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Studies on the Reaction of Greenhouse Soils to the Growth of Plants

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STUDIES ON THE REACTION OF GREENHOUSE SOILS TO THE GROWTH OF PLANTS

W. W. WIGGIN AND J. H. GOURLEY

INTRODUCTION

Much has been written concerning the hydrogen-ion concentration in its relation to many branches of science. In agriculture, the lime requirements of soils and crops have been topics toward which a great deal of experimental work and discussion have been directed. More recently this work has been expanded until it includes the several types or causes of soil acidity. There is some disagreement among scientific soil workers as to the number of important types of soil acidity. Practically all agree, however, that the hydrogen-ion concentration, the intensity of acidity, is one of the more important phases.

The work along agricultural lines has been confined largely to field crops, although a small amount of work has been done on truck crops and small fruits. This bulletin deals with hydrogen-ion concentration as it is related to greenhouse flowers and ornamentals.

CAUSE AND EFFECT OF ACID SOILS

Soils in their natural state are composed of a mixture of different materials and vary according to the character of the source and to the temperature and rainfall conditions to which they have been subjected. Agricultural soils are complex because of crop culture and because of the addition of fertilizers and organic matter to them.

In areas where the rainfall is sufficient, there is often a leaching out of a large proportion of the basic elements leaving an excess of acid compounds. This results in an acid soil.

An acid soil affects crops in different ways. Many crops, judging from the literature, seem to have an optimum reaction at which the best growth is made; hence, if the soil is either too acid or too alkaline, plants do not grow at their best. The solubility of certain soil constituents is affected by the soil reaction. Also, acidity affects the growth of soil organisms in a variety of ways.

METHODS EMPLOYED IN STATING REACTION

Soil reaction has been stated in several ways. The simplest method is to designate whether a soil is "acid" or "alkaline." A simple test for these conditions is litmus paper. The degree of acidity or alkalinity, however, is not indicated by this test.

The term pH value, which is the common logarithm of the reciprocal of the hydrogen-ion concentration expressed in normality, is a convenient measure more generally used to express the reaction. A pH value of 7.0 indicates neutrality. A pH value of 5 indicates ten times as great hydrogen-ion concentration as pH 6, and pH 6 is ten times as great a concentration as pH 7. The acidity between pH 5.0 and pH 4.0 is many times more intense than that between pH 7.0 and pH 6.0; the same is true in the consideration of alkalinity.

To express the degree of acidity in familiar terms Wherry (27) has suggested the following:

pH 3.0—Superacid pH 4.0—Mediacid pH 5.0—Subacid pH 6.0—Minimacid	Increasing in acidity
pH 7.0—Neutral	Neutral
pH 7.0 to 8.0—Minimalkaline pH 8.0 to 9.0—Subalkaline pH 9.0 to 10.0—Medialkaline pH 10.0 to 11.0—Superalkaline	Increasing in alkalinity

A soil having a reaction of pH 5.0 is a very acid soil; whereas one having a pH 9.0 is very alkaline. Soil samples taken from greenhouses in many sections of Ohio have been in most cases within the range pH 5.0 to pH 8.0.

LITERATURE

SOIL ACIDITY

It is not the purpose of this bulletin to go into a discussion of the extensive literature pertaining to soil acidity. A brief sketch of the more important contributions should suffice. Since many phases of liming and soil reaction are still debatable questions among soil workers, only present tendencies and the more recent opinions of noted authorities on the problems are used.

One of the earliest phases of hydrogen-ion concentration investigations was a study of the effect of hydrogen and hydroxyl ions on crop growth.

Loew (15), Hartwell and Pember (13), Truog and Meacham (23), Joffe (14), Duggar (12), Conner (8), Connors (10, 11), Atkins (2), and Wherry (25, 26, 27, 28) worked with plants growing in soils and cultural solutions of varying hydrogen-ion reactions. They found that for the majority of cultivated plants tested, mostly cereal crops, there seemed to be a wide range of soil reaction that will support plant growth satisfactorily. The majority of plants tested showed a slight preference for slightly acid conditions. Native plant distribution, however, seems to be dependent to a large degree on the soil reaction, due to the keen competition among plants under natural conditions.

Salter and McIlvaine (20), Joffe (14), and others have reported the effect of varying soil reactions on the germination of seeds and the growth of the resulting seedlings. They found that the germinating seeds were less sensitive to the reaction of the growing medium than was subsequent growth. Germination was satisfactory in some cases in media with pH values as low as 2.96; the resulting sprouts were generally much smaller under the very acid treatments.

Miyake (17) reports that the toxicity of aluminum salts, as well as free acids, was the cause of infertile soils. Mirasol (16) concluded that aluminum is the determining factor in the acidity of soils. Conner (8) studied the relation of liming to the injurious inorganic compounds in the soil and concluded that lime lessens the harmful action of these compounds by neutralizing their acidity; the hydrogen-ion concentration is thus decreased by precipitating many injurious soluble compounds. Aluminum, iron, and zinc compounds were made less soluble and less harmful by lime applications. He also suggested that on sandy and peaty soils phosphates should be applied in addition to lime to correct aluminum toxicity.

Stephenson (22) studied the effect of humus and buffer action on the hydrogen-ion concentrations of soils and noted that a large excess of pure lime carbonate (20 tons) brought the pH value to only a little more than 8.0, which seems to be about the limit of alkalinity produced by limestone. Blair and Prince (5) first recognized the possibility of assigning a definite lime requirement to a given pH value.

