ACID TOLERANCE OF STRAWBERRY PLANTS

Thesis for Degree of M. S.

Laval Sidney Morris

1926

THESIS

Stravinsky

Title

Horticulture – fruit-culture

ACID TOLERANCE OF STRAWBERRY PLANTS

BY

Laval Sidney Morris

-ooOoo-

A Thesis

Submitted to the Faculty of the Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of Master of Science.

- ooOoo -

Department of Horticulture

East Lansing, Michigan

1926

Approved June 1, 1926. V. R. Gardner.

THESIS

ACID TOLERANCE OF STRAWBERRY PLANTS

Introduction

Strawberries rank first in importance among the small fruits. Due to their high quality as a fruit and their wide adaptability both to climate and soil conditions they are grown extensively in many parts of the United States. The fourteenth census of the United States--1920, v. 5--gives the area of strawberries in 1919 as 119,395 acres, and the value of the crop as $36,004,245.00.

It has been frequently stated in horticultural literature that strawberries require an acid soil. This belief has been based upon the fact that many wild strawberry beds are found growing on acid soils.

Review of Literature

In 1912 Wright (24) sent out a circular letter to prominent growers asking for the results of any experience that they may have had with liming strawberries. Replies were received from twenty-nine growers who had made observations. Of this number six had secured favorable results from liming; twenty-three reported unfavorable results. Wright states, "Of 100 or more tests of soils in New York, Michigan, and Pennsylvania where wild strawberries, blackberries and black raspberries were growing, luxuriantly, practically all gave an acid reaction with litmus and none gave an alkaline reaction." His experiments showed that in most cases liming an acid soil was harmful to strawberries. However, twice out of a series of pot culture experiments the limed plants produced more fruit, though the difference fell within the bounds of experimental error.

Hartwell and Damon (11) summarize the results of liming experiments with about 280 different kinds and varieties of plants at the Rhode Island Experiment Station. Some of those worked with, which were supposed to be acid-loving, were actually benefited by liming. Wheeler and Tillinghast (23) of the same station give a detailed account of the work on strawberries, subsequently summarized by Hartwell and Damon (11). In 1897 and 1898 Wheeler and Tillinghast grew three varieties of strawberries under four treatments: (A) Sulfate of ammonia, limed; (B) Sulfate of Ammonia, unlimed; (C) Nitrate of soda, limed; (D) Nitrate of soda, unlimed. In all but one instance the limed out-yielded the unlimed plots. They make the statement, "It is probable that on a soil but slightly acid lime would prove of little or no value to the strawberry and upon an alkaline soil one would reasonably expect it, if used in considerable quantity, to exert even a slightly injurious action. On very acid soils lime is nevertheless beneficial and particularly so if sulfate of ammonia and possibly other manures leaving acid residues are employed."

Beatty (2) cites experience in various states of the central West, which shows that moderate liming of acid soils is somewhat beneficial to strawberry plants.

Darrow (7) states that, "Experiments show that lime has a harmful effect upon the roots of strawberries. Lime may improve a poor physical condition but it should be added considerably in advance of planting.

There are a number of such general statements suggesting that lime is harmful to strawberries, current in horticultural literature, yet there is about as much evidence for lime as against it. Common sense would indicate that the liming of an extremely acid soil should prove beneficial to strawberries, though the opposite might prove true if the soil were neutral or only slightly acid.

Although data on the reaction best suited to other plants may have no direct application to the strawberry, the results of certain recent investigations with cultural solutions of known H-ion concentration are not without interest. A knowledge of the general behavior of certain plants growing in nutrient solutions is helpful in knowing what to expect from strawberry plants. Due to the many variables of soil cultures, physiologists have developed a recent practice to determine the acid requirements and acid tolerance of various plants in nutrient solutions. By varying the H-ion concentration of nutrient solutions it is a simple matter to determine the exact range of acidity plants tolerate under given conditions. The following are some of the findings of various physiologists on plants grown in nutrient solutions.

Alstine (1) using Shive's solution at different PH values found that soybeans died in nutrient media ranging from PH 3.2 to PH 3.6 and that buckwheat showed root injury in solutions ranging from PH 3.2 to PH 4.0. Soybeans growing in solutions that were only slightly acid soon showed chlorosis and died.

Hoagland (12) showed that barley seedlings did best in a solution with a PH 5.1 and that a concentration of PH 3.5 on the one extreme and PH 8.2 on the other were toxic. Reed (17) found that the roots of walnut seedlings were injured in two of Hoagland's solutions, i.e., PH 7.37 and PH 10.85, after 24 to 36 hours' exposure. When the seedlings were placed in a nutrient solution of PH 5.2 the roots recovered and grew well. He states, "It seems that injury is due to calcium starvation rather than high hydroxyl concentration."

