

INFLUENCE OF SODIUM CHLORIDE UPON THE PHYSIOLOGICAL CHANGES OF LIVING TREES

W. RUDOLFS

Research Fellow, Rutgers College

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Various observations in the neighborhood of factories, salt refineries and salt mines seem to have led to the general belief that sodium chloride always has a harmful effect on plants and trees. Our knowledge of the rôle of chlorine and sodium in plant growth is very limited. Only recently an attempt has been made to study more fully the influence of sodium chloride upon plant growth.

REVIEW OF LITERATURE

The literature on the subject of fertilization with common salt presents considerable evidence that often an increase in yield may be expected, but a number of investigators report failures with the use of salt for certain agricultural crops. Agriculturists in different countries have been using sodium chloride to a certain extent, but the beneficial effects were often ascribed to the sodium-ion only, due perhaps to the view that sodium might replace potassium. In recent years, however, several investigators take the viewpoint that the chlorine-ion might have a direct fertilizing value, or an indirect fertilizing value by the acceleration of certain processes. An indirect result might be caused by the increase of acidity in certain soils, which would make certain plant-food constituents more available.

Effect on exterior form

Studies made by a number of investigators of the effect of the physiological changes on the exterior form of plants, caused by applications of sodium chloride, often show marked responses. Dasonville (8) observed that the morphological characters of *Lupinus albus* under the influence of different salts were greatly modified. Hansteen (12) found that wheat plants grown in cultural solutions containing chlorides produced larger roots and shorter leaves than when grown in solutions containing other salts. Marked changes in the leaf structure and the transpiring power of wheat have been observed by Harter (14). Saline soils containing 1, 1.5 and 2 per cent of total salts, of which 0.7, 1 and 1.4 per cent were NaCl (70 per cent), were diluted with garden loam on the basis of dry weight. The mixed soils were then placed

in containers sealed with paraffine to make comparative transpiration measurements by weighing possible. Plants of wheat, oats and barley grown from seeds in these saline soils very soon developed a pronounced waxy bloom on the leaf surface and a thickening of the cuticle occurred. The thickness of the cuticle increased with the concentration of the soil. The size of the epidermal cells decreased as the concentration of the salt in the soil increased, the cells of the plants grown on the non-saline soils being the largest. Leaves of wheat detached from plants grown in non-saline soils on which the bloom was not conspicuous, lose by transpiration two to three times as much moisture as leaves from plants grown in soil containing 1 per cent of sodium chloride. Nobbe and Siegert (24, 25) reported a higher transpiration in buckwheat plants grown in water cultures containing NaCl. Investigations made by Laurent (20) with sugar beets and carrots in connection with the plant-food supply in its relation and variation in plants, showed that NaCl in soil had the effect of lengthening both carrots and beets, but reduced the diameter of these plant roots. Buckwheat grown to maturity in water cultures by Tottingham (32) showed that the length of roots and the production of dry matter in leaf blades was depressed in solutions containing an addition of NaCl. Sugar beets when grown in the greenhouse were more watery where chlorides were applied, and the yield of the dry matter was greatly increased. Van Hecke (17) conducting experiments with salt to prevent the gummosis of fruit trees, treated the trees with salt, giving 1, 2 and 3 pounds per tree, and found at the end of the season that the tree receiving 3 pounds did not suffer from gummosis, while the ones receiving 1 and 2 pounds were slightly injured by the decrease. The other untreated trees were severely injured, lost most of their branches and bore but little fruit. The effect of salt water on cultivated plants is reported by Wohltmann (35). If the amount of salt was from 5 to 10 gm. per liter of solution the growth of the better grasses and leguminous plants was dwarfed and the yield reduced. Common salt used as top-dressing on oats in the manurial experiments carried on by the Agricultural Society of Scotland (38), gave satisfactory results against lodging, but the effect of top-dressing with salt on barley reported by the Board of Agricultural Education in Great Britain (36, 37) was to cause the barley to lodge rather than to stiffen the straw.

Effect on chemical composition

Physiological changes influencing the chemical composition of plants have been reported in a great number of cases. Hartwell and Wessels (16) found that the per cent of phosphorus in crops treated with salt as a fertilizer was increased. Studying the influence of chlorine compounds in crude Stassfurt salts upon the composition of potatoes, Sjollesma (28) found that the effect of the chlorine salts was to lower the starch content. Süchting (31) came to the same conclusions, while Tottingham (32) found that by an application of

sodium chloride alone the composition of the potato tubers was only slightly altered, but the quality was seriously affected. According to Bolin (5, 6) the dry matter per hectare is not less with NaCl. De Ruijter de Wildt et al (9) found that although the yield of beets was high with an application of 300 kgm. NaCl per hectare, the salt content of the soil had changed their composition, reducing the sugar content, changed the relation of potassium and sodium by greatly increasing the sodium content and also increased the content of chlorine and of ash. Micheels (23) studying the effect on germination, length of leaf, length of root and weight of wheat plantlets grown in solutions of NaCl and KCl, reports that the chlorine-ion was harmful, decreasing the lengths of root-hairs and of leaf, and depressing the weight of the plants. Nobbe (25), giving data on ash analyses for buckwheat, points out that the per cent of ash in roots was increased by sodium chloride. Comparing garden plants with his culture plants the increase was from 6.8 to 15.3 per cent for roots and from 8.7 to 18.6 per cent for stems. Prinsen Geerlings (27) who made a study of the influence of sodium salts in the soil upon the composition of sugar cane, found that an application of either NaCl, CaCl_2 or MgCl_2 to the soil caused an increase in potash in the ash of the cane.

