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The Winter--Killing of Trees and Shrubs.

BY THE BOTANIST.

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The Winter-Killing of Trees and Shrubs.

AVEN NELSON.

The cause of the winter-killing of trees and shrubs is a question of no little importance to those who are attempting to grow them, whether it be for pleasure or profit. Of interest everywhere, this question becomes especially so in the arid regions of the higher altitudes of the western plateaus and mountain valleys where pomology and forestry is carried on with the greatest difficulty.

Trees and shrubs of all kinds are quite readily started and thrive during the irrigation season as well as elsewhere, but too often even the most promising fail to get through the first winter. Shade trees well started and rooted, as they will be if successfully carried through the first two or three winters will usually survive if the requisite amount of water is received during the summer months. To some extent, but not so largely, is this true of fruit trees, small fruits and shrubbery. However, these latter need to be guarded more carefully, for even after the bearing stage has been reached the mildest and most open winters may prove too much for them. In view of these facts it seems well to seek for other causes than those usually assigned, viz., the severity of the climate with respect to temperature. It is true that a few days of the year prove quite cold but not any colder than do some in the New England states or even in Michigan or Minnesota where winter-killing is far less common than here. Both deciduous and evergreen vegetation seem well adapted to withstand the extremes of temperature to which they are sometimes subjected in this latitude and it does not seem probable that winter-killing is due to mechanical injury produced by frost nor to the action of cold upon the living tissues. On the other hand it appears very probable that

DESICCATION

is the principal cause of so large a loss winter after winter.

If this be true the causes of this greater desiccation in high altitudes must be sought in order that the remedy may be more intelligently applied.

For the sake of comparison and that the new factors in the problem may be more clearly defined let us note the processes and influences which tend to abstract from the plant the water necessary to its constituent living tissue. It will not be necessary in this bulletin to enter into a discussion of the functions of the organs of a plant, but merely to state in a general way the purposes of root, stem and leaf in order to recall the main facts in plant nutrition.

The function of roots with which we are now concerned is the absorption from the soil of large quantities of water in which are dissolved much of the plant's food. This is accomplished by means of countless hairs or tubular protuberances of the epidermal cells of the root just back of the growing tip. The food thus absorbed, salts and gases in solution, is in a crude state and unfit for assimilation, hence must be carried into the plant's laboratory where it is decomposed and recomposed into compounds which will serve to build up plant tissue.

The stem, besides serving as an organ of support for the branches and leaves that these, the organs of elaboration, may be carried out into the air and sunlight, is also admirably adapted for conducting the crude sap from the roots to the leaves and the elaborated product back to the several parts of the plant.

The leaves and young shoots are well supplied with chlorophyl or leaf green, the only agency through which inorganic materials are built up into organic. Since the water absorbed by the roots contains the food materials in very small quantities, some disposition must be made of the excess of water which is carried into the plant. If water were always in excess the problem would be a much easier one, but as there come periods of drought in which the plant must guard against loss of water we find the epidermal cells of young shoots and leaves water-proofed by a substance known as cutin. This guards against undue loss by way of the leaves. To facilitate the interchange of gases between the plant and the atmosphere and the escape of excess water, all green portions are provided with stomata. These are rifts or openings enclosed by two curiously modified epidermal cells, known as guard cells, which act automatically in increasing or diminishing the opening, thus facilitating or retarding the escape of water from the plant. The stomata usually open into comparatively large air spaces within the leaf tissue. During the elaboration of the crude sap in the surrounding chlorophyl bearing cells the excess water is evaporated into the intercellular air spaces from which it escapes through the stomata into the surrounding atmosphere. This elimination of water from the plant has been called

TRANSPIRATION.

Transpiration is thus distinguished from evaporation from water surfaces, but it is in reality nothing more than the evaporation of excess water from the plant, regulated by the cutinized surfaces perforated by myriads of automatic stomata. It is to be remembered that the most important result of this removal of water from the cells of the leaf is that it permits of new supplies being brought up from the water of the soil and that in this movement from soil to leaf new supplies of food are furnished in such quantities as the plant can elaborate.

These being the main facts in connection with transpiration let us note those conditions which accelerate and those which retard it, to discover, if we may, the conditions which tend to greater transpiration in the higher altitudes.

First we may note that the rate of transpiration varies directly in proportion to the intensity of the light. Stomata close in the darkness, opening wider and wider as the intensity of the light is increased, hence in high altitudes, with their dry and rarified atmosphere, and slight cloudiness, transpiration is greatly accelerated.