Tarr and Noble (20) used three of Whittier's solutions, one Shreiner and Skinner solution, one Hartwell and Wheeler solution, one Knop solution, one Pefeffer, one Tottingham, one Shive and one McCall solution. Reaction values ranging from PH 3 to PH 9 were established by the addition of H_3PO_4 and NaOH. Seedlings of wheat, soybeans and corn were grown. A reaction of PH3 was prohibitive to growth in all cases. Wheat seedlings grew best in a solution with PH4, soybeans at approximately PH5, and corn behaved practically the same as soybeans. "Chlorosis was due to the insolubility of iron at all concentrations less than PH 6."

Crist (6) growing lettuce seedlings in Theron's solution obtained best growth at PH 5.

McCall and Hagg (16) grew wheat in sand cultures in which the reaction was varied by adding H_2SO_4 and K_2SO_4 or KOH. PH 3.06 to PH 3.56 solutions produced normally green plants. Plants growing in cultures with a lower concentration than PH 4.02 became chlorotic.

Salter and McIlvaine (18) found that best growth was obtained from seedlings of wheat, soybeans and alfalfa, when the reaction of the nutrient solution adjusted with H_3PO_4 and NaOH was PH 5.94. Corn did best at a reaction of PH 5.16.

Duggar (9) using a number of nutrient solutions in which were grown wheat, corn and field peas, found results similar to those already enumerated. Chlorosis took place in all cases where plants were grown in a solution above PH 6.

From the literature so far reviewed it will be observed that all the plants grown in nutrient solutions require an acid reaction of PH 3.06 to PH 5.94 for best development. It will also be noted that all the plants used are not supposedly "acid-loving."

When plants refuse to grow in a nutrient solution with a reaction below PH4 it might be concluded that H-ion concentration per se is the direct limiting factor. However, under soil conditions there may be various other limiting factors of growth, which accompany acidity, rendering it impossible to attribute the cause to any one factor. For instance Burgess and Pember (3) show that aluminum is responsible for toxicity in certain acid soils, and that less aluminum is taken in by plants when lime is added. They also present evidence showing that many plants which are able to grow normally in fairly high concentrations of H-ions in water - and sand-cultures, are unable to subsist in certain soils of similar or even lower H-ion concentrations.

Hoffer and Carr (13) found that aluminum and iron were the limiting factors of growth in certain acid soils in Illinois. To check with their soil observations they injected solutions of iron and aluminum salts and also a number of dilute acids into healthy corn plants. Most of the aluminum injections proved fatal, some iron injections were injurious, while only formic acid, out of seven acids, was harmful. They also present numerous data from other work to show that in certain soils aluminum compounds associated with soil acidity are more limiting to growth of some plants than acidity per se. However what might prove toxic to some plants may be beneficial to others. Coville (5) treated Rhododendron catawbiense seedlings with aluminum sulfate as a substitute for an acid growing medium and obtained beneficial results. The plants grew practically as well in their natural habitat. Thus it is seen that this problem of acid requirements and acid tolerance of plants is highly complex.

The Problem Stated

As shown by the review of literature, former work to determine the soil reaction tolerance of the strawberry has been of a cursory nature, the results of which are merely suggestive. The purpose of this investigation was to study the behavior of strawberry plants grown in media with various lime requirements and PH values. More specifically, the primary purposes were

(1) to determine whether or not strawberry plants require an acid medium, (2) to determine the acid and alkaline range (if there is an alkaline range) in which strawberries will grow, and (3) to determine the optimum PH value of certain growing media, for the plants, under given conditions.

It was a secondary aim to observe every peculiarity of behavior of strawberry plants subjected to various acid and alkaline conditions.

The first experiment was started in the autumn of 1923 and later ones were performed during the summers of 1924 and 1925. General observations concerning natural habitats and soil reaction in numerous cultivated plantations in Michigan, Utah and a few in Colorado were made at various times. There are three experiments and general observations discussed in this paper. The first experiment deals with soils to which were added various amounts of lime. The other two experiments have to do with strawberry plants grown in nutrient solutions, with various concentrations of H-and OH-ions.

Experimental Work

Experiment I: The purpose of this experiment was to study the influence on the growth of strawberry plants of liming certain soils known to be very acid.

I. DESCRIPTION AND METHODS: This work was started September 1, 1923. Two acid soils, a sandy soil and a muck, were employed. The sandy soil, with a lime requirement (Jones method) of 1864 pounds of $Ca(OH)_2$*, per acre was supporting a fairly dense growth of so-called acid soil plants. The muck had a lime requirement of 39,826 pounds per acre, and was supporting no vegetation. It was evidently too acid for even very acid-tolerant plants. However, blackberries, strawberries and other acid soil plants were growing at the edge of this area where presumably acidity was less extreme.

* The term lime in this paper refers to $Ca(OH)_2$.

