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THE STIMULATION OF ROOT DEVELOPMENT IN HERBACEOUS CUTTINGS AS INFLUENCED BY THE HYDROGEN ION CONCENTRATION OF THE ROOTING MEDIUM

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CONTENTS

THE STIMULATION OF ROOT DEVELOPMENT IN HERBACEOUS CUTTINGS AS INFLUENCED BY THE HYDROGEN ION CONCENTRATION OF THE ROOTING MEDIUM.

INTRODUCTORY

The stimulation of root growth in cuttings, a problem of widespread importance, is a subject which until recently has not been investigated to any great extent. The practical horticulturist has long realized the importance of the problem and has laboriously arrived at methods of propagation which assure a measure of success.

It is the purpose of this study to show what influence, if any, the hydrogen ion concentration of the rooting medium may have upon the development of roots on soft wood or herbaceous cuttings.

EXTRINSIC CONDITIONS

There are a number of extrinsic conditions affecting the rooting of cuttings which the practical propagator considers when attempting to root cuttings of any kind. A little bottom heat, proper temperatures, a supply of oxygen, proper rooting medium, atmospheric moisture--all these details must be given careful attention. It is the author's impression that the hydrogen ion concentration of the soil solution also may greatly influence the development of roots.

The application of mild bottom heat has long been recognized as beneficial in stimulating root development of cuttings. As a matter of fact, bottom heat has seemed absolutely essential to obtain any degree of success in the rooting of cuttings of many plants. This may be explained by the fact that the higher temperature of the medium causes greater growth activity in the portion of the cutting in the warmer medium than in that portion of the cutting in the cooler air. This fact, however, does not completely explain the matter, for

while maintaining this unbalanced temperature relation between top and bottom, one may supply temperatures that are too high or too low with consequent unsatisfactory rooting. The phenomenon may, however, be explained by the examination of several related facts.

All growth processes are understood to be the result of c rtain oxidation processes going on within the plant cells. It is known that oxidation takes place relatively faster at higher temperatures. Manifestly it is not possible to supply the high temperatures necessary for carbohydrate oxidation to living plant tissues. However, oxidation is carried on in the plant tissues by means of certain oxidizing enzymes. The activity of these enzymes is very largely dependent on a proper temperature. This has been amply proved by a great many investigators, Cook (5), Bayliss (2). Moreover, it is quite possible that different plants have enzymes requiring somewhat different optimum temperatures. Blagoveschensk (3) found that every plant splits its own globulin more actively than those from other plants. He came to the conclusion that proteins and enzymes probably are undergoing evolutionary processes comparable to that going on within the physiological charactors of the plant. This possibly indicates the existence of differont strains of the same enzymes which operate under slightly different conditions. The existence of different strains of the same enzymes in different plants may further explain the difference in temperature requirements of different plants.

Since a certain optimum temperature, which may be quite different in different plants, is necessary for the normal action of oxidation enzymes, it follows that greater success will operate where the temperature factor is satisfied. Various means have been adopted by the commercial propagator to satisfy this temperature factor. L. H. Bailey, in his "Nursery Book", describes a method practised by nurserymon of inverting hard wood cuttings temporarily to stimulate root action. In the propagation of soft wood or herbaceous plants,

however, the temperature factor is usually satisfied by means of bottom heat.

From the above it may be deduced that a sufficient supply of oxygen is quite essential. Therefore, the selection of a medium that will permit the circulation of sufficient oxygen is important. Limiting the oxygen supply has been found by numerous investigators to have an injurious effect. Herele (9) found that immersion of dahlia cuttings in distilled water for two hours gave deleterious results. The author likewise has tried immersing cuttings in water for varying lengths of time with more or less injurious effects to the cuttings. The effect may be partly due to accumulation of carbon dioxide in sufficient quantity to have a toxic effect, but to a greater extent, to the cutting of of the oxygen supply, Gibson (8). Proper aeration prevents accumulation of carbon dioxide and furnishes a plentiful supply of oxygen, Livingston (11). The selection of a rooting medium the particles of which are neither too fine nor too course,is, therefore, important. Where the medium is too fine, there will be insufficient aeration. If the medium is too coarse, there will not be sufficient contact of the particles with the cutting. Commercial propagators advise a medium sharp quartz sand that will pass through a ten or twelve mesh screen.

The nature of the medium itself doubtless has a certain effect. Data gather by Schübler regarding the heat-absorbing capacities of various kinds of soils would seem to indicate that a soil having a high heat-absorbing capacity is best.

The maintenance of high moisture content of the air has long been recognized as important in the rooting of cuttings. It is required in order to prevent wilting due to too rapid evaporation of moisture.

INTRINSIC CONDITIONS

Certain intrinsic conditions may also vitally affect the rooting of the cutting. The severing of a cutting from a plant very

seriously disturbs the functional capacity of the severed part. It is the attempt to establish a functional balance which causes the plant to establish a new root system. In accomplishing this the storage foods in the tissues of the cutting assume great importance. Starring (15), in determining the influence of the carbohydrate-nitrate content of cuttings upon the production of roots, found that nitrate content appeared to be of little significance, but that carbohydrate content of cuttings is a very important factor in influencing production of roots. Starring further suggests that the propagating value of sand may thus lie in its low nitrate content, but this is a question that seems to be open to further study. The presence of proper storage foods within the plants seems to be quite important. This emphasizes the necessity of selecting strong, vigorous wood for propagation purposes.

PREVIOUS INVESTIGATIONS

Recently there has been some investigation of the effect of various chemicals in stimulating the production of roots on cuttings. Herele (9) claims that immersion of dahlia and ageratum cuttings for two hours in various strength solutions of magnesium chloride showed that this chemical at certain concentrations, namely, N/3 for one hour for the dahlia and N/2 for one hour for the ageratum, has a distinctly beneficial effect in stimulating root and top growth of cuttings. He states that the ageratum was found to be more resistant to strong solutions of the chemical than was the dahlia.

The work of James Small, Queen's University, Belfast, Ireland and that of Otis F. Curtis at Cornell University stand pre-eminent in this field.

Small (14) has concluded from his work that vinegar (acetic acid) is a useful medium in the propagation of many plants by cuttings. His explanation of the results is that of a theory of "Acid roots, alkaline shoots".

Curtis (6), after very exhaustive experiments, arrived at the

conclusion that treatments with potassium permanganate may result in a very marked increase in root growth of various types of stem cuttings. He assigns five possible explanations and of these five he believes the probable explanation is that potassium permanganate increased respiratory activity by catalytically hastening oxidation. He further found that manganese dioxide, manganese sulphate, aluminium chloride, ferric chloride, ferric sulphate, boric acid and possibly phosphoric acid, may at times show a slight stimulating effect on the rooting of cuttings.

This conclusion seems to be borne out in the experiments described in this thesis. Of the materials mentioned above the writer has included in the present experiments potassium permanganate, manganese sulphate, ferric sulphate and phosphoric acid. All these materials show some effect on stimulation of root growth.

The reasons assigned by both these scientists did not entirely satisfy the writer. He believed that possibly the hydrogen ion concentration of the rooting medium may greatly influence the rooting of cuttings.

This theory was further strengthened by the work of Robert M. Salter and T. C. McIlvaine (13) who found that a pH determination of the medium of around 5.0 to 5.3 seemed to encourage root formation in seedlings. These workers found that there was some variation in the lowest and highest points of acidity which might be harmful to plant development, but in general they have concluded that approximate neutrality and strong acidity, pH 3.0, were about the outer limits beyond which the plants died. In general the optimum acidity appears to have been at a point indicated by a pH value of 5.0 to 5.3, although this varies somewhat with different plants.

Summing up the information available, it seemed to the writer that the solutions used by previous investigators might give satisfactory results under certain conditions, expecially when applications of the

solutions would bring the medium to the optimum point of acidity. However, it was not his impression that they would be effective in all cases. Experiments conducted by both Curtis and Small seem to point to this theory also, although, so far as the writer knows, no determinations of hydrogen ion concentration were made by either of these investigators.