In the second place we note that increase in temperature causes a corresponding increase in transpiration, to some extent because evaporation in general is thus facilitated. The rays of the sun in the rarified air of high altitudes fall upon exposed objects with peculiar force, raising their temperature considerably beyond that of the surrounding atmosphere. We must further note the frequent and often prolonged winds with the accompanying thorough shaking as factors tending to accelerate transpiration.

There are yet other causes operating to produce in high altitudes excessive loss of water, among which may be mentioned the fact demonstrated by Vesque that transpiration and absorption are not always proportional, but that under certain conditions the former may greatly exceed the latter. Only under the most uniform conditions is the amount of water given off just equal to the amount absorbed by the roots, and where atmospheric and soil conditions are so exceedingly variable as in the arid regions these two functions are correspondingly variable.

An excessively dry atmosphere tends to increase transpiration which in turn stimulates root activity, but even in a moist soil they are not quite able to make good the loss. Much more is this true if the roots are in a very dry soil or in a frozen soil. In the latter case absorption is probably retarded for two reasons, viz., that the low soil temperature decreases the absorbing power of the roots and the conducting power of stem, and that frozen soil yields its water much more slowly.

That plants do transpire at quite low temperatures is no longer questioned, for Burgerstein has shown that the yew transpires at —10.7° C. and Wiesner that the leafless shoots of horse-chestnut transpire at —13° C.

The usual sandy or gravelly character of the soil is also a point unfavorable to the plant, for Sachs has demonstrated that a clayey soil yields its water more uniformly than a sandy soil. The latter giving up its water quickly to the plants and atmosphere is soon incapable of yielding more to the wilting vegetation. Although, in the absence of leaves the wilting may not be so noticeable, yet if the plant dies from loss or want of water it is as truly wilting in January as in July.

The plants of the arid regions of high altitudes then are subjected to many conditions which conspire against them, namely, a dry atmosphere, a gravelly soil, a great difference in temperature between the roots in the frozen soil and the branches in the intense sunlight, frequent desiccating winds and sudden changes of temperature, all of which operating together cause transpiration far in excess of the absorption by the roots, a process soon bankrupting the plant so far as cell sap is concerned and soon causing wilting and death.

ATMOSPHERIC PRESSURE.

The question of the effect of dimminished atmospheric pressure upon transpiration does not seem to have received any attention from botanists and this fact led the writer to undertake a series of experiments* to determine if possible the relation of atmospheric pressure to transpiration.

It seemed probable that diminished pressure would exert a direct influence upon transpiration independent of the fact of a dryer atmosphere in the higher altitudes. To determine the truth of this supposition the following means and methods were adopted.

TRANSPIRATION BOX.

A cubical box, dimensions twenty inches, was made as follows: The sides of heavy tin, the top of glass and the bottom of heavy rubber packing. Near the center of each of two opposite sides was fitted a short brass tube containing a stop-cock. In a third side a small glass window was inserted against which was hung a thermometer. In one corner at the bottom was placed an aneroid barometer to indicate the atmospheric pressure.

The rubber bottom was slit a distance of seven or eight inches to permit the insertion of a plant, leaving the pot on the outside and fitting the rubber close to the stem. The box was supposedly air tight and the slit in

*The following experiments were carried on in the Botanical Laboratory of Harvard University.

the bottom was hermetically sealed about the stem of the plant by means of gum rubber and cement.

By means of an aspirator which was connected with rubber tubing to one of the stop-cocks of the box and a water faucet in the room, the air was slowly but constantly changed within the box and was drawn out through a bottle of calcium chloride which absorbed all the moisture from the air. As the air admitted to the box by the other stop-cock was also passed through calcium chloride all the gain in weight of first mentioned calcium chloride must have been due to the moisture given off by the enclosed plant.

The first two experiments conducted with an Ilex Paraguayensis and a Ficus were wholly unsuccessful. The difficulty of getting a box that would remain air tight and that would remain so when a partial vacuum was formed within it was greater than was anticipated. By a liberal use of gums, paints and shellac this was finally accomplished and the third experiment resulted successfully.

As will be seen from the following table the experiment was carried on for several days under different conditions. The plant, an Ilex Paraguayensis in good vigorous condition, was used and, as a check experiment, transpiration under normal conditions was first noted.

Table of Results.