A certain amount of each soil was divided into five lots and lime added to give a gradation in acidity from the original to a theoretical alkaline condition. Table 1 shows the amounts of lime added to the various lots to produce different theoretical degrees of acidity and alkalinity. The soil was kept moist to facilitate bacterial action, and thoroughly mixed to break up all particles of lime. In order to allow the soil and lime to come to a fair degree of equilibrium, before setting the plants, it was allowed to stand, with an occasional mixing, for six weeks. These soils were then employed as media for growing strawberry plants. Twenty-four five-inch pots each supporting one plant were used for each treatment. The plants were left exposed to outside conditions for six weeks after potting to become rooted and also that they might undergo at least a short rest period to insure growth, before being transferred to the greenhouse. Upon introduction to the greenhouse, one-half of the pots of both sand and muck were each fertilized with .5 gm. ammonium sulfate, .5 gm. potassium chloride and 1.5 gm. acid phosphate. This was for the purpose of determining whether the plane of nutrition materially influences the harmful or beneficial influence of certain degrees of acidity. The plants were watered uniformly as possible whenever it was needed.

Notes were taken from time to time on the condition of the plants during the course of the experiment; and final records including soil reaction were made at the conclusion of this experiment, June 28, 1924.

2. <u>RESULTS</u>:

The results of this experiment are summarized in Table 1. The following notes are explanatory.

Table 1. Influence of lime and fertilizer applications to two acid soils on initial and subsequent lime requirements and on plant growth.

Soil	Soil	Initial lime requirements (lbs.per acre)	Theoritical degree of satisfying lime requirements	Lime added per acre (lbs)	Lime requirements Nov. 15,1923. (lbs. per acre)	Lime requirements July 2, 1924. (lbs. per acre)	Total green wts. (gms)
Unfertilized	Muck	39,826	0	0	32560	19240	56.2
			1/3	13,275	19240	8995	72.2
			2/3	26,550	13320	2331	80.2
			3/3	39,826	5920	1998	63.1
			4/3	53,100	2368	666	63.6
Fertilized[1]	Muck	39,826	0	0	32560	----	Plants dead
			1/3	13,275	19240	8658	100.9
			2/3	26,550	13320	4985	59.0
			3/3	39,826	5920	1323	80.1
			4/3	53,100	2368	666	64.3
Unfertilized	Sand	1864	0	0	2664	0	-
			1/3	621	1332	0	-
			2/3	1242	532	0	-
			3/3	1864	532	0	-
			4/3	2485	666	0	-
Fertilized[1]	Sand	1864	0	0	2664	0	-
			1/3	621	1332	0	-
			2/3	1242	532	0	-
			3/3	1864	532	0	-
			4/3	2485	666	0	-

1. The fertilizer treatment consisted of .5 gm. ammonium sulfate, 1.5 gm. acid phosphate and .5 gm. potassium chloride added to each pot.

Practically no growth took place by any of the plants during the first four weeks after being transferred to the greenhouse. All the plants in the unlimed, fertilized muck soil died during the first ten weeks. The plants in the unlimed, unfertilized muck were very sickly during the first eight weeks but gradually developed new leaves. The plants in the limed muck and sand started to grow before those in the unlimed soil. During the early

part of the experiment the plants which received heavy applications of lime did the best, while towards the end there was very little difference in the general appearance of the plants in plots which had received various amounts of lime. However, table 1 suggests very strongly that liming the unfertilized muck had a decided influence upon the weights of the plants. It will be observed that the twenty-four plants produced in the unlimed unfertilized muck weighed 56.2 gms. As compared with 72.2 gms. and 80.2 gms. the weights of plants grown in muck whose lime requirements were one-third and two-thirds satisfied, respectively. Thus the applications of lime were beneficial up to 26,550 lbs per acre. Where the applications of lime were 39,826 lbs and 53,100 lbs per acre the plants were no better than where no lime was added. This difference is due apparently to applications of lime which were too heavy.

The only conclusion to be drawn from the results on the muck soil which received fertilizer is that the fertilizer without lime was very harmful. The plants grown in the sand were not weighed because all the sand tested neutral at the end of the experiment.

The fact that all of the soil became less acid is interesting. The sand, regardless of previous treatment was entirely neutral, perhaps due to only a slight initial degree of acidity. This decrease in acidity may have been due to at least three causes: (A) The water used was highly charged with $CaCO_3$ which to some extent would be deposited in the soil. (B) Liming and aeration would make possible the propagation of a soil flora which destroy certain organic acids (10). This statement verifies the popular assumption that it is well to apply lime to soil sometime previous to planting the crop. (C) Leaching would wash out some of the acid content in spite of caution to avoid excessive watering.

There seemed to be a correlation in the rate of growth of the plants and decrease in acidity of the soil up to a certain point.

This experiment shows that strawberries were actually benefited by liming an extremely acid muck, and that lime did not seem to interfere with growth of the plants grown in a moderately acid sand.

Experiment II.

Since soil acidity is so complex and the factors involved are so difficult to deal with satisfactorily, either individually or en masse, in work of this kind, it was decided to grow strawberry plants in nutrient solutions maintained at different P H concentrations.

1. <u>Description and Methods</u>.-- A modification of Hoagland's solution, presented in table 2 was used.

Table 2.--Composition of Nutrient Solutions Used in Experiment 2.