If the solutions gave beneficial results under all conditions, then the explanation lay in the solutions used. If the solutions were not effective in every case, or if entirely different solutions gave equally good results, then it might be assumed that it was a question of soil acidity. If this were true, vinegar applied in proper dilution might stimulate root development when the medium tended toward alkalinity, but some other material, as sodium hydroxide, might stimulate when the mddium was quite acid.

Early experiments using acetic acid and potassium permanganate in the manner described by Curtis (6) and Small (14), showed no spedial stimulating effect and in the case of acetic acid showed some inhibiting effect. The author, therefore, concluded from the varying results obtained by these investigators that the stimulating of roots was not due to the solutions used, but to the resultant hydrogen ion concentration of the soil solution.

If the hydrogen ion concentration of the medium is the factor involved, very much would depend on the concentration of the acid or other solution used. Some solutions being little dissociated in concentration, but being considerably dissociated in dilution, would have quite variable effects on the hydrogen ion concentration of the soil solution at different concentrations.

Some solutions do not give the results that might reasonably be expected at first thought. The use of such material as sodium carbonate

may not give constant results for at times there may be indications of greater acidity when this is used. This condition is explained by Gesell (7) as probably due to a release of carbon dioxide. The absorption of the carbon dioxide into the plant cell may materially change the acidity of the cell sap.

Solutions of strong concentration may have toxic effects due either to inhibiting natural metabolic processes, or to chemical decomposition of the tissues, Bunzell (4).

Wientjes (18), experimenting with the stimulation of germination of seeds, found that, with strong acid, acceleration of germination was apparent with some seeds, but that the radicles were killed when they came into contact with the acid.

Occasionally substances, which are considered toxic, may be harmless or even beneficial under certain conditions, if in very weak solution. In this connection the author quotes "Jost's Plant Physiology" as translated by Gibson, p.162. ---"Many poisons have not only no injurious effect in dilute solution, but are actually of service to the organism by stimulating its respiratory and metabolic activity."

McCall (12), in summing up data from various experiment stations, states that the intensity of the acidity in many instances is of greater significance in bio-chemical processes than is the quantity of acid present. He further states that the intensity of acidity, measured by hydrogen ion concentration determinations bears, in general, no direct or simple relation to the quantity of acid present.

THE EXPERIMENTS OUTLINED

The author has experienced great difficulty in rooting cuttings in the greenhouse of the Department of Horticulture at Rhode Island State College (Kingston, R.I.) and has tried many times to correct the trouble. Four years ago a student under the author's supervision conducted some experiments with potassium permanganate on apple, Iresine and carnation cuttings. The results were disappointing, but in the light of later experience the author believes the chemical was used at too great a concentration.

At the same time the author became interested in using sodium carbonate because the rooting medium, a sand of poor quality, is extremely acid, below that indicated by a pH value of 4.9. Spraying herbaceous cuttings with a weak solytion of sodium carbonate seemed to have a decidedly beneficial effect on some lots of cuttings; at other times the results were disappointing. With there experiences in mind the writer determined to carry on a series of experiments to determine whether the acidity of the medium has any effect on the stimulation of roots.

It was decided to use the regular propagating sand in one series, designated as native sand. Another series was set up using a specially treated beach sand. The latter was obtained at Scarborough Beach, Narragansett Pier, R.I. It was first washed with water and then treated with muriatic acid, heating to 90° C. The sand was then thoroughly washed with distilled water and treated again with acid. This was repeated eight times until the residue was shown to amount to but .0063g. per 10cc. In the last two treatments c.p. HCl was used. The sand finally received a thorough washing with distilled water allowing the water to run through the sand completely. It was found that the use of eighty to one hundred portions of water did not thoroughly remove every trace of acid.

For setting up tho experiments, it was decided to use glass tumblers because it seemed that conditions could be more accurately controlled. Cuttings of chrysanthemum "Golden Wedding" and carnation, "Matchless" were used since these varieties have rooted most readily under the existing conditions. Twelve cuttings were placed in each tumbler, seven chrysanthemums and five carnations. The tumblers were placed in a rose grafting case in order to control evaporation and temperature more accurately than in the open greenhouse. The night temperature ranged between 58° and 62° F.

In determining the solutions to be used, it was decided to limit the preliminary experiments to representative acids, both organic and inorganic and bases. The materials finally decided upon were formic acid, acetic acid, amino acetic acid, phosphoric acid, hydrochloric acid, sulphuric acid, manganese sulphate, ferric sulphate, sodium carbonate, lithium carbonate, sodium hydroxide and potassium permanganate.

Investigators have found that best results were obtained with very weak solutions. Small (14) advises approximately .0001N solutions of acetic acid. Curtis (6) also found best results obtained with the weaker solution. The latter states that it is shown fairly clearly that nutrient solutions of the strengths used in culture work with seedlings are distinctly injurious to woody cuttings. Other investigators have arrived at the same conclusions. A. F. Vierheller (17) carried on experiments with acetic acid to stimulate rooting of apple cuttings. Solutions of varying hydrogen ion concentrations were used with pH values varying from 3.0 to 4.5 and the cuttings watered with solutions each day for a month. Doubtless water evaporation and the continued treatment rendered the rooting medium extremely acid which may offer an explanation for the non-rooting of the cuttings. The writer, therefore, decided to use solutions closely approximating .0001N.

The tumblers (ninety-six) were divided into three equal groups, or series. Series I receiving one application of the solutions, Series II, two applications and Series III, three applications. The first application of the solutions was made when the tumblers were set up. The second application, given only to Series II and Series III, was made eight days after setting up. The third application given to Series III only was made after sixteen days.

The pH determinations were made by the colorimetric method using Soiltex. This was decided after discussing the matter with Dr.Basil E. Gilbert of the Rhode Island Experiment Station staff, Professor H.Louis Jackson of the Department of Chemistry and others, it being generally agreed that the colorimetric method should serve the purpose.

The first pH determinations were made two days after setting up the tumblers, the second pH determinations, sixteen days later. The third pH determinations were made at the end of the experiment, twenty-seven or twenty-eight days after setting up the tumblers.

These preliminary experiments showed that evidently there was an optimum hydrogen ion concentration of the soil medium and that apparently this optimum varied for the two plants involved. The chrysanthemum seemed to root better in somewhat greater hydrogen ion concentration than the carnation.

The results of these experiments, however, were not quite satisfactory so that it was decided to continue the experiments more extensively. In the preliminary experiments the glass tumblers did not prove entirely satisfactory; there being no provision for drainage, it was very difficult to prevent saturation of the sand when applying the solutions. Furthermore, it was found that each tumbler could not be given a certain same quantity of solution at each treatment as there was not equal evaporation. Therefore, three inch clay pots were selected. In order to make conditions of aeration

and evaporation as nearly uniform as possible, the pots were soaked in hot paraffin wax. Pieces of broken pot, also soaked in hot paraffin, were placed over the holes in the bottom of the pots.

Four media were selected, the native sand, the acid treated sand (as used in the preliminary experiments), granulated peat and pink quartz. With the solutions used, these media furnished a fairly wide range of hydrogen ion concentration. Colorimetric determinations of each rooting medium gave the following results,--native sand pH 5.4, acid treated beach sand pH 4.8, peat pH 4.0, pink quartz pH 6.6. LaMotte standards and indicators were used.

The experiments were set up in series as indicated in the tables. Each series was kept in an open box. The boxes were kept on a shelf in the greenhouse with a night temperature of 50° to 55° F. Careful notes were kept and pH determinations made from time to time as necessary. As needed the media were treated with the proper solutions. The solutions were the same as those used in the preliminary experiments. Ten series (Tables 1-10) were set up with carnation cuttings, seven cuttings in each pot. Besides these there were five series of chrysanthemums, four series of Coleus Blumei and two series each of Piqueria trinervia, Antirrhinum majus and Iresine sp. The series in chrysanthemums were a failure due to an insect infestation which caused the death of the cuttings before adequate data could be obtained. Insufficient propagating material made it impossible to repeat the experiments. The remaining experiments were quite satisfactory.

TABULATION

The results of the experiments have been arranged in tables, accompanying the text, which are arranged in five columns. The first column indicates the solution with which each pot was treated. The second column indicates the rooting medium. The third column gives the pH range, the first figure being the first determination and the last figure, the last determination.