Toxic effects of sodium chloride

It seems that a number of investigators hold the view that sodium chloride, even in small amounts, is not only harmful but also dangerous to plant life. Still Hugo de Vries (33) pointed out already in an early study that it is "a wrong viewpoint however widely held, that strong salt solutions (for example a sodium chloride solution of 10 to 20 per cent) are dangerous for the life of plant cells." Harter (15), who made extensive comparisons of his own results with those of other investigators relative to the growth of wheat seedlings in salt solutions, concluded that sodium chloride in a concentration of about 300 parts per million, is not toxic to these plants. Guthrie and Helms (11), working with pot cultures to determine the limits of endurance of different farm crops to injurious substances, found that a salt solution of 0.05 per cent prevented germination of wheat by only 0.2 per cent, of corn by 0.25 per cent and of rye by 0.2 per cent. The growth was affected to a still lesser degree. Hendry (18) using 13 varieties of legumes in pure quartz sand with NaCl of 0.04, 0.16, 0.3, 0.5 and 1 per cent of the dry weight of the sand, found that as a general rule the germination was retarded, the height of the plants was lessened, the blossoming period changed, a reduction in number and size of the leaves was caused, and finally premature death resulted. Birger (3), however, studying the influence of sea-water upon the germination of seeds, placed 27 species of Scandinavian seeds for a period of 30 days in sea-water containing 3.4 per cent of salt, and found that although the vitality of a number of species was destroyed, the vitality of others was little or not at all affected. In some instances he found that the number of seeds which ger-

minated was increased by having been in the sea-water for 30 days as compared with dry seeds. By the extensive investigations on the effects of chlorides in alkali soils of Utah, Harris (13) found sodium chloride the most toxic of a number of common chlorides. He found that at a concentration of 0.2 per cent sodium chloride in the soil, the germination of wheat was reduced by 50 per cent.

EXPERIMENTS

In a cut-over swampy soil on the College Farm at New Brunswick, N. J., a number of selected tree stumps, which has been allowed to grow for 5, 6 or more years, were treated with common rock salt. One hundred and thirty stumps of as nearly equal size as could be found were selected, including white oak, black oak, birch, maple, and a few chestnut, dogwood and

TABLE 1
Chosen tree stumps treated with common rock salt in 1919

NUMBERS	APPROXIMATE AVERAGE HEIGHT	SALT APPLIED PER TREE	VARIETY OF TREE			
			Oak	Birch	Maple	Chestnut, etc.
	<i>feet</i>	<i>pounds</i>				
1 to 10	11	1	2	2	5	1
11 to 20	12	2	3	2	2	3
21 to 30	13	3	4	2	1	3
31 to 40	13	4	7	2		1
41 to 50	13½	5	3	4	3	
51 to 60	12	6	7	1	1	1
61 to 70	13½	7	7	1	2	
71 to 80	13	8	6	1	2	1
81 to 90	14	9	8	1		1
91 to 100	14	10	5	1	3	1
101 to 130	14	None	14	6	5	5
Total.....			66	23	24	17

cherry. The trees were treated in the manner given in table 1. The stumps were surrounded by a large number of tree stumps, which could also be used to collaborate the results. Only thirty trees not treated with salt, however, were under constant observation.

Analyses made of the rock salt used, show from 96 to 98 per cent sodium chloride, very little magnesium chloride and some impurities.

The salt was applied in a dry state, on top of and around the stumps. The application was made during the days of April 3, 4 and 5, 1919. The weather was sunny and dry, but soon after the application heavy rains partly dissolved the salt. It was not until far along in the summer that all of the salt was dissolved where the heavier applications were made.

A general examination on May 14 showed that some birch trees which were given the greater amount of salt (above no. 60) were already injured, the

TABLE 2
Condition of tree stumps four months after the treating with common rock salt