K_2HPO_4	KH_2PO_4	$MgSO_4$	$Ca(NO_3)_2$	Na Cl	P H
7.0 cc	------	.3cc	1.0cc	.3cc	7.5
3.0 cc	6.0cc	.3cc	1.0cc	.3cc	6.4
1.0 cc	8.0cc	.3cc	1.0cc	.3cc	5.7
-----	9.0cc	.3cc	1.0cc	.3cc	4.4
3.cc1% H_3PO_4	4.0cc	.3cc	1.0cc	.3cc	3.6

Note: The above amounts refer to molecular solutions and were added to one liter of water.

The table shows that four degrees of acidity and one of alkalimity were employed. Quart mason jars, fitted with cork-stoppers (Figures 1 to 5) each containing two holes to support strawberry plants were employed. Sixteen plants were used in each solution.

Young plants selected for uniformity of size and vigor, and which were still attached to the mother plants were used. The plants were severed from the ones to which they were attached by runners, carefully lifted, so as not to injure the roots, and washed in tap water. The plant roots were then placed in tap water and allowed to stand over night that they might adjust themselves gradually to a somewhat abnormal growing medium. After rinsing the roots in distilled water, the plants were weighted individually, set in the cultural solutions and numbered.

It was the original plan to change the solutions every third or fourth day; however, the PH values remaining practically constant longer than was expected, changes were made only once a week. The PH values were tested at the beginning with a type K Leeds and Northrup potentiometer, and afterwards at definite intervals, colormetrically.

The plants were set in the cultural solutions August 2, 1924 and grown four weeks and five days.

2. <u>Results</u>.--

The data obtained from this experiment are given in table 3. Figures 1 to 5 inclusive show the condition of the roots three weeks after the plants were set in the solutions

Table 3. Gain in wt., gain in leaf area and condition of plants in Experiment 3.

PH Reaction of sol	Mortality (percent)	Total gain in green wt. (gms.)	Average gain in green wt. (gms.)	Total gain in leaf area (sq.Cm)	Average gain in leaf area (sq.Cm).	Remarks.
7.5	37.5	13.26	1.33	113.48	11.35	Plants sickly, young leaves chlorotic, roots brown, declining at and of the experiment.
6.4	18.7	29.27	2.25	419.76	32.29	Young leaves slightly Chlorotic, but fairly vigorous; roots white, healthy, medium length.
5.7	0	39.76	2.48	782.5	48.9	Plants normally green, vigorous; roots well developed, laterals longer than any others.
4.4	18.7	6.42	.49	453.19	34.86	Plants normally green, not vigorous; roots white, short laterals poorly developed.
3.5	31.2	2.96 lost	---	34.17	3.11	Plants sickly, lost in weight, a few small leaves developed; roots dies under the solution, short roots developed at crown.

Note; Sixteen plants, in each degree of acidity were used.

3. Discussion.--

The data presented in table 3 together with figures 1 to 5 show conclusively that the plants grew best in PH 5.7 solution. All the plants lived in this particular lot and the largest average gain in weight took place here. The second best solution was apparently PH 6.4 where the mortality was 18.7 per cent, and the average gain in weight per plant was 2.25 gms. The plants grown in the solution with a reaction of PH4.4 were decidedly inferior to those grown in the PH6.4 solution. Singularly the average gain per plant in the PH7.5 solution was relatively higher than was expected; however, the plants were sickly and seemed to be declining rapidly at the end of the experiment.

Experiment III

This experiment, set up July 1, and concluded July 29, 1925, was for the purpose of again checking on the results of the solution cultures already described.

I. Description and Methods

Young Premier strawberry plants, of the current season's growth, were secured from the field as soon as roots had become one or two inches long. The plants were first set in clean sand for four days to promote greater root development and make possible more uniform selection. Sixteen plants to each degree of acidity were used. The plants receiving the same treatment were grown in a single three-gallon crock, fitted with suitable supports and set on a rotating table (figure 6) to provide uniform insolation.

Theron's (21) solution and titration curve were employed though it was necessary to modify his titration curve as the distilled water used contained different amounts of CO_2 at different times. Seven degrees of reaction ranging from PH3 to PH9, at definite intervals of one, were employed. The reactions of the solutions were kept practically constant by adjusting the desired PH value with normal solutions of HCl and NaOH twice daily. All testing was done colorimetrically.

Marsh and Shive (15) found that iron could best be supplied by adding small amounts to the cultural solutions to meet the apparent requirements of the plants. Consequently 1cc of a .5 percent solution of ferric citrate per liter of solution, was used alternately with the same amount of ferric tartrate at the beginning of each change of solution; and small additional amounts (a few drops) were added alternately each day.

It has recently been demonstrated by Trelease and Livingston (22) that climatic conditions have an influence on the salt proportion requirement. Consequently for the sake of completeness of record, temperature and humidity were recorded with a Fries hygrothermograph, regulated once a day with a standard thermometer and sling psychrometer; evaporation was measured by a Livingston white bulb-atmometer, and influence of light calculated by comparing the evaporation from a radio-atmometer and the white bulb-atmometer. Table 4 gives data on environmental conditions.

Table 4. Environmental Factors in Experiment 4.