When figures appear between these two, they are for the purpose of indicating determinations that varied from the normal trend. The fourth column indicates the number of cuttings rooted and the last column shows the average length of roots in inches.

Although the experiments were usually carried along five to six weeks, the results tabulated were obtained the fourth week after setting up the pots. The tabulation was made after this interval in order to get a better comparison of the stimulating effect of the various solutions.

CARNATIONS

The first experiments with carnations consisted of four series/ In each series a different medium was used in order to get as wide a range of pH as possible. These four media were pink quartz, native sand, acid treated beach sand and granulated peat. The data obtained (Tables 1 to 4) show that there seems to be a more or less definite pH range within which are found the normal processes of root development.

Table 1.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Pink quartz	6.6-6.4	3	1/4
" "	" "	6.8-6.1	5	3/8
Lithium carbonate	" "	6.8-6.4	4	1/8
Phosphoric acid	" "	6.8-6.2	5	1/8
Hydrochloric acid	" "	6.6-6.2	6	1/8
Amino acetic acid	" "	6.6-6.2	3	1/2
Sodium carbonate	" "	6.6-6.4	2	1/4
Acetic acid	" "	6.6-6.3	6	1/2
Potassium permanganate	" "	6.6-6.4	1	1/16
Sodium hydroxide	" "	6.6-6.4	3	3/8
Sulphuric acid	" "	6.5-6.0	4	3/8
Formic acid	"" "	6.6-6.2	3	1/4
Ferric sulphate	" "	6.5-6.3	4	3/8
Distilled water	" "	6.6-6.4	2	3/8

In this table the extreme range is 6.0 to 6.8 and there is quite general rooting of the cuttings. In every series the pots were carried on several weeks after the data were obtained; in this series very fine root development was observed in every case when the pots were discontinued. In the case of one pot

treated with hydrochloric acid solution the pH determination went to 5.8 after the fifth week; the final examination of this pot after the sixth week showed a noticeable inhibition of roothgrowth.

Table 2.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
* Manganese sulphate	Native Sand	5.9-6.0	0	0
* " "	" "	6.1-6.2	5	3/4
Lithium carbonate	" "	6.2-6.0	5	1/4
Phosphoric acid	" "	6.0-5.8-6.0	4	3/16
Hydrochloric acid	" "	5.8-5.4	0	0
Amino acetic acid	" "	6.0-6.1-6.0	3	1/2
Sodium carbonate	" "	6.2-6.0	2	3/8
Acetic acid	" "	6.1-6.0	1	1/4
Potassium permanganate	" "	6.2-6.0	1	1/8
Sodium hydroxide	" "	6.2-6.0-6.2	4	3/8
Sulphuric acid	" "	6.0-5.4	1	1/16
Formic acid	" "	6.2-5.8	4	1/2
Ferric sulphate	" "	6.1-6.0	4	3/8
Distilled water	" "	6.0-6.0	1	1/4

* These two experiments with manganese sulphate are especially noteworthy. See Figure 1 and subject mattor.

It will be observed that the pH range was somewhat lower than in Table 1 and that there are some other interesting points. In the two pots where there was no root development, the hydrogen ion concentration was greater than that indicated by a pH value of 6.0. In the case of manganese sulphate there were two pots; in one the pH range was 5.9-6.0 with no root development, in the other, 6.1-6.2 with good root development (Figure 1). In the former,after seven weeks, one cutting developed a single root one-eighth inch in length and at no time did the hydrogen ion concentration become less than that indicated by a pH value of 6.0 The other pot, after seven weeks, showed six of seven cuttings well rooted with roots up to an inch in length and at that time the hydrogen ion concentration had decreased almost to a point indicated by a pH value of 6.2. This is a most interesting comparison as the experiments, in toto, seem to indicate that extreme hydrogen ion concentration for root growth in carnation cuttings was that indicated by a pH value of something less than 6.0.

The pot treated with the hydrochloric acid solution in this series, even after seven weeks, showed no sign of root development. That this was not due to any toxicity of the hydrochloric acid is apparent by comparison with Table 1, where the corresponding pot shows good root stimulation with the hydrogen ion concentration less than that indicated by a pH value of 6.0.

Another interesting case was that of the pot treated with the amino acetic acid. At the end of the second week the pH value was 6.1. At the end of the third week the author found that three cuttings were well rooted, but the pH value dropped back to 6.0. The pot, continued for seven weeks, showed a constant pH value of 6.0. During this time the roots increased only one-eighth inch in length and only one other cutting dev loped a small root. Apparently those cuttings which did not develop roots when the acidity was at a point indicated by a pH value of 6.1, were not able to develop roots when the hydrogen ion concentration increased to a point indicated by a pH value of 6.0.

Contrary to the results of other investigators, Small (14), acetic acid in this series did not show positive results. The one cutting developing roots did so at a time when the hydrogen ion concentration was at a point indicated by a pH value of 6.1. Thereafter there was a very gradual increase of hydrogen ion concentration to a point where the pH value was something greater than 6.0. at the end of seven weeks. No other cuttings developed roots. Potassium permanganate likewise showed no special stimulating effect, Curtis (6); the one cutting rooted apparently did so while the pH value was at 6.2. In the fifth week the hydrogen ion concentration decreased to a point indicated by a pH value of 6.1. In the interim the pH value had remained at 6.0 and there appeared to be no increase in length of roots of the one cutting. However, after the decrease of hydrogen ion concentration to a point indicated by a pH value of 6.1, the roots attained a length of one-half inch. while a second cutting also developed roots.

A marked inhibition of root development was shown in the case of sulphuric acid in this series when the hydrogen ion concentration increased.

Inspection of the cuttings at the end of twenty days showed three cuttings had developed small roots (one-sixteenth inch in length). A week later the roots had entirely disappeared on two of the cuttings while the third had not increased in length. At this time the pH value was at 5.4. After seven weeks only the one cuttingsshowed any roots and these had not made any observable growth in length. Here again the effect cannot be ascribed to toxicity of the acid for in Table 1 sulphuric acid gave good results. It is, therefore, the author's opinion that the inhibiting action was due to the intensity of the acid rather than to any toxic effect, McCall (12).

The pot treated with formic acid developed roots while the hydrogen ion concentration was less than that indicated by a pH value of 6.0. After the hydrogen ion concentration increased beyond a pH value of 6.0 there was no further root growth, even after seven weeks.

Table 3.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of root in inches
Manganese sulphate	Beach Sand	6.0-6.2	1	1/16
Lithium carbonate	" "	5.9-6.2	0	0
Phosphoric acid	" "	6.0-6.0	0	0
Hydrochloric acid	" "	6.3-6.0	1	3/8
Amino acetic acid	" "	6.0-6.2-6.0	2	5/8
Sodium carbonate	" "	5.9-6.0	0	0
Acetic acid	" "	5.9-6.1	1	1/8
Potassium permanganate	" "	5.9-6.0	3	3/8
Sodium hydroxide	" "	5.8-6.1-6.0	1	3/8
Sulphuric acid	" "	6.0-6.1	2	1/4
Formic acid	" "	5.8-6.0	0	0
Ferric sulphate	" "	6.0-6.0	0	0
Distilled water	" "	5.8-6.0	0	0

This table summarizes the series where the acid-treated beach sand was used as a medium. In this series the small size of the particles of sand doubtless had some effect in slowing up root development.

At the end of seven weeks, six of the seven cuttings in the pot treated with manganese sulphate had developed fine root systems. At no time was the hydrogen ion concentration greater than that indicated by a pH value of 6.0.

The pot treated with phosphoric acid showed no root development, even at the end of seven weeks.

The pot treated with the hydrochloric acid solution showed one cutting that had rooted while the hydrogen ion concentration was at a point indicated by a pH value of less than 6.0; after seven weeks the hydrogen ion concentration had gradually increased to a point indicated by a pH value of 5.7; no other cuttings rooted. However, the one cutting rooted continued to develop and at the end of seven weeks the roots had reached a length of one and three-eighths inches.