NUMBER OF TREE STUMP	VARIETY	APPROXI- MATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		<i>feet</i>	<i>pounds</i>	
1	Birch	12	1	Healthy appearance
2	Oak	9	1	Healthy appearance
3	Maple	12	1	Slight yellowish tint in most of the leaves
4	Maple	7	1	Healthy appearance
5	Maple	15	1	Vigorous growth, leaves large
6	Maple	8	1	Leaves yellowish tinted
7	Maple	8	1	Healthy appearance
8	Birch	15	1	Healthy
9	Oak	12	1	Healthy
10	Dogwood	10	1	Healthy
11	Dogwood	10	2	Healthy
12	Oak	12	2	Healthy
13	Birch	18	2	Vigorous growth; leaves dark green
14	Chestnut	12	2	Injured; leaves curling, yellowish
15	Chestnut	11	2	Healthy; vigorous growth
16	Maple	10	2	Healthy
17	Birch	20	2	Vigorous growth; leaves extremely large and shiny; dark
18	Oak	16	2	Vigorous growth
19	Maple	6	2	Seriously injured; leaves curling; brown at the edges
20	Oak	15	2	Healthy; broad, shiny leaves
21	Oak	10	3	Healthy; bluish-green, large leaves
22	Oak	10	3	Bluish colored, large leaves
23	Oak	11	3	Healthy; bluish-green, large leaves
24	Chestnut	7	3	Injured; all leaves dropped except leaves of top shoots
25	Maple	8	3	Injured; leaves at the top of the branches dead; leaves only one third of normal size
26	Birch	13	3	Slightly injured; leaves brown at the tips and somewhat at the edges
27	Birch	18	3	Healthy
28	Cherry	17	3	Healthy
29	Walnut	10	3	Healthy
30	Oak	8	3	Healthy; leaves shiny; bluish color
31	Birch	18	4	Healthy; thrifty
32	Oak	15	4	Slightly injured; leaves brown at the edges and slight change in tint of color towards yellow
33	Oak	8	4	Injured; leaves brown, curled
34	Cherry	10	4	Injured; leaves curled; sickly appearance
35	Oak	12	4	Thrifty; large leaves
36	Oak	15	4	Main stem healthy; side stems injured; leaves curling with brown edges
37	Oak	13	4	Healthy
38	Oak	9	4	Healthy; head veins of leaves have a slightly yellowish tint

TABLE 2—Continued

NUMBER OF TREE STUMP	VARIETY	APPROXI- MATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		<i>feet</i>	<i>pounds</i>	
39	Oak	17	4	Healthy; bluish-green leaves; thrifty
40	Birch	18	4	Sickly appearance; leaves large, yellowish in color; catkins have a peculiar conical shape (plate 4)
41	Oak	12	5	Healthy
42	Birch	15	5	Older leaves small and sickly; second-growth shoots are large and shiny; catkins conical shape
43	Birch	15	5	Top shoots dead; leaves brown and curling; catkins deficient in vigor
44	Birch	12	5	Healthy; head veins of leaves slightly yellow; no catkins
45	Birch	18	5	Healthy; catkins conical
46	Maple	13	5	Old leaves small and sickly in appearance; new shoots with thrifty large leaves
47	Oak	18	5	Healthy
48	Maple	14	5	Leaves partly curled as if there was lack of moisture; sickly appearance
49	Oak	13	5	Healthy
50	Maple	8	5	Leaves which are left curled; sick appearance; partly dead
51	Oak	12	6	Healthy
52	Birch	14	6	Dead; small new shoots died also
53	Oak	10	6	Partly injured; main stem thrifty; injured leaves brownish and curling
54	Sumach	10	6	Sickly appearance; leaves drooping
55	Oak	18	6	Healthy; second growth shoots have large leaves
56	Oak	10	6	Healthy, with large leaves
57	Oak	12	6	Healthy
58	Oak	12	6	Healthy
59	Maple	8	6	Dead
60	Oak	15	6	Healthy with bluish-green, shiny leaves
61	Oak	18	7	Healthy with bluish-green but small leaves
62	Oak	12	7	Injured; leaves brown and curling
63	Oak	13	7	Healthy
64	Oak	18	7	Leaves large; bluish in color, shiny; vigorous growth in new top shoots; leaves of tall main stem (18 feet) much larger than leaves of side stems (8 to 9 feet), which are slightly injured; leaves of side stems spotted with small yellow blotches; part of leaves curling
65	Oak	15	7	Healthy; veins on the back of the leaves a little yellow
66	Birch	12	7	Dead
67	Oak	15	7	Partly injured; leaves brownish in color
68	Oak	12	7	Partly injured; leaves on main stem healthy

TABLE 2—Continued

NUMBER OF TREE STUMP	VARIETY	APPROXI- MATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		<i>feet</i>	<i>pounds</i>	
69	Maple	8	7	Injured; leaves dropped; making second growth but leaves tiny and curled, clustering around the stem; size of new leaves from one-tenth to three-tenths of normal size; these small clustered leaves wither after a short time
70	Maple	10	7	Seriously injured; only a few leaves (top) of highest branches left, these brown and curled
71	Oak	10	8	Injured; all leaves brownish; lower leaves of branches dropping, remainder had a sick appearance; curling
72	Birch	13	8	Dead
73	Oak	14	8	Slightly injured; leaves brownish in color
74	Oak	17	8	Partly injured; leaves with brown edges
75	Oak	13	8	Injured; leaves yellow; sickly appearance; curling
76	Oak	15	8	Veins on the back of the leaves yellow; developing later into spotted leaves
77	Cherry	13	8	Injured; leaves yellowish
78	Oak	18	8	A number of leaves brown, dried; some with only brown edges
79	Maple	10	8	All leaves dropped and very small new shoots formed which dried out later
80	Maple	10	8	All stems dead, but a few small new shoots starting from roots
81	Oak	12	9	Slightly injured; second growth extremely vigorous
82	Chestnut	18	9	Seriously injured; all leaves brown and curling
83	Oak	13	9	Injured; sickly appearance. (A birch standing nearby killed by the same dose)
84	Oak	12	9	Partly injured; most of the leaves look sickly, with a shiny brown surface
85	Oak	11	9	Injured; brownish leaves, curling at the edges
86	Oak	16	9	Seriously injured; highest leaves of top shoots dropped and remainder brown and sickly
87	Oak	16	9	Yellow tint on all leaves
88	Oak	15	9	Injured; leaves brownish with a rubber-like consistency
89	Birch	15	9	Seriously injured; only few leaves at the end of the highest shoots left. (A maple standing nearby also badly injured by the same dose)
90	Oak	18	9	Partly injured; leaves of the shorter stems brown and curled; those of the higher stems, however, very large
91	Oak	18	10	All veins on the back of the leaves yellowish, giving the appearance of lace-work