Factors	July 1 to July 5	July 5 to " 10	July 10 to " 15	July 15 to " 20	July 20 to " 25	July 25 to " 29
Temp.(av night in F^{o})	70	70	66	63	60	66
Temp.(av day in F^{o})	83	84	83	79	77	72
Rel. Humidity(av night in %)	81	81	82	83	83	82
Rel. Humidity(av day in %)	46	46	51	50	49	59
W. Atmometer (av night in cc)	86.67	92.34	102.6	102.8	96.39	58.32
B. Atmometer (av day in cc)	106.4	114.4	124.8	125.6	122.4	72.8

The plants were weighed at the end of the experiment to determine the amount of growth made. Ash, calcium, iron and aluminum contents of the plants were determined by A.O.A.C. methods.

2. Results

Gains in weight and general conditions of the plants are given in table 5.

Table 5. Weights and general condition of plants in Experiment 4.

PH Value	Mortality	Total gain Green wt. (gms.)	Average gain Green wt. (gms)	Dry Wt. Tops	Dry Wt. Roots	Remarks
3.0	16					All died during first 12 days.
4.0	0	28.1	1.76	14.9	2.9	Plants normally green, apparently more variable than others; roots mostly vigorous, short laterals, some white, a few bluish. 5 to 13 cm long.
5.0	0	30.4	1.90	12.6	3.0	Plants normally green, vigorous; roots well developed, many short laterals, 10 to 13.5 cm. long.
6.0	1	32.6	2.17	14.3	2.7	A few young leaves slightly chlorotic, plants vigorous; roots have longer laterals than in PH4 or 5, slightly brownish, 10 to 15 cm. long.
7.0	1	25.6	1.71	12.6	2.1	Young leaves chlorotic, plants fairly vigorous; roots grew faster at first then turned brownish, 7.5 to 15 cm. long.
8.0	9	8.7	1.45	5.2	.7	Plants very sickly, growth was made early then tendency was to go backwards; roots dark brownish.
9.0	16					Plants lived longer than those in PH 3 solution, all were dead July 29; roots dark brown, slimy.

After five days the plants in PH3 solution had become sickly, the leaves were somewhat flaccid and the roots slightly darkened. Twelve days after the experiment had been set up all the plants in PH3 solution were dead. The roots had turned dark bluish black and were gelatinized. Figure 6 shows the dead plants in the PH3 solution July 12.

The plants in solutions PH4, PH5, PH8 and PH7 appeared to be very similar in development during most of the time. Table six shows that the differences in behavior between these four lots were not great.

There was a gradual weakening of the plants in PH8 solution, with very little growth taking place. The plants in PH9 solution started to die six days after being set in the nutrient solutions.

Table 6 gives the percentages, dry weight basis, of ash, calcium, and iron and aluminum.

Table 6.-- Ash, calcium, and Iron and Aluminum content of Plants, Dry wt. Basis.

P H	Ash percent		Calcium percent		Iron and Aluminum percent.	
Value	Tops	Roots	Tops	Roots	Tops	Roots.
3.0	--	--	--	--	--	--
4.0	13.660	17.450	1.471	1.376	.577	1.959
5.0	-- *	15.250	--*	1.269	--*	1.701
6.0	14.050	16.600	1.763	1.339	.549	1.649
7.0	12.700	21.350	1.574	2.129	.474	1.357
8.0	12.790	17.590	1.207	2.178	.569	1.240
9.0						

*Sample was lost.

There was a change in reaction in all solutions except the extremely acid one. The following data give the total amounts of HCL and NaOH required to keep the solutions at the desired PH values.

PH Value	Amount added CC
3	0
4	5.0 HCL
5	8.5 HCL
6	38.0 HCL
7	23.5 HCL
8	29.0 NaOH
9	60.0 NaOH

3. Discussion:

The two extreme limits of acid and alkaline tolerance of strawberry plants were reached. Although six of the plants in the PH8 solution survived the duration of the experiment, it seems certain that if the period of growth had been continued a little longer, this solution would have appeared in the record as the alkaline limit instead of the PH9 solution. The demarcation in behavior of the plants grown in PH4 and PH3 solutions is sharp. At first it was thought that a mistake had been made in the reaction of the PH3 solution but upon carefully checking the PH values this was not found to be the case. The plants grew well in a fairly acid solution -- PH4 -- but refused to grow and soon died when the concentration was any higher.

Best results were obtained in the PH6 solution; however, there was not a striking difference between the plants grown in the four solutions from PH4 to PH7 inclusive. Some data will be presented under "General Observations" to substantiate these data showing that acid tolerance is not limited to a narrow range.

The last column in table 7 shows that the roots absorbed iron in proportion to the degree of acidity of the solution. This was also apparent from the color of the young leaves. However not enough growth was made by the plants in PH8 solution for much chlorosis to develop. (Chlorosis did not show in the old leaves of any of the plants.) The reason for a higher percentage of iron and aluminum in the plant tops produced in PH8 solution, may be explained as being due to the very small amount of growth made by the tops, hence the original amounts would tend to remain constant.

