physiological drought are provided with cell sap of high osmotic strength. If the physiological drought had been accompanied by a diminution in turgescence of the cells, the increased osmotic strength might conceivably have been due to abstraction of water and a resulting concentration of salts in the remaining portion. This, however, is not at all the state of affairs, for the plants examined were in all cases completely turgid. Hence it is the cell sap, with its normal complement of water, which is osmotically strong. The inter-dependence of osmotic strength and environment may be illustrated by considering in detail some of the results tabulated in the list just given.

Bog plants.—The bog plants examined were collected in a bog at Cathole, in Derbyshire, situated on the shaly clay immediately underlying the uppermost grit of the Millstone series. The bog consists of small pools, amongst which are tufts of moss, principally *Sphagnum* and *Hypnum*, which are saturated with water. In the pools grow *Callitriche* sp., *Myosotis palustris*, Relh., and *Nasturtium officinale*, R.Br. The submerged *Callitriche* is in contact with an unfailing supply of pure water; its osmotic strength is 3389.60 mm. The partially submerged plants, *Myosotis* and *Nasturtium* are in closely similar circumstances with regard to their water supply, and their sap has the same strength as the wholly submerged plants. In the partially submerged plants it is true a fairly rapid transpiration may take place, but the supply which compensates for this is readily accessible at all times. *Ranunculus repens*, L., growing on the saturated tufts of moss is in similar circumstances, and has sap of the same strength. All these are low-growing plants, and are not much exposed to the wind. *Angelica sylvestris*, L., grows in the same places as *Ranunculus repens*, but it is a tall plant and is much more exposed to the wind, which will promote transpiration. Its strength of sap is greater—3728.56 mm. The low-growing plants are not only protected from the wind by the surrounding vegetation, but, as Schimper

(15) has mentioned, the actual velocity of the wind is very greatly retarded as the surface of the ground is approached. The plants growing on the stiff clay at the edge of the bog have an increased strength of cell-sap—4067·52 mm. Here the water supply, though adequate, is not so immediately accessible as in the former cases. These plants are *Hydrocotyle vulgaris*, L., *Cnicus palustris*, Willd., and *Prunella vulgaris*, L.

By the side of the Thames at Kew, growing amongst long grass in a very damp situation, was gathered a large specimen of *Taraxacum officinale*, Web. This agreed in its strength of sap with the lowest of the Cathole bog plants—3389·60.

Garden Plants.—From a garden at Upper Brighton, Cheshire, on a sandy soil, *Taraxacum officinale*, Web., was growing on a humus surface covered by a dense growth of weeds. It is well known that humus adds considerably to the water-holding capacity of soils (13, 14), and hence in the case under consideration a plentiful supply is ensured. The osmotic strength was found to be 3728·56 mm. A cabbage growing in a cleared portion of the same soil had a less efficient water-holding substratum, and its osmotic strength was 4067·52.

Sir Joseph Hooker's garden at Sunningdale lies on a very sandy soil, with a consequently low water-holding capacity. This has been largely counteracted by the addition of a large quantity of humus. *Spiraeae* sp. and *Mahonia* sp., gathered in the shrubbery, showed a strength of sap equal to 4067·52 mm. of mercury. This value is greater than that found in garden plants from a clay soil, when the strength is generally 3728·56.

Wood plants from an exposed wood.—Bidston Woods lie on a hill overlooking the sea and are greatly subject to high winds. The cell sap of the plants growing there varies from 4406·48 in a low-growing plant like *Athyrium Filix-foemina*, Roth., surrounded by other vegetation and generally confined to sheltered hollows, through *Taraxacum officinale*, Web., 4626·80 mm., found in more exposed places, to *Rubus fruticosus*, L., 5253·88 mm., growing well above

the surrounding undergrowth and hence more exposed to the wind. The sap of *Oxalis acetosa*, L., with its high oxalic acid content, has a strength equal to that of *Rubus*, in spite of its low-growing habit. This is a point to which reference will be made below.

Moorland plants.—These were collected from Holymoore in Derbyshire, where extensive tracts of moorland lie on the dip-slope of the first Millstone Grit, at an elevation of about 1,000 ft. At the edge of the moor there is a fairly good soil, where grass and other plants flourish. *Rumex crispus*, L., gathered here, has a sap strength of 6440·24 mm. An increase of strength was at once found in the plants which penetrate on to the moorland proper. Here the soil is dry and the whole area is subject to high winds. In accordance with the physiological dryness of the environment the strength of sap is 7626·64 mm. This is found in *Pteris aquilina*, L., *Rubus fruticosus*, L., and *Cnicus lanceolatus*, Willd.