The pot treated with acetic acid in this series is interesting because of the very evident response to change in hydrogen ion concentration. By referring to the table, it is seen that there was one cutting with roots one-eighth inch in length. One week later the hydrogen ion concentration had decreased to a point indicated by a pH value of 6.2 while the roots had grown to a length of one-half inch. Two weeks later the hydrogen ion concentration had increased to a point indicated by a pH value of 6.0 without increase in length of roots.

In the pot treated with the sodium hydroxide one cutting had rooted. Apparently the root development occurred while the hydrogen ion concentration was less than that indicated by a pH value of 6.0. In this instance, at the end of the fifth week, the pH value was 5.8 and the roots had not gained any in length. At the end of seven weeks the pH value was 5.6 and all roots had disappeared.

The sulphuric acid treatment showed increase in root growth up to the fifth week. Thereafter the hydrogen ion concentration increased to a point indicated by a pH value of 5.8 while root growth remained stationary.

The pot treated with ferric sulphate showed a pH value of slightly less than 6.0 with no root development.

The check pot treated with distilled water showed no root development. The hydrogen ion concentration remained at a point indicated by a pH value greater than 6.0. There could have been no toxic effect due to the water. Evidently the effect was due to too great hydrogen ion concentration.

Table 4.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Peat	4.6-5.6	0	0
Manganese sulphate	"	4.4-5.0	0	0
Lithium carbonate	"	4.4-5.8	0	0
Phosphoric acid	"	4.4-4.6	0	0
Hydrochloric acid	"	4.4-4.2	0	0
Amino acetic acid	"	4.4-5.0	0	0
Sodium carbonate	"	4.8-4.8	0	0
Acetic acid	"	4.4-5.2	0	0
Potassium permanganate	"	4.4-4.8	0	0
Sodium hydroxide	"	4.4-4.6	1	1/16
Sulphuric acid	"	4.4-4.6	0	0
Formic acid	"	4.4-4.7	0	0
Ferric sulphate	"	4.6-5.0	0	0
Distilled water	"	4.5-5.2	0	0

Table 4 shows the results of the use of granulated peat as a medium for the rooting of cuttings. The peat is of a very acid nature pH 4.0. Only one of more than one hundred cuttings rooted. After seven weeks no roots were observed, not even on the one cutting that had previously developed a small root.

At this time it was decided to determine the effect of a decrease in the hydrogen ion concentration. Each pot was watered with sodium carbonate .0003N. One week later pH determinations were made and it was found that hydrogen ion concentration was apparently too great. Practically no rooting had occurred. Each pot was then given 1.5 cc of sodium hydroxide .1N and treated with distilled water. Two weeks later the hydrogen ion concentration was found to be materially reduced and in the cases of least hydrogen ion concentration roots were appearing. (Table 5). Almost invariably roots appeared only when the hydrogen ion concentration was reduced to a point indicated by a pH value of 5.8.

Table 5.-- pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Peat	4.6-5.2-5.6	3	1/8
" "	"	5.2-5.4-5.8	1	3/4
Lithium carbonate	"	5.4-5.4-5.8	1	1/4
Phosphoric acid	"	4.6-5.2-5.8	2	1/2
Hydrochloric acid	"	4.2-4.2-5.2	0	0
Amino acetic acid	"	4.7-5.2-5.4	1	1/8
Sodium carbonate	"	4.8-5.2-6.0	1	1/8
Acetic acid	"	4.6-5.2-5.4	0	0
Potassium permanganate	"	5.0-5.2-5.8	3	1/4
Sodium hydroxide	"	5.2-5.4-5.8	3	1/4
Sulphuric acid	"	4.8-5.0-5.4	0	0
Formic acid	"	4.6-4.8-5.2	0	0
Ferric sulphate	"	4.8-5.4-5.6	0	0
Distilled water	"	4.6-5.0-5.4	0	0

Note. First pH determination taken at end of seven weeks, second at end of eights, third, at end of ten weeks.

This series shows very plainly the effect of too great a hydrogen ion concentration in inhibiting the development of roots of carnation cuttings.

Table 6.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Pink Quartz	6.7-6.2	7	1/2
" "	" "	6.5-6.2	7	1/2
Lithium carbonate	" "	6.6-6.2	7	3/8
Phosphoric acid	" "	6.4-6.1	7	5/8
Hydrochloric acid	" "	6.5-6.1	7	5/8
Amino acetic acid	" "	6.4-6.2	5	3/8
Sodium carbonate	" "	6.7-6.2	7	1/2
Acetic acid	" "	6.5-6.2	6	3/8
Potassium permanganate	"	6.7-6.2	6	1/2
Sodium hydroxide	" "	6.5-6.3	6	3/8
Sulphuric acid	" "	6.5-6.1	7	1/2
Formic acid	" "	6.7-6.2	6	3/8
Ferric sulphate	" "	6.5-6.5	7	3/8
Distilled water	" "	6.4-6.2	7	5/8

Table 6 gives the data for a series run as check against those in Table 1. The figures show the root development at the end of twenty days. In every

case the hydrogen ion concentration was less than that indicated by a pH value of 6.1. Two weeks later inspection showed every cutting rooted and the root systems well developed. In every case the increase in length was 300 to 400 per cent. This series was one of the most successful due to a combination of circumstances. At the time the series was run there were particularly favorable weather conditions. In addition, the rooting medium was of a particularly good type, the variety of carnation used was a very easy rooting sort and finally the hydrogen ion concentrations of the soil solution were quite close to what appeared to be the optimum in the previous series.

Comparison of Table 6 with Table 7 shows very marked differences which may be ascribed to the difference in hydrogen ion concentration.

Table 7.-- pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Native sand	5.8-6.1	2	3/8
" "	" "	5.8-6.0	1	1/8
Lithium carbonate	" "	6.2-6.2	3	3/16
Phosphoric acid	" "	5.8-6.0	3	1/8
Hydrochloric acid	" "	5.6-5.2	0	0
Amino acetic acid	" "	6.0-6.2	1	3/8
Sodium carbonate	" "	6.2-6.0	4	1/16
Acetic acid	" "	6.0-6.0	1	1/16
Potassium permanganate	" "	6.0-6.1	2	3/16
Sodium hydroxide	" "	6.0-6.1	2	1/16
Sulphuric acid	" "	6.3-5.4	4	1/16
Formic acid	" "	6.2-5.6	1	1/16
Ferric sulphate	" "	6.2-6.0	3	1/8
Distilled water	" "	6.2-6.0	3	1/16

These two series (Tables 6 and 7) were run together under identical conditions. It is to be noted that root stimulation is not as great at the lower hydrogen ion concentration.Continuance of the latter series for two weeks longer showed further root development, especially where the hydrogen ion concentration was less than that indicated by a pH value of 6.0; more of the cuttings had rooted and increase in length of roots was from 300 to 500 per cent. In the pot treated with hydrochloric acid one cutting had

rooted at the end of six weeks. This was an interesting exception as the pH determination at this time was at 5.4. The sulphuric acid treated pot was another interesting case; here evidently roots were stimulated early when the pH value was at 6.3, for even after six weeks no other cuttings had developed roots. During this time the pH value remained constant at 5.4. Comparison of this pot with the corresponding pot in Table 2 brings out the influence of the hydrogen ion concentration rather forcibly. In Table 2 the least hydrogen ion concentration was at a point indicated by a pH value of 6.0, only one cutting developing roots. In Table 7 the initial pH value was 6.3 with four cuttings showing roots.