There is no direct relationship between the calcium content of either the roots or the tops and the reaction of the nutrient solution or the tendency to become chlorotic. Growth, in this case, did not seem to be contingent on the amount of calcium within the plant.

General Observations

During the course of the laboratory experiments observations were made on the acid tolerance of both wild and cultivated strawberry plants growing in the field.

Numerous tests were made on the reaction of soils, where indigenous strawberry plants were growing. "Soiltex" (19) a solution of bromthymal blue dye, saturated to the neutral point with calcium hydroxide, was used for all testing. At the beginning the Jone's method for lime requirement determination was used to obtain a quantitative test, but later abandoned due to a lack of sensitivity. In some cases the Jone's method indicated a lime requirement of over 300 pounds per acre, which is of course a very light application, while 'soiltex' a very sensitive and accurate indicator, as far as quality is concerned, gave an alkaline reaction.

Practically all of the Michigan soils supporting a growth of wild strawberry plants gave an acid reaction with "soiltex." Over forty-five samples were tested in various parts of the state. In some cases the plants showed a very high degree of acid tolerance. One particular lot of strawberry plants were observed growing with blackberries at the edge of a muck area, the main part of which was so extremely acid (with a lime requirement of 23 tons per acre) that no vegetation could grow. The lime requirement of the soil where strawberries were growing, was eight tons per acre. It was found, however, that in many places the soil was only slightly acid. These observations support Wright's (24) findings. However in two cases the soil was found to be slightly alkaline. Possibly some old wall plaster had been dumped in these two particular places as they were in close proximity to recently constructed houses.

A few tests were made of soils supporting wild strawberry plants in the mountains of Colorado; all of which tested slightly acid. A few of the Utah soils, supporting wild strawberry plants, tested slightly acid while some were distinctly alkaline. The alkalinity was undoubtedly due to limestone formations adjacent to the soils.

Observations on cultivated plants.- Agricultural soils supporting strawberries were found to range from alkalinity to acidity. Of a number of Michigan soils tested, a few recently limed plots were alkaline, a number were neutral, while some were acid.

No cultivated acid soils were found supporting strawberry plants in Utah. Most of the soil tested was slightly alkaline; some was neutral. One plantation visited near Provo, Utah, had produced a crop of strawberries on the same soil for nine consecutive years. The soil tested alkaline. It will be remembered that the average life of a strawberry bed is not greater than three years. The success of this particular plantation is not explained by the reaction of the soil, but obviously the alkalinity has not been toxic. On the other hand a number of attempts have been made to grow strawberries in Millard Valley, Utah, the soil of which has the same alkaline concentration as Salt Lake soils where strawberries luxuriate. (See table 7) The plants in Millard grow for a short time and then die.

There are two possible explanations why strawberry plants grow in most Utah soils but refuse to grow in the Millard section:

(1) Because the alkalinity may be of a different nature, even though, as shown by table 8, the relative PH values of the two soils are the same. The causes of alkalinity in both cases are not completely understood.

(2) It seems, however, more logical that the real cause is a greater amount of soluble salts in Millard. Table 7 presents data pertaining to the alkaline and salt nature of the two soil types.

Table 7. Relative Alkaline Value and Salts Contentof Two Soils.

	Millard Soil	Salt Lake Soil
PH of diluted soil solution	7.2	7.2
Soluble Salts	182.60 P.P.M.	11.20 P.P.M.
Soluble Calcium (CaO)	10.85 "	2.01 "
Soluble chloride (cl)	65.00 "	.18 "
Soluble sodium (na_2O)	41.73 "	1.10 "
Soluble carbonate	none	none
	Strawberries die	Strawberries grow.

Note: In preparing the soil for analyses, it was treated as follows: Sifted through a 2 mm. sieve and the coarser pebbles discarded. 100 gms. of the soil and 100 cc. of freshly boiled distilled water were placed in an Erlenmeyer flask, shook occasionally for several hours, let stand over night and filtered several times through folded filters. It follows then that the PH values given are merely relative; it seems that the true alkaline values of a natural soil solution (before dilution) would be greater than PH 7.2.

The data in table 7 show that the soluble Salt (alkali) content of the Millard soil is over 16 times as great as that of the Salt Lake soil. This is also made apparent by the accululation of alkali salts on the surface of much of the Millard soil. Sarcobatus vermiculatus, an alkali tolerant plant, further describes the condition of the Millard soil by growing very profusely in it. It is apparent then that the failure of strawberry plants to grow in the Millard section is due largely to the high concentration of alkali salts and not to alkalinity.

GENERAL DISCUSSION.

There are many factors which might have an influence on nutrient and reaction requirements of plants in growing media. Climatic conditions may have an influence(22). The physiological nature of growing media is certain to play an important part. Plants in the extreme acid, Hoagland's solution, behaved very differently from plants in the extreme acid Theron's solution. In the former case short roots developed at the crowns of the plants, in the latter the plants died outright. Davis (8) statistically analyzing data from a number of important experiments showed that a one best solution for a particular species is quite impossible except under identically the same conditions. Thus emphasis is placed on the fact that it is beyond reason to state definitely that a given plant requires a certain H-or O H-ion concentration for best development without consideration of numerous contingent factors.