TABLE 2—*Concluded*

NUMBER OF TREE STUMP	VARIETY	APPROXI- MATE HEIGHT	SALT APPLIED	CONDITION AUGUST 7, 1919
		<i>feet</i>	<i>pounds</i>	
92	Oak	12	10	Injured; sickly appearance; leaves having a mass of local discolorations, starting at the extreme end of the small veins and gradually increasing; after some time leaves become dry, but have a rubber-like consistency; difficult to break or tear these leaves
93	Oak	12	10	Part of the leaves brown and curled
94	Maple	8	10	All leaves that are left are brown and curled
95	Birch	15	10	Most of stems dead; a few seriously injured and one apparently healthy; small new shoots from roots
96	Maple	12	10	Dead
97	Ash	10	10	Dead, except two small new shoots starting from the roots
98	Oak	17	10	Slightly injured; only few leaves curled and brownish
99	Maple	12	10	No leaves of the first growth left, but a few tiny shoots of the second growth appearing; these small shoots dried out
100	Oak	15	10	Sickly appearance like no. 92; only end-leaves of branches left; all leaves near stems dropped, giving the stems the appearance of a tree in the late autumn, when a few leaves are still left before heavy frost
101-130	Oaks, Maples, Birches, Chestnuts, etc.		None None None	All trees healthy throughout the entire season except two of the chestnut trees, which were sick; their leaves being brownish and curling toward the end of the season

young leaves having a withered appearance. The salt was at this time not yet completely dissolved under these injured trees. On June 7 the birch trees which showed injury at the earlier date were making new sprouts; long before the second growth of the control birch trees started. The treated oaks appeared at this time more thrifty than the untreated, having a much darker green foliage. An examination on June 15 showed that some maple and birch trees which received the larger application were dying. Some of the oaks with the same application were injured; the leaves getting brown edges and slightly curling. Those with smaller amounts had an entirely different appearance. Here the salt seemed to act as a fertilizer, producing broad, heavy, dark bluish-green leaves.

An individual examination was made on August 7, at the height of the season. The results are given in table 2.

DISCUSSION

The physiological influence of sodium chloride upon the different species of trees is by no means the same. The susceptibility to injury differs greatly not only for the different species, but also within the same species. Individuals, often standing close to each other, and apparently growing under the same circumstances—as far as moisture, weather conditions and soil type go—react so differently that it is difficult to say where the injury of a certain amount of salt starts and where the stimulating or beneficial effect stops. This is especially true for the hardy oak woods. The soft-wood trees are much more easily injured. However, the range of injury for maple and birch is also rather wide. A small application of salt acts apparently as a fertilizer for oak trees. Some trees make even a vigorous growth with an application of 7 pounds of sodium chloride. In some cases injury occurs when 4 pounds are applied. In the case of birch trees slight injury is recorded by an application of 3 pounds. The range for birch trees, of a height of approximately 15 to 18 feet, between stimulation and injury seems to be approximately 2 to 3 pounds. The maple, which grows fast and consequently takes up moisture more rapidly for transpiration of food materials, etc., is affected by as little as 1 or 2 pounds of salt.

As a rule the stimulating or fertilizing effect results in longer shoots and larger leaves which have often a darker green color than the leaves of untreated trees. The surface of these leaves is shiny, sometimes having a waxy consistency. The larger the leaves are, the darker green is their color, and the more glossy is their surface. With oak trees the leaves are not only extremely large, but also a greater number have developed. This gives the leaves the effect of a very luxuriant, tropical growth.