Table 8.-- pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Pink Quartz	6.2-6.3	3	1/4
Lithium carbonate	" "	6.3-6.3	2	1/4
Phosphoric acid	" "	6.2-6.3	4	1/4
Hydrochloric acid	" "	6.0-6.1	2	1/4
" "	" "	6.2-6.0	2	1/8
Amino Acetic acid	" "	6.2-6.4	2	3/8
" " "	" "	6.2-6.4	4	1/8
Sodium carbonate	" "	6.2-6.3	3	1/4
Acetic acid	" "	6.2-6.3	3	1/8
" "	" "	6.4-6.3	2	1/16
Potassium permanganate	" "	6.6-6.3	2	1/14
Sodium hydroxide	" "	6.2-6.2	2	1/16
Sulphuric acid	" "	6.2-6.3	4	3/8
" "	" "	6.0-6.2	3	1/4
Formic acid	" "	6.6-6.3	3	1/4
" "	" "	6.4-6.4	3	1/16
Ferric sulphate	" "	6.4-6.4	3	1/4
" "	" "	6.4-6.2	2	1/4
Distilled water	" "	6.2-6.3	2	1/16
" "	Pink quartz and 15% Peat	4.8-4.8	0	0

This table shows a series of experiments which were arranged to check the previous work summarized in Tables 1 and 6. The results in Table 8 seem to compare well with the previous series treated in the same manner. In this series, as in the previous series, after six weeks more cuttings were rooted and there was a great increase in length of roots where the hydrogen ion concentration did not exceed that indicated by a pH value of 6.0. The distilled water treat-

ment is worthy of note; two pots were set up, one consisting of pink quartz, the other having about 15% (by volume) granulated peat mixed with pink quartz. The pure quartz pot showed a pH value of about 6.2 with stimulation of roots; the other pot showed a pH value of 4.8 with no root development.

The series of experiments tabulated in Tables 9, 10 and 11 are repetition of the experiments summarized in Tables 1, 2, 3, 6, 7, 8 and serve to corroborate the facts brought out in the previous series.

Table 9.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. Rooted	Average length of roots in inches
Manganese sulphate	Pink Quartz	6.8-6.4	6	1/4
" "	" "	6.4-6.6	5	3/8
Lithium carbonate	" "	6.6-6.6	6	3/8
Phosphoric acid	" "	6.5-6.3	7	3/8
Hydrochloric acid	" "	6.5-6.2	7	1/4
Amino acetic acid	" "	6.4-6.6	5	1/4
Sodium carbonate	" "	6.6-6.4	6	1/4
Acetic acid	" "	6.6-6.4	6	1/2
Potassium permanganate	" "	6.4-6.6	5	1/4
Sodium Hydroxide	" "	6.8- 6.3	6	3/8
Sulphuric acid	" "	6.8-6.6	6	1/4
Formic acid	" "	6.8-6.4	6	1/4
Ferric sulphate	" "	6.6-6.4	5	1/4
Distilled water	" "	6.6-6.4	6	3/8

Table 10.--pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Native Sand	6.2-6.6-6.2	4	5/8
" "	" "	6.2-6.4	2	1/4
Lithium carbonate	" "	6.2-6.1	3	1/4
Phosphoric acid	" "	6.2-6.0	4	1/16
Hydrochloric acid	" "	5.8-5.6	1	3/8
Amino acetic acid	" "	6.2-6.4	4	1/2
Sodium carbonate	" "	6.2-6.3	4	3/8
Acetic acid	" "	6.2-6.2	4	3/8
Potassium permanganate	" "	6.2-6.3	4	3/8
Sodium hydroxide	" "	6.6-6.3	5	1/8
Sulphuric acid	" "	5.6-6.0	1	1/2
Formic acid	" "	6.0-6.2	2	1/8
Ferric sulphate	" "	6.0-6.3	3	1/8
Distilled water	" "	6.4-6.2	4	3/8

Table 11.-- pH range and root development of carnation cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Beach sand	6.2- 6.0	1	1/2
" "	" "	6.0- 6.4	2	1/8
Lithium carbonate	" "	6.2- 6.2	2	1
Phosphoric acid	" "	6.3- 6.1	3	1/16
Hydrochloric acid	" "	6.3- 6.1	3	1/14
Amino acetic acid	" "	6.1- 6.1	4	3/8
Sodium carbonate	" "	6.4- 6.1	3	1/4
Acetic acid	" "	6.2- 6.2	4	1/8
Potassium permanganate	" "	6.5- 6.4	4	3/8
Sodium hydroxide	" "	6.2- 6.0	2	1/16
Sulphuric acid	" "	6.2- 6.0	3	1/16
Formic acid	" "	6.4- 6.0	1	1/8
Ferric sulphate	" "	6.4- 6.1- 6.4	4	1/16
Distilled water	" "	6.2- 6.2	2	1/16

The series tabulated in Table 9 shows quite general root development. This is expected since proceeding series gave similar results in every case when the hydrogen ion concentration was less than that indicated by a pH value of 6.0.

It should be noted in Table 10 that in the sulphuric acid treated pot one cutting rooted while the hydrogen ion concentration was quite low, An unexplainable decrease in hydrogen concentration gave fine root growth. The corresponding pot in Table 2 shows one cutting rooted, but, as might be expected, there was a gradual increase of the hydrogen ion concentration from a pH value of 6.0 to 5.4. In this case there was no further growth in length of the root. The inference is that decrease of hydrogen ion concentration stimulated root growth.

Comparison of the pots treated with hydrochloric acid in Tables 2 and 10 also shows an inhibiting effect of increasing hydrogen ion concentration.

The pots treated with distilled water in these two series (Tables 2 and 10) likewise show difference in root stimulation with different hydrogen ion concentrations. Table 11 may be compared with Table 3. It should be noted that in general the hydrogen ion concentrations indicated by the pH ranges in Table 3 are greater than in Table 11. This was not due to a difference

in concentration of the solutions used, but to an accumulation of the material used. The same pots were used for both series; the cuttings, data on which are given in Table 11, were inserted about one week after the completion of the series summarized in Table 3. The rooting indicated by Table 11 was more successful than that indicated in Table 3 with its greater hydrogen ion concentrations as would be expected.

OPTIMUM HYDROGEN ION CONCENTRATION FOR ROOTING CARNATION CUTTINGS

These experiments are sufficiently extensive so that by a careful study of the data the range of hydrogen ion concentration within which carnations will root successfully may be established. To achieve this result a rearrangement of the data is essential in order that the effect of a single solution may be compared in all cases.

Manganese Sulphate

pH Range	No. Rooted	Average length of roots in inches	Optimum pH
6.8-6.4	3	1/4	
6.8-6.1	5	3/8	
5.9-6.0	0	0	
6.1-6.1	5	3/4	
6.0-6.2	1	1/16	
6.7-6.2	7	1/2	
6.5-6.2	7	1/2	
5.8-6.1	2	3/8	6.0- 6.8
5.8-6.0	1	1/8	(6.5)
6.2-6.3	3	1/4	
6.8-6.4	6	1/4	
6.4-6.6	5	3/8	
6.2-6.6-6.2	4	3/8	
6.2-6.4	2	1/4	
6.2-6.0	1	1/2	
6.0-6.4	2	1/8	

Lithium Carbonate

pH Range	No. Rooted	Average length of roots in inches	Optimum pH
6.8-6.4	4	1/8	
6.2-6.0	5	1/4	
5.9-6.2	0	0	
6.6-6.2	7	3/8	
6.2-6.2	3	3/16	6.0-6.8
6.3-6.3	2	1/4	(6.5)
6.6-6.6	6	3/8	
6.2-6.1	3	1/4	
6.2-6.2	2	1	

Phosphoric Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.8-6.2	5	1/8	
6.0-5.8-6.0	4	3/16	
6.0-6.0	0	0	
6.4-6.1	7	5/8	
5.8-6.0	3	1/8	
6.2-6.3	4	1/4	6.0-6.8
6.5-6.3	7	3/8	(6.4)
6.2-6.0	4	1/16	
6.3-6.1	3	1/16	

Hydrochloric Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.2	6	1/8	
5.8-5.4	0	0	
6.3-6.0	1	3/8	
6.5-6.1	7	3/8	
5.6-5.2	0	0	6.0-6.6
6.0-6.1	2	1/4	(6.3)
6.2-6.0	2	1/8	
6.5-6.2	7	1/4	
5.8-5.6	1	3/8	
6.3-6.1	3	1/4	

Amino Acetic Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.2	3	1/2	
6.0-6.1-6.0	3	1/2	
6.0-6.2-6.0	2	5/8	
6.4-6.2	5	3/8	
6.0-6.2	1	3/8	
6.2-6.4	2	3/8	6.0-6.6
6.2-6.4	4	1/8	(6.4)
6.4-6.6	5	1/4	
6.2-6.4	4	1/2	
6.1-6.1	4	3/8	