Date.	Condition of soil.	Atmospheric pressure.	Wt. of Ca Cl_2	Time.	Gain.	Average.
Feb. 12...	Moist	Normal	550.660g			
" 13...	"	"	554.731g	1 day	4.071g	4.472g
" 15...	"	"	564.075g	2 days	9.344g	
" 15...	"	Reduced	549.881g			
" 16...	"	"	562.770g	1 day	12.889g	11.295g
" 17...	"	"	572.480g	1 day	9.710g	
" 17...	Slightly dry....	Normal	572.480g			
" 19...	" "	"	576.230g	2 days	3.750g	1.875g
" 19...	Almost dry	Slightly reduced....	576.230g			
" 20...	" "	" " ...	578.860g	1 day	2.630g	2.630g
" 20...	Dry....	Greatly reduced....	578.860g			
" 22...	"	" "	590.500g	2 days	11.640g	5.820g
" 24...	Very dry	Reduced	547.250g			
" 25...	" "	"	548.350g	1 day	1.100g	1.100g

The apparatus used was not sufficiently delicate to regulate exactly the diminution of pressure, nor was the aneroid of sufficient accuracy to give absolute readings, but comparative pressures were obtained.

While the experiments were not continued so as to demonstrate many points of interest that it seemed desirable to prove, yet one point appears conclusively proven, viz: That the rate of transpiration or evaporation from the surface of a plant is directly and proportionately increased by the diminution of the atmospheric pressure. This, added to the several other causes of desiccation, all of which are seen to be specially operative in the plateau and plains regions, points out plainly enough the cause of such a large percentage of winter-killed trees and shrubs.

THE REMEDY.

The remedy is easily seen and pointed out, but often difficult of application. It consists in the use of all possible means by which the plant, especially the roots, can be kept in a fairly moist condition. On this point the following suggestions are offered:

Irrigate late in the fall and if possible occasionally during the winter months. It frequently happens that, although the soil temperature is below the freezing point, there is not enough moisture in the particles of the soil to cause them to adhere to each other, and, so far as the plant is concerned, the soil is absolutely dry. Flow the water over the soil on a warm day—some of it will enter the interstices of the soil; and if a coat of ice forms over the surface, no matter. The ice will prevent loss of water from the soil by evaporation. Those who have observed the natural groves of cottonwood and other trees and shrubs that border western mountain and plains streams will recall that the ground in winter is usually covered with ice and snow, or that the whole is a frozen winter marsh.

Irrigation is especially essential during the first two or three years after transplanting, while the roots are few and near the surface and the absorbing area small. After the roots have spread out and penetrated deep into the soil, even beyond the frost line, the plant will be much better able to care for itself. The first winter is especially critical, for then, by reason of the transplanting, the transpiring surface is in excess of the absorbing and the slight connection of roots with soil is more easily broken by the violent winds which sway it to and fro.

Where rain or wet snows are infrequent good may result from an occasional spraying with water, if hose and water under pressure be at hand, probably rather from the water that reaches the soil than from the absorbing power of twigs and leaves.

The great difficulty experienced in growing on the plains the pines and other evergreens that thrive so luxuriantly on the neighboring storm-riven mountain sides, may be explained by the fact of the much greater snowfall, the frequent clouds and fogs in which the mountains and their vegetation are bathed and the much higher relative humidity of the atmosphere, all tending to reduce transpiration as well as furnishing the plant an abundance of moisture. On the other hand, when transferred to the plain the soil moisture is reduced, the atmosphere is relatively dry, the sun's rays, penetrating readily the dry and rarified air, raises the temperature of the leaves, which accelerates transpiration while the absorbing power of the roots in the frozen or dry soil remains the same.

In all cases, whether irrigating is feasible or not, a liberal mulching with straw, leaves or coarse manure will be of great advantage. That will prevent frost from penetrating so deeply, will retard evaporation from the soil, will keep the moisture near the surface and will give the plant the fullest benefit of all water received, whether from artificial or natural sources.

In the case of tender and half-hardy plants special protection is advisable, not only to prevent desiccation but to protect them from sudden changes of temperature. In the case of shrubbery and small young trees this may best be done by wrapping the stem and branches, which should be tied up closely, with straw, hay or even paper, securing the same in place with a liberal use of twine. Another very simple but effective method for small shrubs or trees is the placing of old barrels, first knocking out the bottoms, over the plants to be protected, and then packing hay or straw around them. Protection of this kind is especially necessary during the first one or two winters.

The following method, I am informed, is practiced successfully in some places in the case of some of the less hardy fruit trees; e. g., the peach. The roots are trained from the first in two opposite directions only. In the late fall a shallow pit is dug close to the tree at one side; the tree is then bent over to one side till it lies as nearly horizontal as may be. The soil is then thrown up about and over it, holding it down and serving as its best protection from loss of water and against sudden changes. In the spring the soil is removed, the tree straightened up none the worse for its winter sleep, except in so far as its roots have been disturbed, and with care this may be so slight as not to cause any serious injury nor retardation of growth.