The injury by all trees is shown in a somewhat similar way. In several cases the main (tallest) stems of oak trees were affected in such a way, that the leaves were large, bluish-green, with a vigorous growth in the secondary top shoots, while leaves of the side (shorter) stems showed slight injury. In several cases the leaves of the different stems of the same tree were measured. Number 64 for instance (plate 1) shows a number of leaves of the main stem which had an average length (measured from base to tip) of 30 cm. and a width of 24 cm., while the average length of a number of leaves of the side stems was only 15 cm. with a width of 12 cm. All leaves were taken from top shoots. The shape of the leaves, due to their great difference of dimensions, was accordingly different, the deep incisions more or less disappearing with increasing size. These large leaves were quite often bloated, the parenchyma bulging up between the primary and secondary veins, giving the leaves an unnatural, dropsical appearance (plate 1, fig. 1). Signs of injury of the oak trees started usually at the extreme end of the smaller veins. At the end of the tracheids occurred a very slight discoloration, probably due to the chlorine-ion entering the cell and changing the composition of the chlorophyll.

This slight discoloration extended until the leaf was spotted with yellow-brown regions. These regions touched each other after some time and gave the leaf a peculiar sickly appearance. If the injury showed at the extreme edges first, the leaf would turn brown at those places and curl; the center of the leaf might remain green for some time afterward, until the injury proceeded, resulting finally in brown closely curled leaves. In the former case the leaves may keep their usual flat surface until they drop. In both cases the leaves quite often become very glossy, dry out and become rubber-like. It is very difficult to break or tear these leaves. Sometimes the injury appears at first only in the primary and secondary veins, usually best seen on the under-side of the leaves. A light yellow discoloration becomes evident, giving the leaves an appearance of being temporarily covered with a fine yellow lace-work. The badly injured oak trees do not always shed their leaves, but as far as could be observed, the shedding took place in all cases where the leaves did not curl. Curling of the leaves as a rule appeared first on the lower branches, the leaves closest to the stem being attacked first. The injury spread gradually by attacking the higher leaves, and the leaves of the top shoots were affected last. This resulted in several cases in giving the trees in midsummer an appearance of autumn trees before heavy frost has removed the leaves of the end branches and top shoots.

Although the influence of sodium chloride on the birch trees was similar to that on the oaks, in some respects the results were different. Trees which were given smaller applications made vigorous growth, the leaves of the treated trees becoming larger and more glossy than those of the untreated trees. Instead of having a greater number of leaves, however, as in the case of oaks, the shoots quite often were elongated so much that the leaves seemed to be placed farther apart (no. 40, plate 3). Where only 1 or 2 pounds of the salt was applied, the trees were very luxuriant but when given 3, 4 or 5 pounds injurious effects were predominant. The leaves became slightly yellow-spotted and turned more or less suddenly into the typical autumn yellow color of birch trees. After dropping these leaves, tiny new shoots with light yellowish-colored leaves appeared, which stood usually close to the stems. These shoots were probably the latent buds forced to grow under the influence of the sodium chloride in an effort to survive. These small new shoots would soon turn black and dry out (plate 3). In some cases a third effort was made by the trees which sent out small new shoots from the roots. In nearly all cases these young stems suffered the same fate, as the tiny new "secondary" shoots.

Another peculiarity is shown in plates 3 and 4. The trees which produced the elongated branches looking as though they were outgrowing themselves, made a peculiar-shaped catkin. The catkins while in bloom were observed to have an abundance of stamens on the part nearest to the stems, while the upper part was relatively poor in stamens. This resulted in giving the catkins a conical, pointed shape. The writer was not able to detect an untreated

birch tree in this swamp which had similar-shaped catkins. They occurred only when the tree was moderately injured. Photographs (plate 4) of the dry catkins made in the middle of November show the same rather pronounced pointed shape, due to fewer and smaller seeds. The seeds of the tips of these catkins were smaller, the wings of the seeds toward the upper ends compared with the wings of the nutlets nearest to the stem were much smaller, the length and the width of the wings gradually decreasing toward the tip of the catkin. The salt seemed to shrivel these catkins in a similar way as it did the leaves. Whether the shriveling is due to the chlorine itself or to the preventing of the necessary food materials from entering the cells, could not be made out.

The soft-wooded maples were affected most quickly. Even when an application of only 1 pound of sodium chloride was made, a yellowish tint occurred in the leaves. This yellow tint changed rapidly into a black-brown by a heavier application. The leaves curled, became brown at the edges and finally dropped. The leaves at the end of the top shoots were quite regularly injured first, the other leaves of these branches following and the leaves of the lower branches, progressing in the same order, last. The brown edges were very dry, and broke easily by slight rubbing or when the wind shook the branches. If the wind moved the branches more vigorously, the leaves rattled as leaves will do which have remained on the trees in the fall. The new shoots of the secondary growth in the cases of slight and moderate injury were very short. They would cluster together, curling, and had a yellow-green color. The leaves and branches which survived never became larger than from one-tenth to three-tenths of the ordinary size of leaves (plate 6). The older injured leaves began gradually to drop soon after the heavier applications were given, and the tree made the usual effort to survive by sending out small new shoots from latent buds (plate 6). Those tiny branches clustered around the stem, became yellow, curled and dropped in nearly all cases.

If the height of the trees was taken into consideration it was quite evident that the injury decreased with the increasing size of the trees. A same application by weight would often do no harm, or injure only slightly a tall tree, while a lower one of the same species would be badly injured or sometimes killed.