Sodium Carbonate

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.4	2	1/4	
6.2-6.0	2	3/8	
5.9-6.0	0	0	
6.7-6.2	7	1/2	
6.2-6.0	4	1/16	6.0-6.7
6.2-6.3	3	1/4	(6.4)
6.6-6.4	6	1/4	
6.2-6.3	4	3/8	
6.4-6.1	3	1/4	

Acetic Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.3	6	1/2	
6.1-6.0	1	1/4	
5.9-6.1	1	1/8	
6.5-6.2	6	3/8	
6.0-6.0	1	1/16	6.0-6.6
6.2-6.3	3	1/8	(6.5)
6.4-6.3	2	1/16	
6.6-6.4	6	1/2	
6.2-6.2	4	3/8	
6.2-6.2	4	1/8	

Potassium Permanganate

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.4	1	1/16	
6.2-6.0	1	1/8	
5.9-6.0	3	3/8	
6.7-6.2	6	1/2	6.0-6.6
6.0-6.1	2	3/16	(6.4)
6.6-6.3	2	1/4	
6.4-6.6	5	1/4	
6.2-6.3	4	3/8	
6.5-6.4	4	3/8	

Sodium Hydroxide

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.4	3	3/8	
6.2-6.0-6.2	4	3/8	
5.8-6.1-6.0	1	3/8	
6.5-6.3	6	3/8	
6.0-6.1	2	1/16	6.0-6.8
6.2-6.2	2	1/16	(6.4)
6.8-6.3	6	3/8	
6.6-6.3	5	1/8	
6.2-6.0	2	1/16	

Sulphuric Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.5-6.0	4	3/8	
6.0-5.4	1	1/16	
6.0-6.1	2	1/4	
6.5-6.1	7	1/2	
6.3-5.4	4	1/16	
6.2-6.3	4	3/8	6.0-6.6
6.0-6.2	3	1/4	(6.3)
6.8-6.6	6	1/4	
5.6-6.0	1	1/2	
6.2-6.0	3	1/16	

Formic Acid

pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.6-6.2	3	1/4	
6.2-5.8	4	1/2	
5.8-6.0	0	0	
6.7-6.2	6	3/8	
6.2-5.6	1	1/16	
6.6-6.3	3	1/4	6.0-6.8
6.4-6.4	3	1/16	(6.4)
6.8-6.4	6	1/4	
6.0-6.2	2	1/8	
6.4-6.0	1	1/8	

Ferric Sulphate			
pH Range	No. rooted	Average length of roots in inches	Optimum pH
6.5-6.3	4	3/8	
6.1-6.0	4	3/8	
6.0-6.0	0	0	
6.5-6.5	7	3/8	
6.2-6.0	3	1/8	
6.4-6.4	3	1/4	6.0-6.6
6.4-6.2	2	1/4	(6.5)
6.6-6.4	5	1/4	
6.0-6.3	3	1/8	
6.4-6.1-6.4	4	1/16	

Distilled water			
pH Range	No. rooted	Average length of roots in inches	Optimun pH
6.6-6.4	2	1/8	
6.0-6.0	1	1/4	
5.8-6.0	0	0	
6.4-6.2	7	5/8	
6.2-6.0	3	1/16	6.0-6.6
6.2-6.3	2	1/16	(6.4)
4.8-4.8	0	0	
6.6-6.4	6	3/8	
6.4-6.2	4	3/8	
6.2-6.2	2	1/16	

It will be seen that the range of hydrogen ion concentration within which carnation cuttings will root readily is that indicated by a pH value of 6.0 to 6.8. By careful study of the root development in each case the optimum hydrogen ion concentration may be determined as that indicated by a pH value of approximately 6.4

In general it appears that, when the hydrogen ion concentration changes, best results are obtained when the change is toward a slight increase of the hydrogen ion concentration, provided that the increase does not exceed that indicated by a pH value of 6.0.

Several interesting facts were brought out that perhaps are not so evident in the tabulation. Often in the case of pots treated with potassium permanganate, when the hydrogen ion concentration was excessive, there was a disintegration of the tissues at the base of the cutting. This fact does not agree with results obtained by Curtis (6). The present experiments were made with soft wood cuttings, while Curtis used chiefly hard wood cuttings of

Ligustrum sp. Probably the harder wood of the Ligustrum resisted the disintegrating effect of the potassium permanganate more than would be the case with soft wood cuttings.

Pots treated with potassium permanganate and those treated with acetic acid did not give results noticeably better than any of the other solutions, the hydrogen ion concentration apparently being the more important factor. This was not to be expected in view of the work of other investigators.

Comparisons of the results from pots treated with acetic acid and those treated with amino acetic acid show some slight advantage obtained with the amino acetic acid. This was probably due to the amino radical of the amino acetic acid.

EXPERIMENTS WITH OTHER PLANTS

A large number of experimentswith other plants indicate that the hydrogen ion concentration of the rooting medium affects the development of roots from the cuttings. Some plants have a much wider range, i.e., they will withstand greater acidity or greater alkalinity than will other plants. This is quite apparent in the case of Iresine (Tables 12 and 13). Ten cuttings were used in each pot in the two series.

Table 12.--pH range and root development of Iresine sp.cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Pink Quartz	6.4-6.4	7	1/4
Lithium carbonate	" "	6.4-6.4	5	3/8
Phosphoric acid	" "	6.2-6.4-6.0	6	1/8
Hydrochloric acid	" "	6.2-6.4-6.2	4	3/8
Amino acetic acid	" "	6.4-6.4	8	3/8
Sodium carbonate	" "	6.2-6.4	6	1/4
Acetic Acid	" "	6.4-6.4	9	3/8
Potassium permanganate	" "	6.4-6.4	7	1/4
Sodium hydroxide	" "	6.2-6.4	8	1/4
Sulphuric acid	" "	6.0-6.0	8	1/8
Formic acid	" "	6.2-6.4-6.2	6	1/4
Ferric sulphate	" "	6.2-6.4	8	3/16
Distilled water	" "	6.5-6.4-6.6	5	1/4

Table 13.--pH range and root development of Iresine sp. cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Native Sand	6.0-5.8	9	3/8
Lithium carbonate	" "	5.9-6.0	6	1/4
Phosphoric acid	" "	5.8-6.0	7	1/4
Hydrochloric acid	" "	5.6-5.6	5	3/8
Amino acetic acid	" "	6.0-6.0	8	1/4
Sodium carbonate	" "	6.0-6.0	5	1/4
Acetic acid	" "	5.8-6.0	6	1/4
Potassium permanganate	" "	5.8-5.8	5	1/4
Sodium hydroxide	" "	5.8- 6.0	4	1/4
Sulphuric acid	" "	5.7-5.8	4	1/4
Formic acid	" "	600-5.8	6	1/4
Ferric sulphate	" "	5.8-6.0	5	1/4
Distilled water	" "	5.8-5.8	9	1/4

The experiments carried out showed that this plant would root readily in hydrogen ion concentrations varying from a pH value of 5.6 to 6.6. This is in line with known facts for the commercial progagator describes this plant as easy to root.

Table 14.--pH range and root development of Piqueria trinervia cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	Native Sand	5.8-6.0	3	1-1/2
Lithium carbonate	" "	6.0-6.0	2	1-1/2
Phosphoric acid	" "	6.0-5.8	3	5/8
Hydrochloric acid	" "	5.9-5.0	0	0
Amino acetic acid	" "	6.0-5.6	1	1/2
Sodium carbonate	" "	6.1-6.0	3	1-3/4
Acetic acid	" "	5.9-6.0	3	1-1/4
Potassium permanganate	" "	6.0-6.0	1	1-1/4
Sodium hydroxide	" "	6.0-5.9	1	1/4
Sulphuric acid	" "	5.9-5.0	1	1/16
Formic acid	" "	5.9-5.6-5.8	2	3/8
Ferric sulphate	" "	6.1-5.8	4	1-1/4
Distilled water	" "	5.9-5.9	5	1-3/4

Table 15.--pH Range and root development of Piqueria trinervia cuttings treated with various solutions .0001N

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Pink quartz	6.2-6.4	3	1¾
" "	" "	6.2-6.3	2	3/8
Lithium carbonate	" "	6.4-6.6-6.3	1	1½
Phosphoric acid	" "	6.4-6.2	3	1
Hydrochloric acid	" "	6.2-6.0	2	1/8
Amino acetic acid	" "	6.2-6.4-6.2	1	2¾
Sodium carbonate	" "	6.2.6.3	2	1
Acetic acid	" "	6.2-6.4	2	2½
Potassium permanganate	" "	6.4-6.2	3	1
Sodium hydroxide	" "	6.1-6.3	3	1¼
Sulphuric acid	" "	6.2-6.0	1	¼
Formic acid	" "	6.2-6.3	2	3/8
Ferric sulphate	" "	6.2-6.3	3	1½
Distilled water	" "	6.0-6.4	2	2

Stevia seems to be quite similar to the carnation in its reaction. Apparently, however, it will root in somewhat greater hydrogen ion concentration than will the carnation. In this series six cuttings were inserted in each pot.