The investigation lends confidence to the view that in practically all agricultural soils reaction per se is not an important limiting factor in strawberry production. Rarely are agricultural soils so extremely acid that strawberries will not grow and do well. Exception to this rule might be taken in the case of a few mucks which support little or no vegetation. Furthermore strawberries grow and do well on neutral and even alkaline soils. (Alkali, however, is a different matter.) For some reason they seem to have little difficulty in securing iron in neutral or many alkaline soils, even though they do in cultural solutions of similar reaction. It follows then that there is seldom occasion for applying treatments to strawberry fields or to land to be planted in strawberries primarily to change the soil's reaction. Ordinarily it is other limiting factors which need corrective treatments in strawberry growing.

The popular notion that strawberries are acid tolerant and even acid loving is correct, but to say that strawberries require an acid soil is erraneous.

Summary

One experiment with soils and two experiments with nutrient solutions, adjusted to definite PH values, were performed to determine the acid requirements of strawberry plants. Field observations on wild and cultivated strawberries were made to study the reaction tolerance of the plants.

The findings of the ivestigation are as follows:

1. Strawberry plants grew better on an extremely acid soil which received an application of lime, than on the same soil which received no lime. At the end of the experiment there was practically no difference between plants grown in acid soil which received light, medium and heavy applications of lime; however, there was a noticeable difference during the early periods of growth.

2. All the soil, whether sand or muck or whether limed or unlimed, became less acid after being placed in the pots and the plants set. This is explained (1) by the application of tap water charged with $CaCO_3$ which would tend to neutralize the acid and (2) by making possible for a soil flora to destroy certain organic acids.

3. Experiments two and three show optima reactions of Ph 5.7 and Ph 6.0 respectively.

4. The roots of strawberry plants grown in the Theron nutrient solution contained iron and aluminum in proportion to the degree of acidity; the greater the H-ion concentration of the solution the more iron and aluminum were contained by the roots.

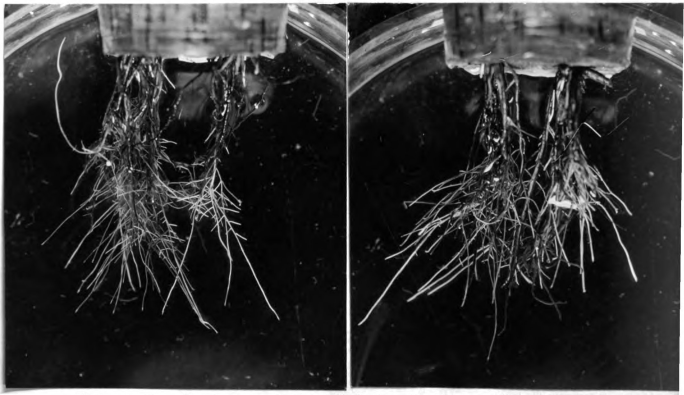
5. Strawberry plants were found growing on both acid and alkaline soils.

6. It seems evident that reaction per se is not an important limiting factor in strawberry production.

Acknowledgements

The writer wishes to express his appreciation to Professor V. R. Gardner for many suggestions regarding the planning of the work and the organization of the manuscript; to Dr. J. W. Crist for assistance with the technique of the solution cultures; to Professor R. E. Loree for assisting in caring for the plants; to Professor W. Dutton for helping with the photography, and to other members of the Department of Horticulture for assistance at various times. Special mention is also due the Experiment Station Chemists for making a number of analyses.

Figure 1. Roots grown in PH 7.5 solution. Exp. Two.



Fiture 2. Roots grown in PH 6.4 solution. Exp. Two.

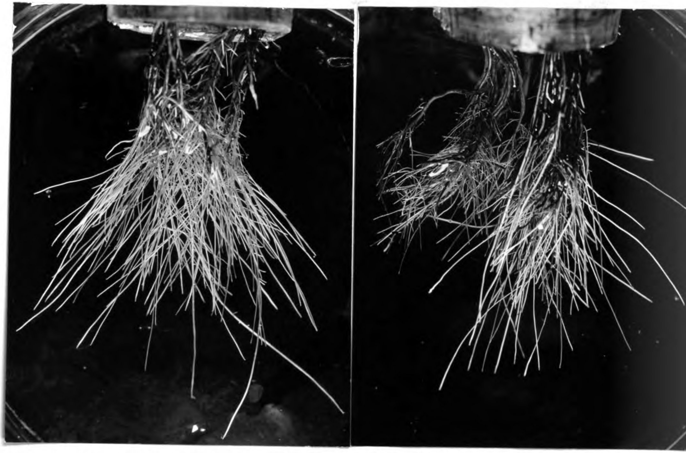


Figure 3. Roots grown in PH 5.7 solution. Exp. Two.

Figure 4. Roots grown in PH 4.4 solution. Exp. Two.