It does not seem justifiable to describe in detail and draw conclusions from the behavior of the chestnut trees. Only comparatively few chestnuts were included and two of the five labelled "control" had a sickly appearance at the height of the season. Some of the same kind of trees standing in the swamp were also brownish and sickly. The data of the few cherry and dogwood trees in this experiment are given only for completeness of the record. All twenty-five trees marked "control" which were under constant observation, besides hundreds of others in the swamp were healthy throughout the entire season.

POSSIBLE EFFECTS OF CHLORINE

Whether it is a combination of the sodium and chlorine-ions or the chlorine-ion alone which causes the physiological responses within the cell, is not known. Bolin (4) concludes from his various fertilizer tests with a number of different soils, that the influence of the NaCl used, depended on its chlorine content, but not on its content of sodium. Söderbaum (29), experimenting with a poor sandy soil deficient in chlorine, admits that the remarkable increase might have been caused partly by the replacing of potassium by sodium, but the proportionate growth was beyond the amount of potassium and phosphorus added. He used three portions of soil, adding a complete fertilizer containing nitrogen in the form of NaNO_3 , $(\text{NH}_4)_2\text{SO}_4$ or NH_4Cl . Sodium chloride was added in equivalent amounts to the NaNO_3 . A noticeable increase in yield in behalf of the salt when added to the NaNO_3 and $(\text{NH}_4)_2\text{SO}_4$ was found, but not with NH_4Cl . There could not have been any hygroscopic action of the salt, as the pots were constantly watered. The investigator estimates an absorbed amount of 0.126 gm. of chlorine by the plants. These investigations were repeated and correlated by Söderbaum (30) in 1915. He makes the statement (page 20): "It can hardly be doubted any longer, the chlorine is an important factor in physiological changes."

Only hypotheses are given by some of the investigators concerning the way sodium chloride may react within the plant cell. The fact that there is a relation between the chlorine content and the accumulation of starch in potatoes, led Pfeffer and his students (26) to the suggestion that enzyme action might be the controlling factor. Tottingham (32) makes the supposition that the concentration of chlorine in the cell may exert marked controlling influences upon the activities of intracellular enzymes and if, in turn, many vital activities of the plant are controlled by enzyme action, the physiological responses might be brought about. From the data secured in our experiment it seems quite evident that the injurious and stimulating effects are caused mostly by the chlorine. Whether the chlorine combines with the chlorophyll or acts upon it in some other way to destroy it, can not be made out as yet. It is possible that the chlorine increases the acidity in the cell, which could accelerate the vital activities or enzymatic actions to a certain extent. By a too large increase of acidity the acceleration would change into a toxic action. The fact that applications of small amounts of NaCl which resulted in a luxuriant growth, giving the leaves an extremely dark color, change to a toxic effect whereby the leaves become gradually brown, when a greater dose is given, seems to support this supposition. Another observation seems to point in the same direction. A comparison between dead and live wood of trees of the same species, showed that the hydrogen-ion concentration differs. The pH values for live wood were lower than for dead wood, indicating that the acidity of these live trees was higher than of the dead trees. The preliminary studies on this part of the subject, however, are not yet far enough advanced to permit of drawing conclusions.

SUMMARY

Experiments were made upon 100 trees (oak, birch and maple) with sodium chloride; applications ranging from 1 to 10 pounds were made to individual trees.

Some trees showed injury as early as 6 weeks after the application, while after 10 weeks a number of trees were seriously injured and some dying. The leaves of these trees turned brown and curled. An examination made at the height of the season showed some marked external changes. Smaller applications of salt apparently acted as a fertilizer. The trees treated with a small application were making a vigorous growth, the leaves becoming very large and thick, having a dark blue-green color and glossy surface. Others elongated their branches making the distance between the leaves unusually wide. The first signs of toxicity appeared usually at the edges of the leaves at the extreme end of the tracheids, or in the primary and secondary veins. The injury spread gradually until the leaves had a spotted sickly appearance. After some time the leaves dried out with a rubber-like consistency. These leaves kept their flat and glossy surface and dropped from the branches. If the injury started at the edges of the leaves, they gradually turned brown, curled, but remained on the trees. When the injury appeared in the veins first a beautiful yellow-colored lace-work seemed to cover the under-side of the leaves.

Quite frequently the trees made an effort to survive by sending forth tiny new branches from latent buds. These small branches in nearly all cases turned black-brown and dried out.

Most of the trees which were given smaller applications made a secondary growth long before the untreated trees standing nearby.

Of the trees experimented with, the maple is the most easily affected by sodium chloride, followed by the birch and finally by the oaks.

The rate of injury seems to be dependent upon the height of the trees. The higher trees were more resistant than the lower ones of the same species.

It is possible that the chlorine increases the acidity in the plant cell, accelerating or harming the vital activities, according to the amount employed.

The fact that a small amount of sodium chloride acts as a fertilizer or as a stimulant for trees and shrubs, may lead to the more general use of common rock salt for certain plants, while the toxic effects of the larger applications might be employed in the eradication of weeds and the clearing of farm land from live stumps.