Passing into the midst of the heather moors the principal plants are *Calluna Erica*, DC., and *Galium saxatile*, L., with a strength 7880·82 mm., and *Vaccinium Myrtillus*, L., with 7916·40 mm. The greater strength of the sap in this last plant will be referred to again below.

It is customary to set fire to the heather in certain parts of the moor each year. These burnt patches thus become possessed of a dry soil, rich in salts. Colonisation of these burnt patches takes place slowly. The first plant to establish itself is *Potentilla reptans*, L., which only attains a small stunted, woody habit, and possesses a strong sap, with pressure equal to 8474·80 mm. of mercury.

Mountain plants.—These were collected on the hills above Cwm Idwal, in North Wales. The conditions vary considerably from place to place. The rocks near the streams are comparatively damp, and on these grow many plants which are not typically mountain forms, such as *Geranium Robertianum*, L. This plant had a strength of sap equal to 7033·42 mm. of mercury. The plants growing on the nearly bare rocks of the exposed summits of the hills showed a greatly increased strength of sap—8474·00 mm.

Sand-dune plants.—These were collected from the sand dunes of the Wirral Peninsula. Here the conditions are conducive to extreme xerophily. The sand in many places is almost without admixture, and its water-holding power is very small (14). The high sea winds, the absence of any shade from the direct rays of the sun, and the salt spray which at the highest tides is blown over the dunes, all tend to render the conditions extremely dry physiologically.

Growing on the barest patches of the sand, in addition to *Psamma arenaria*, R. and S., are *Brassica monensis*, Huds., *Anthyllis Vulneraria*, L., *Plantago lanceolata*, L., and *Galium verum*, L., all with the high strength of sap—8812·96 mm. When decaying vegetation has added humus to the sand other plants obtain a hold, amongst which are *Hypochaeris radicata*, L., and *Taraxacum officinale*, Web., with a strength of sap—8474·00. Both these plants have long tap-roots, from 18 inches to 3 feet in length, when growing in the sand. At the same time their evaporating surface is comparatively small, and hence they can economise their water supply. *Senecio Jacobaea*, L., is still better adapted to life in these regions. Its tap-root is long and branched, and in the water-holding humus layer lying on the surface of the sand it produces a dense growth of lateral roots. Having thus a good command of the water supply, its osmotic strength, 7287·64, is lower than in other plants in the same situation less well adapted. *Sedum acre*, L., with a comparatively small root system, and hence a limited area from which to draw its supply of water, has a high osmotic strength of 7880·82 mm.

Brackish water plants.—These were collected from ditches inside the Leasowe embankment in the Wirral Peninsula. Three plants were selected for examination. Unfortunately the results are not quite comparable, as the plants were not all collected from the same ditch, and the concentration of salt in the water varies slightly from ditch to ditch. In spite of this the results are striking. The submerged *Zygnema* has a strength of 5253·88. There can be no lack of water, and the high osmotic strength serves principally to resist the physical action of the brackish water.

In some of the ditches, *Cotula coronopifolia*, L., an alien plant introduced some years ago, has spread rapidly. It grows rooting in the water, but with its leaves exposed to the air, with resulting transpiration. Its strength of sap is higher than in the submerged alga, being 7626·64 mm. *Glaux maritima*, L., on the edge of the ditch and liable to be reached by the water occasionally, though usually raised above it, has a strength of 8812·96 mm. In this last case, when the water-level falls, some water will be left in the soil, and, on evaporation, will add to the percentage of salts present in the water available to the plant.

Salt-marsh plants.—These were gathered on the Burton Point marshes, by the side of the Dee. The level expanse of marsh is covered at each recurrence of high tide. Here grow *Aster Tripolium*, L., and *Plantago maritima*, L., with sap strength 14958·13 mm. of mercury, and a variety of *Festuca ovina*, L., with strength 14660·02 mm. The cells of the plants on this moist soil would be plasmolysed twice a day, if they did not possess a high osmotic strength of sap which offers considerable resistance to the water-extracting action of the sea. When the tide recedes the plants are exposed to a progressively concentrating soil-water, which must render physiological drought a very potent factor in the plant's daily life.