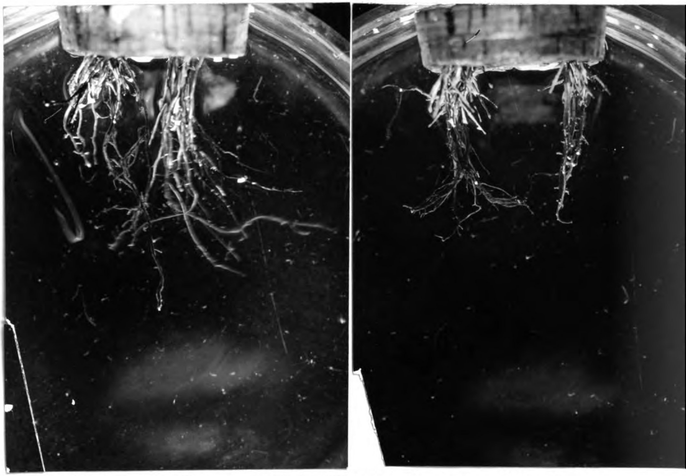


Figure 5. Roots grown in PH 3.5 solution. Exp. Two.

Figure 6. Arrangement of plants in experiment three. Picture taken after the experiment was started. The numbers on or near the plants represent the PH values of the nutrient solutions.

Literature Cited

1. Alstine, E. Van. The interrelation between plant growth and the acidity of nutrient solutions. N. J. Agr. Exp. Sta. Ann. Report p. 395, 1920.

2. Beatty, F. E. Market Growers Journal. 11:266, 1912.

3. Burgess, P. S. and Pember, F. R. Active aluminum as a factor detrimental to crop production in many acid soils. R. I. Agr. Exp. Sta. Bul. 194, 1923.

4. Carlsberg Lab. Report. The concentration of hydrogen ions in the soil. Abstract by O. Carsten. Science. 54.

5. Coville, F. V. The effect of aluminum sulfate on rhododendron seedlings. Am. Hort. Soc. Bul. 1. 1923.

6. Crist, J. W. Growth of Lettuce as influenced by reaction of culture medium. Mich. Agr. Exp. Sta. Tech. Bul. 71. 1925.

7. Darrow, G. M. Strawberry Culture. U. S. D. A. Farmer's Bul. 1026, 1923.

8. Davis, A. R. The variability of plants grown in water cultures. Soil Sci. 11:1, 1921.

9. Duggar, B. M. Hydrogen ion concentration and the composition of nutrient solutions in relation to the growth of seed plants. An. Mo. Bot. Garden 7:1, 1920.

10. Fraps, G. S. Agricultural Chemistry 158.

11. Hartwell, B. L. and Damon, S. C. The comparative effects on different kinds of plants of liming an acid soil. R. I. Agr. Exp. Sta. Bul. 160. 1914.

12. Hoagland, D. R. The effect of hydrogen and hydroxyl ion concentration on the growth of barley seedlings. Soil Sci. 3:6, 1917.

13. Hoffer, G. N. and Carr, R. H. Accumulation of aluminum and iron compounds in corn plants and its possible relation to root-rots. Jour. Agr. Res. 23:10, 1923.

14. Kurz, H. Hydrogen ion concentration in relation to ecological factors. Bot. Gaz. 76:1.

15. Marsh, R. P. and Shive, J. W. Adjustments of iron supply to requirements of soy beans in solution culture. Bot. Gaz. 79:1, 1925.

16. McCall, A. G. and Haag, J. R. The relation of the H ion concentration of nutrient solutions to growth and chlorosis of wheat plants. Soil Sci. 12:69, 1921.

17. Reed, H. S. and Haas, A. R. C. The effect of hydroxyl ion concentration on the growth of walnut roots. Am. Jour. of Bot. 11:2, 1924.

18. Salter, R. M. and McIlvaine, T. C. Effect of reaction of solution on the germination of seeds and on the growth of seedlings. Jour. Agri. Res. 19:73, 1920.

19. Spurway, C. H. Soiltex method for soil reaction. Mich. Agr. Exp. Sta. Quart. Bul. 6:93, 1924.

20. Tarr, L. W. and Noble, S. C. The effect of hydrogen ion concentration upon the growth of seedlings, Del. Agr. Exp. Sta. Bul. 131, Tech. 1, 1922.

21. Theron, J. J. Influence of reaction on inter-relations between the plant and its culture medium. Univ. of Calif. Pubs. in Agr. Sci. 4:413. 1924.

22. Trelease, S. F. and Livingston, B. E. The relation of climatic conditions to the salt proportion requirement of plants in solution cultures. S. C., N. S. 59:168. 1924.

23. Wheeler, H. G. and Tillinghast, J. A. The sixth year's observation upon the growth of plants upon an acid upland soil, limed and unlimed. R. I. Agr. Exp. Sta. Ann. Rpt. 11:144, 1898.

24. Wright, W. J. The injurious effects of lime on some small fruits. Proc. Soc. Hort. Sci. 9:14, 1912.