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PLATE 1

FIG. 1. Two top branches of the same oak tree showing the difference in length and width of leaves. The shape of the leaves is changed, because of the great difference in dimensions. The largest leaves show unnatural, vigorous growth, with the parenchyma bulging up between the primary and secondary veins.

FIG. 2. Another view of the smaller branch in figure 1, showing signs of injury starting with the lowest leaves of side branches and top shoots; leaves beginning to curl.



FIG. 1



FIG. 2

PLATE 2

FIG. 1. Oak branch with leaves which have a sickly appearance. Injury starts at the extreme end of the tracheids and proceeds. Leaves do not curl.

FIG. 2. Oak branch showing injury which results in the dropping of the leaves; this gives the tree an autumn-like appearance.



FIG. 2

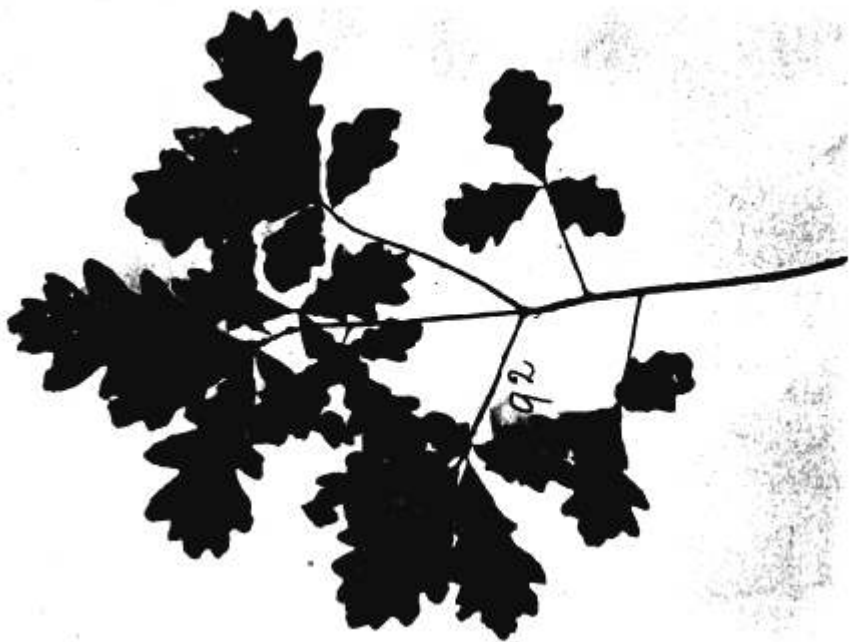


FIG. 1

PLATE 3

FIG. 1. Birch with elongated shoots as result of the application of NaCl. Catkins have a conical shape.

FIG. 2. Birch with shoots from latent buds, which turn black-brown, dry out and drop off. Leaves from last year's buds have dropped previously.