A further point calls for notice. In the garden at Upper Brighton is a sandy patch, with very little admixture of humus; the situation is, however, sheltered from direct insolation and from high winds. Here the chief plants are *Chenopodium urbicum*, L., and *Stellaria media*, Cyr., growing under almost precisely similar conditions. *Chenopodium* has a greater height and is hence more exposed to the action of the wind. One might reasonably expect that the osmotic strength of the sap would be higher than in *Stellaria media*, but the reverse is the case. Again, on the moors, *Calluna Erica*, DC., and *Vaccinium Myrtillus*, L., have a close similarity of growth, and yet the cell-sap of *Vaccinium* is stronger than that of *Calluna*. In Bidston Woods, the low-growing *Oxalis* has a greater strength of sap than *Taraxacum* or *Athyrium*, and equal to the much exposed *Rubus*.

A striking feature in the plants which have thus shown a departure from the expected strength of sap is the thin and sometimes delicate texture of their leaves and the small development of cuticle, as compared with the leaves of their neighbours. Structurally they are more subject to loss of water; as will be mentioned below, this tendency is, to some extent, compensated by the increased concentration of the cell sap.

It appears from a general review of the results obtained, that for any given area, the plants which have most difficulty in obtaining an adequate supply of water have a higher concentration of cell sap than have their more favourably situated neighbours. Also, the osmotic strength of plants as a whole growing in any district is generally influenced by the physiological drought of the district.

PHYSIOLOGICAL BEARING OF RESULTS

(i) *Effect of increased concentration of sap on Transpiration.*

Increase in concentration of a solution lowers the vapour pressure of the solvent. Thus, the addition of a salt to water lowers its vapour tension proportionally to the amount of the salt added.

The dependence of vapour tension on osmotic strength has been calculated, and is found to be expressed by the following formula :—

$$P = \frac{\pi - \pi_1}{\pi} \cdot \frac{0.0819T \times 1000S \times 760}{M}$$

When P is the osmotic pressure at absolute temperature T expressed in millimetres of mercury, π and π_1 , are the vapour tensions of the solvent and solution at the temperature T, S is the specific gravity of the solution, and M the molecular weight of the pure solvent.

Hence we can find the vapour tension of any solution whose osmotic pressure is known. π can be found from the published tables, T is the observed temperature, S in all cases dealt with in our work is sensibly equal to unity and 1000 S becomes 1000, and M is 18.

Now the vapour tension is directly proportional to the rate of evaporation from a free surface of the solution, and thus it is possible to calculate the relative rate of evaporation from any two solutions of known osmotic strength. Substituting in the above equation the values for the experimental conditions we have for 18° C. :—

$$P = \frac{15.4 - \pi_1}{15.4} \cdot \frac{0.0819 (273 + 18) \times 1000 \times 760}{18} \left(1 - \frac{\pi_1}{15.4}\right) \times 1006278$$

Thus for the osmotic pressures 3728 mm., 8812 mm., and 14958 mm., we obtain the vapour tensions 15.34, 15.26, and 15.17 mm. That is to say, the rates of free evaporation from cell saps of the above osmotic strengths will be proportional to 15.34, 15.26 and 15.17, or as 1.011 : 1.005 : 1. Hence the differences of concentration met with in the cell sap in the plants can exercise but little effect in checking evaporation, and by far the greatest part in conservation of water must be played by structural configuration. The above calculation only applies to free evaporation. How this may be modified by the intervention of a semi-permeable membrane is not known. An attempt is being made to attack the problem, but the experimental difficulties are great.

(ii) *Effect of Concentration of Cell Sap on the Freezing Point.*

One gram molecule of a non-electrolyte dissolved in one litre of water exercising an osmotic pressure of 16948 mm. of mercury will depress the freezing point of a solution by about 1.89° C. Of course decrease in temperature will diminish the ionization in the sap, but as we do not know with precision the true constitution of the sap, this effect, which will be very slight, must be neglected. Let us consider an osmotic pressure of 3728 mm. at 18° C. This, at 0° C., becomes 3467.04 mm. This pressure will depress the freezing point by 0.41° C. In a salt-marsh plant the pressure 14958 mm. at 18° C. becomes 13911 mm. at 0° C., and this will depress the freezing point 1.55° C. Hence increased osmotic pressure may serve to check

freezing of the sap, but in all cases this check must be comparatively slight. The calculations given above are not strictly accurate, but for our purposes they are quite sufficiently so.