Table 16.--pH range and root development of Coleus sp. cuttings treated with various solutions .0001N

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Pink quartz	6.4-6.4	6	1/8
" "	" "	6.4-6.5	5	1/4
Lithium carbonate	" "	6.8-6.6	5	1/4
Phosphoric acid	" "	6.6-6.3	5	1/8
Hydrochloric acid	" "	6.4-6.2	6	3/8
Amino acetic acid	" "	6.4-6.6	6	1/4
Sodium carbonate	" "	6.4-6.4	6	1/4
Acetic acid	" "	6.4-6.3	6	3/8
Potassium permanganate	" "	6.8-6.4	5	1/4
Sodium hydroxide	" "	6.3-6.5	6	3/8
Sulphuric acid	" "	6.4-6.2	6	1/8
Formic acid	" "	6.6-6.4	5	1/4
Ferric sulphate	" "	6.6-6.4	6	1/4
Distilled water	" "	6.4-6.5	5	1/4

Table 17.--pH range and root development of Coleus sp. cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Native sand	6.2-6.2	6	1/4
" "	" "	6.2-6.3	6	3/8
Lithium carbonate	" "	6.0-6.2	5	1/8
Phosphoric acid	" "	6.0-6.0	6	1/8
Hydrochloric acid	" "	5.8-5.6	5	1/4
Amino acetic acid	" "	6.2-6.4	6	1/4
Sodium carbonate	" "	6.2-6.3	6	1/4
Acetic acid	" "	6.2-6.1	5	3/8
Potassium permanganate	" "	6.3-6.1	5	1/4
Sodium hydroxide	" "	6.2-6.4	5	1/8
Sulphuric acid	" "	5.8-5.6	5	1/4
Formic acid	" "	6.1-6.2	6	1/4
Ferric sulphate	" "	6.2.6.2	5	1/4
Distilled water	" "	6.0-6.4	6	3/8

Table 18.--pH range and root development of Coleus sp. cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No. rooted	Average length of roots in inches
Manganese sulphate	Beach Sand	6.2-6.4	4	1/8
" "	" "	6.2-6.0	3	1/4
Lithium carbonate	" "	6.2-6.2	4	1/4
Phosphoric acid	" "	6.2-6.0	3	1/8
Hydrochloric acid	" "	5.6-5.4	3	1/8
Amino acetic acid	" "	6.1-6.1	5	1/8
Sodium carbonate	" "	6.1-6.2	5	1/8
Acetic acid	" "	6.1-6.2	4	1/4
Potassium permanganate	" "	6.2-6.1	3	1/4
Sodium hydroxide	" "	6.0-6.2	5	1/8
Sulphuric acid	" "	6.2-6.0	6	1/8
Formic acid	" "	6.0-5.8	5	1/8
Ferric sulphate	" "	6.3-6.1	4	1/4
Distilled water	" "	6.2-6.2	6	1/8

Table 19.--pH range and root development of Coleus sp. cuttings treated with various solutions .0001N.

Solution	Medium	pH Range	No.rooted	Average length of roots in inches
Manganese sulphate	*Peat and quartz	5.8-5.8	4	1/4
" "	" " "	5.8-5.9	5	1/8
Lithium carbonate	" " "	5.8-6.0	5	1/8
Phosphoric acid	" " "	5.8-5.8	6	1/4
Hydrochloric acid	" " "	5.6-5.4	3	1/8
Amino acetic acid	" " "	6.0-6.0	4	1/8
Sodium carbonate	" " "	5.8-5.8	4	1/8
Acetic acid	" " "	5.8-6.0	3	1/4
Potassium permanganate	" "	5.6-5.8	2	1/8
Sodium hydroxide	" " "	5.6-5.8	3	1/8
Sulphuric acid	" " "	5.6-5.4	2	1/8
Formic acid	" " "	5.7-5.6	5	1/8
Ferric sulphate	" " "	5.6-5.7	3	1/8
Distilled water	" " "	5.7-5.6	4	1/4

*Mixture of peat and quartz containing about 15% peat by volume.

The case of Coleus is quite similar to that of the Iresine in that it will apparently root throughout a greater range of hydrogen ion concentration than will the carnation. During the experiments with both Iresine and Coleus it was found that apparently the temperature factor was important. The first experiments set up were carried along in a greenhouse with a night temperature 50°-55° F. In these experiments the Iresine rooted very slowly and tended to lose its foliage. The Coleus did not root well and tended to rot, particularly at the base of the cutting. New sets of these experiments carried along in a warm house with a night temperature of 60° to 65° F. did quite well. (Tables 16, 17, 18, 19). Both Coleus and Iresine are well known bedding plants that grow best in very warm weather. The comparison of these experiments emphasized the importance of the temperature factor. While Coleus refused to root and Iresine rooted very slowly in the cooler house, chrysanthemums and carnations rooted well under cool temperature conditions.

Experiments with Antirrhinum majus showed the importance of the size of soil particles as a factor in rooting. Two series of these were set up, one in

pink quartz and the other in native sand. The particles of the pink quartz were larger than those of the native sand. The snapdragon cuttings were small and slender. Those in the pink quartz wilted and dried up in spite of every precaution in shading and watering. The cuttings in the native sand, the particles of which varied in size from very small to the same size as the pink quartz, rooted well. In this connection the results with the use of acid treated beach sand were interesting in that all cuttings produced less vigorous roots than in the other types of rooting medium. This apparently was due to the small size of the particles permitting less aeration and thus limiting the oxygen supply.

DISCUSSION

Too great hydrogen ion concentration on the soil inhibits the oxidation of the organic constituents of the protoplasm of the plant cell. This may possibly be accomplished directly in a chemical manner, but it is more probable that the concentration of the hydrogen ion is so great as to inhibit action by the oxidizing enzymes which are present within the plant cells. It has been shown that cell solytions have a normal hydrogen ion concentration slightly different from that needed for the action of enzymes, Atkins (1). In all probability when the oxidation processes are going on, the cell solution has a hydrogen ion concentration conducive to activity of the oxidizing enzymes. Koehler and Reitzel (10), experimenting with tissues of rabbit, found that in simple chemical oxidation the hydrogen ion concentration plays an important role.

The accumulation of much experimental evidence shows that the hydrogen ion concentration of the soil solution may have some effect on the hydrogen ion concentration of the cell contents, although it is well known that a plant has a certain amount of selective power in absorbing materials. This selective power is doubtless largely mechanical and does not alter the facts as presented. Theron (16), *studying the effect of the reaction of the solution on absorption,*

showed that decreased acidity of the solution increases the rate of absorption of the cations. Excretion of carbon dioxide by the plant gives the plant a certain selective absorption power.

The concentration of hydrogen ion in which enzymatic action will continue has been found to be quite definite unually and very often a change of concentration may inhibit or even destroy enzymatic action. Bunzell (4), from experiments on oxidase activity, thought that the acid sensitiveness constant is the same, or nearly the same, for different genera of the same family of plants. From this it may be inferred that quite different plants contain oxidizing enzymes with quite different acid sensitiveness.