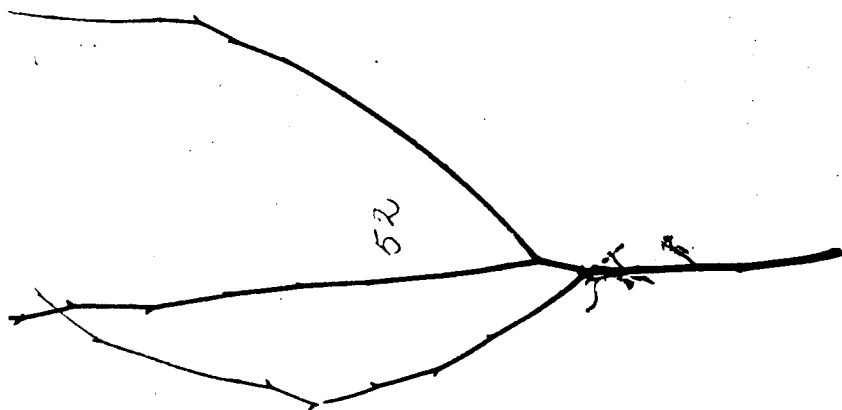


Fig. 2

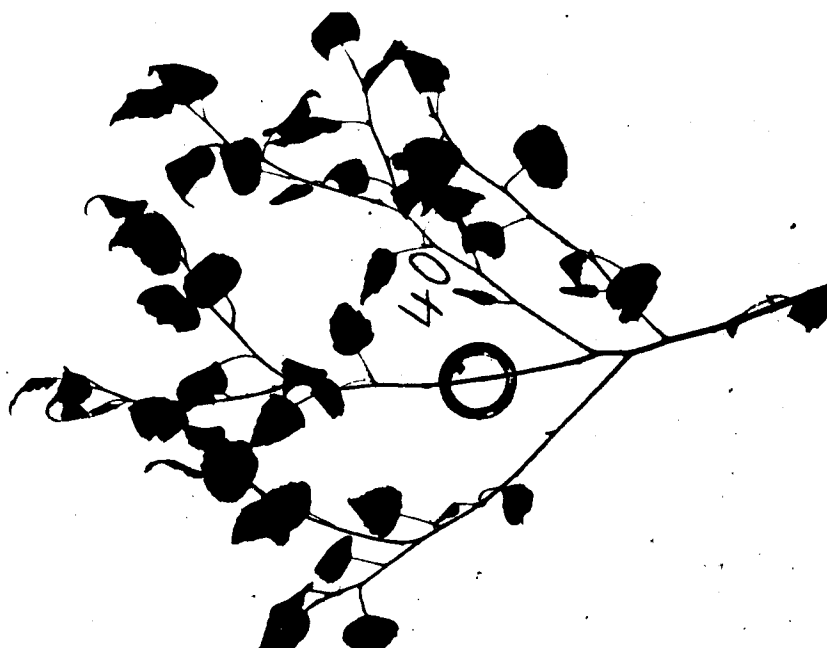


Fig. 1

PLATE 4

FIG. 1. Catkins on branches of birch trees treated and untreated with NaCl; the former having a conical, pointed shape.

FIG. 2. Catkins removed from branches; about two-thirds actual size. Conical catkins have fewer and smaller nutlets toward the tips.



FIG. 1 (Upper)

FIG. 2 (Lower)

!

PLATE 5

FIG. 1. Branch of treated chestnut tree.

FIG. 2. Branch of maple showing beginning of injury on the end leaves of the shoots.
The highest leaves are affected first.



PLATE 6

FIG. 1. Injured maple at a further stage than in plate 5. These leaves dry out and break by slight rubbing or by swaying in the wind.

FIG. 2. Tiny shoots from latent buds made in an effort to survive. These leaves which never grew larger than one-tenth to three-tenths of the usual size, became yellow and curled, and dropped off.

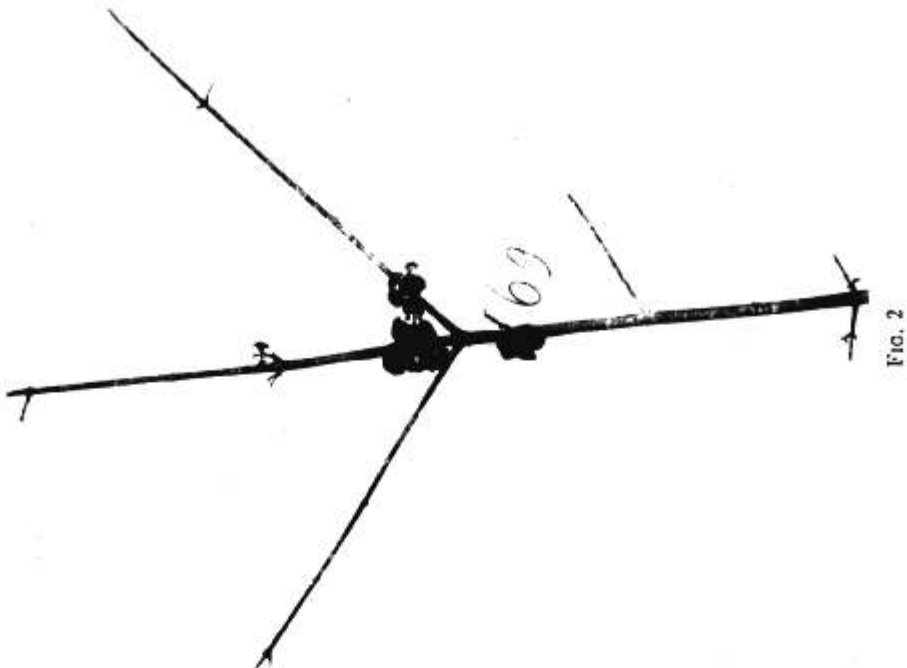


PLATE 7

FIG. 1. Treated birch dying on August 7.

FIG. 2. Treated oak with autumn-like appearance. All leaves nearest to the main stem have dropped.

FIG. 3. Maple which made large leaves in secondary growth. Older leaves all dropped. Only the new leaves on the top shoots remained.

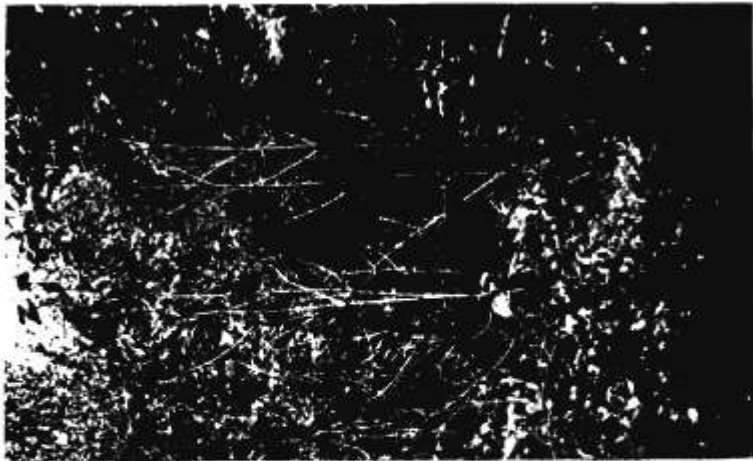


FIG. 3



FIG. 2



FIG. 1