(iii) *Effect of High Temperatures on the Osmotic Strength of the Cell Sap.*

A rise in temperature will cause an increase in the osmotic strength of the sap. A rise of 10° C. will increase the osmotic pressure of sap in a sand-dune plant from 8813 to 9116 mm. As will be shown below, this will add to the plant's power of absorbing water, and thus to some extent counterbalance the increased loss of water by transpiration due to the higher temperature. The osmotic strength will also be augmented by increased ionization at high temperatures. It is impossible to calculate this as we do not know the composition of the sap. Probably many of the osmotically active substances in the cell are non-electrolytes which will not ionize at all, while the electrolytes are a very heterogeneous mixture, each salt dissociating differently. In the present state of our knowledge it is hopeless to attempt any calculation of ionization and temperature in the cell sap.

(iv) *Effect of Increased Osmotic Strength on the Absorption of Water.*

We have experimented with a number of plants growing under different conditions. In every case we have found them to possess the power of absorbing water more or less rapidly through their leaves. In some cases the structural character of the leaves in the more xerophylous conditions favours absorption. Thus the dandelion from the garden has a smooth epidermis which neither holds nor absorbs water readily, while the same species from the sandhills has a rough hairy surface for holding and absorbing moisture. It seems probable that many of the plants growing under conditions of physiological drought normally obtain a considerable quantity of water by direct absorption of precipitated atmospheric moisture through their leaves.

The rate of absorption of water through the protoplasmic layer,

which for our purposes is considered as semi-permeable, will be proportional to the sucking force, namely the osmotic strength of the cell sap. Now we have seen that a great range of osmotic strength is met with in saps. The rate of absorption will be proportional to these strengths of sap, leaving out of account the structural impediments. Thus, neglecting the last-named factor, and considering a garden plant with osmotic strength of sap 3728, a sand-dune plant with 8813, and a salt-marsh plant with 14958, the rate of absorption of water through these leaves will be in the ratio of 1.00 : 2.36 : 4.01. That is to say, a sand-dune plant in virtue of its strength of sap, and neglecting structural modifications, will suck up water more than twice as quickly, and a salt-marsh plant four times as quickly as an ordinary garden plant. To some extent also the rate of absorption of soil moisture through the roots must be proportional to the strength of sap.

It is perfectly evident from a consideration of the environment of the different plants examined that some are much more liable to dessication than others. The submerged plant has an abundance of water at all times, and apparently all that is necessary is for the sap to have a concentration slightly greater than that of the external medium. In a land plant, however, conditions of dessication may set in, and on the sandhills this is very liable to occur. Hence, if a plant can rapidly absorb through its leaves the water of transient showers it will reap an immediate benefit, since such small quantities of rain are unable to penetrate to the roots of the plant. Hence there appears to be a very considerable value attached to concentration of cell sap, quite apart from its importance in the function of root absorption.

In plants liable to be submerged by salt water the value of a rapid absorption of rain water is obvious, though probably the primary utility of the high strength in this case is resistance to the water-extracting action of the sea.

SUMMARY

1. The osmotic pressure of the sap in the turgid cell in the plants examined varies between 3389·60 mm. and 14958·13 mm. of mercury.
2. The osmotic strength is least in submerged freshwater plants and greatest in salt-marsh plants.
3. The greater the physiological drought under which the plants are accustomed to grow, the greater the osmotic strength of the sap in the turgid cell.
4. In any area the osmotic strength varies with the physiological scarcity of water.
5. In all plants growing under the same conditions the osmotic strength of the cell sap is generally the same.
6. Where two plants, growing under similar conditions, have a marked difference in the structural arrangements for checking loss of water by transpiration, that plant with the less adequate anatomical provision has the greater strength of cell sap.
7. The *direct* effect on transpiration of increased osmotic strength of sap will be negligible.
8. The depression of the freezing point of the sap within the range of strengths found will be small, but may be effective in the case of plants with the highest osmotic strength of sap.
9. The effect of increased osmotic strength of sap on absorption will be marked, the rate of absorption of water being proportional to the osmotic strength of the sap.
10. The effect of increased temperature on the osmotic strength of sap will be quite appreciable and will tend to enhance the power of absorption of water by the plants.

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