Since oxidation of carbyhydrates is considered to be necessary for the production of energy of growth and this oxidation is accomplished through the agency of enzymes which operate only under certain conditions of hydrogen ion concentration and this hydrogen ion concentration may be affected by the soil solution absorbed by the plant, it follows that the hydrogen ion concentration of the soil solution is of utmost importance.

It is clearly shown in a series of carnation cuttings using peat at the rooting medium. (Tables 4 and 5). In this series the cuttings in individual pots were treated with different solutions. All solutions used were .0001N. In no case did the hydrogen ion concentration reach a point wherein root growth might be expected judging from results obtained in other series. These cuttings were carried along for seven weeks without any sign of root development. (Table 4). They were then treated with a solution of sodium carbonate, .0003N. After one week it was found that the hydrogen ion concentration was still too great. Each pot was then given 1.5 cc of .1N sodium hydroxide and watered with a little distilled water. Two weeks later a number of cuttings had rooted and in each case where rooting occurred the hydrogen ion concentration was found to have been greatly decreased.

Furthermore, the activity of enzymes is greatly affected by temperature Not much is known as to the optimum temperature for plant enzymes. Experiments have been conducted on separate enzymes, but for the most part these have been on wine and beer fermenting enzymes and on those which are found in the animal body. However, the accumulation of evidence, Bayliss (2) , seems to indicate that enzymes operate within certain definite temperatures. Blagoveschensk (3) indicates the possibility of different strains of enzymes. It may be inferred that different strains are most active at different temperatures. If this is true, it offers a very good explanation of the fact that the cuttings of some plants require higher temperatures than do those of other plants. Where an optimum temperature for enzymatic activity is supplied, normal catabolic processes will function with production of growth energy and stimulation of roots

CONCLUSIONS

From the experiments recorded in this thesis the author has drawn the following conclusions:

(1) Hydrogen ion concentration of the rooting medium affects greatly the stimulation of roots on cuttings.

(2) The optimum hydrogen ion concentration may vary with different plants.

(3) The range of hydrogen ion concentration within which cuttings will root may vary considerably.

(4) The range for the rooting of cutting of carnation "Matchless" is quite limited,(pH 6.0-6.8).

(5) For carnation "Matchless" the optimum hydrogen ion concentration is that indicated by a pH value of 6.4.

(6) The range for the rooting of cuttings of other varieties of carnations will center at a hydrogen ion concentration indicated by a pH value of 6.4, but the limits may vary with different varieties.

(7) Experiments indicate that for Iresine and Coleus the range may be much wider than for carnations.

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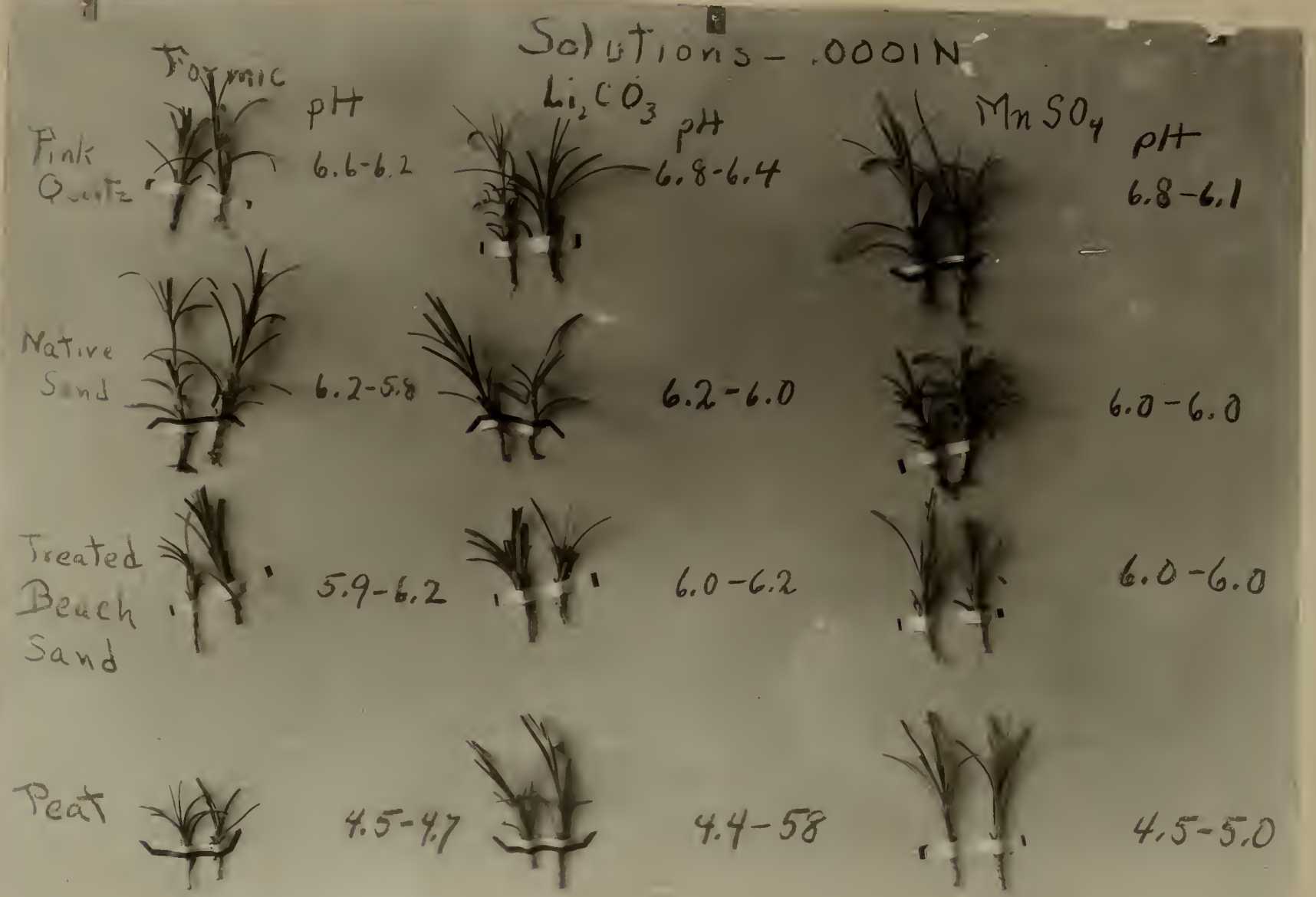
$MnSO_4$

Figure 2. Carnation cuttings. Representatives of two series of cuttings, summarized in Tables 6 and 7, are shown. The figure shows the difference in root development at different hydrogen ion concentrations. (Corrections in the figure should be noted. Under H_2SO_4, 5.7-5.0 should read 6.3-5.4; under $Fe_2(SO_4)$ 5.6-5.9 should read 6.2-6.0.)


Solutions — .0001 N
Li_2CO_3
pH
6.6-6.2
6.2-6.2
NaOH
pH
6.5-6.3
6.0-6.1
H_2SO_4
pH
6.5-6.1
5.7-5.0
$MnSO_4$
pH
6.5-6.2
5.8-6.1
HCl
pH
6.5-6.1
5.6-5.2
Na_2CO_3
pH
6.7-6.2
6.2-6.0
H_3PO_4
pH
6.4-6.1
5.8-5.9
$Fe_2(SO_4)_3$
pH
6.5-6.5
5.6-5.9
Acetic
pH
6.5-6.2
6.0-6.0
Pot. perm.
pH
6.7-6.2
6.0-6.1

Figure 3. Carnation cuttings. This shows root development under stimulus of various hydrogen ion concentrations. Note that no roots appear, regardless of the solution used, where the hydrogen ion concentration is greater than that indicated by a pH value of 6.0. On the other hand, root development occurs when the hydrogen ion concentration is less than that indicated by a pH value of 6.0, no matter what solution is used.


Solutions – .0001N
Formic
pH
Li_2CO_3
pH
$MnSO_4$
pH
Pink Quartz
6.6-6.2
6.8-6.4
6.8-6.1
Native Sand
6.2-5.8
6.2-6.0
6.0-6.0
Treated Beach Sand
5.9-6.2
6.0-6.2
6.0-6.0
Peat
4.5-4.7
4.4-58
4.5-5.0