Baver (3) reported on several phases of the acidity problem: air-drying samples of acid soils did not materially affect the reaction, but it decreased the alkalinity with alkaline soils; grinding samples did affect the reaction. He found that the hydrogen-ion concentration varied throughout the year; it increased in acidity from May to September, returning to about the same pH value each spring. Rainfall also had an effect.

Conner, Morgan, and Conrey (9) summarize soil acidity in a very comprehensive manner, giving a description of the four recognized types, their effect upon plant growth, and the methods used for their determination. They say that "While a thorough laboratory investigation of an acid soil should include tests for pH, for exchange and hydrolytic acidity, and for active calcium, it is not practicable to do this in the field. For field work a determination of pH is probably the most satisfactory single test." They also state that "In general as the hydrogen ion concentration increases calcium decreases, and soluble aluminum increases. Hence, to a certain extent pH tests indicate the trend of the other factors."

In summarizing this work the writers found that opinion seems to favor the hydrogen-ion concentration test as the most valuable single test for determining the lime requirement of the soil. Detrimental effects on plant growth seem to be due, in a large part, to the toxic properties of some of the acid-forming substances in the soil, or to the deficiency of some elements, such as phosphorus, because of their unavailability in strongly acid soil solutions. Lime alone can raise the pH value only a little above 8.0. The majority of cultivated plants tested seem to have a wide range of soil reaction which is satisfactory for their proper growth. The majority of plants reported show a slight preference for acid conditions, although promiscuous liming has been a common practice.

FERTILIZERS

The literature pertaining to the residual effect of fertilizers on the hydrogen-ion concentration of soils is rather limited. Some disagreement is shown in the literature published, indicating that the complexity of the soil again enters into the problem with confusing results.

Veitch (24) reports that superphosphate and sodium chloride reduced the acidity slightly. Conner (7) reached the same conclusion. Bear and Salter (4) found that organic matter reduced the acidity. Nitrate of soda, superphosphate, manure, and lime also decreased the acidity when used alone or in combinations. Skinner and Beattie (21) found the same effect from the use of sodium nitrate, as did Pierre (19) working with sodium nitrate, calcium nitrate, and calcium cyanamide. Morse (18) found that superphosphate, nitrate of soda, and muriate of potash did not materially change the reaction in one field; whereas they all reduced the acidity in another series of plots given the same treatment. Calcium sulfate decreased the acidity in one series and increased it in the other. Calcium carbonate decreased the acidity significantly in both series.

Workers who have found increases in acidity from the use of fertilizers are Veitch (24) working with sulphate of ammonia; Bear and Salter (4) with sulphate of potash; Allison and Cook (1) with sulphate of ammonia; Skinner and Beattie (21) with calcium sulfate, iron sulfate, manganese sulfate, potassium sulfate, and superphosphate applied annually for a 5-year period. Skinner and Beattie also found that stable manure increased the acidity slightly. Morse (18) found an increase in acidity from the use of sulfate of ammonia, as did Pierre (19) with ammonium sulfate, ammonium phosphate, leuna-saltpeter, ammonium nitrate, and urea. Blair and Prince (6) working with soil cylinders report that the long continued use of superphosphate did not increase the soil acidity.

From the literature cited, it is evident that there has not been a great deal of work done in determining the residual effect of fertilizers on the reaction of the soil. Some of the results are found to be contradictory and the degree of change in reactions in many instances is not given. The slight changes in reaction might be misinterpreted under field conditions, due to the fluctuation in hydrogen-ion reaction at different seasons of the year as shown by Baver (3).

MATERIALS AND METHODS

During July 1927, a raised bench in one of the Experiment Station greenhouses at Wooster was filled with Canfield silt loam soil of medium organic matter content. This soil had a pH value of 5.0 at the time it was brought in.

The bench was 48 feet long and 7 feet wide and was divided crosswise into 8 equal plots, each plot, therefore, containing 72 square feet.

From an initial plot with a pH 5.0, an attempt was made to increase the acidity of each succeeding plot by 0.5 pH until a pH of 8.5 was reached. The range in pH of from 5.0 to 8.5 covered all the samples that had been found in the greenhouse soils in Ohio up to that time.

In the direction sheets for the "Morgan Soil Testing Set", directions are given for modifying the soil reaction, as worked out after extensive studies at the Connecticut Agricultural Experiment Station. Briefly, this method is to determine the pH value desired and to multiply the figure thus obtained by a given factor, the factor varying with the soil type and amount of organic matter that the soil contains. The result is the number of tons of limestone needed per acre to produce the pH value desired. Where hydrated lime is added to correct this deficiency, only enough should be added to carry the same amount of calcium as carried by the amount of limestone indicated.

Soil treated according to the method suggested eventually changed to approximately the desired reaction. However, several months elapsed before an approximately constant reading was secured in the plots from week to week. Light applications of aluminum sulfate to acidify the soil and of limestone to decrease the acidity were added from time to time to aid in obtaining the desired reaction in the plots.

Fig. 1.—Left. Cinerarias growing in soil with a pH 5.0 in a greenhouse bench. Right. Cinerarias growing in soil with a pH 8.5 in a greenhouse bench

On September 9, plants were set in the bench; a row or two of each kind extended the length of the bench and, therefore, ran through all of the plots. The plants had been grown previous to setting in the permanent plots in a soil of approximately the same reaction as was found in the plot in which they were grown to maturity. Carnations, snapdragons, calendulas, stocks, chrysanthemums, verbenas, and pot plants were used during the 1927-28 growing season. These plants in the several plots received identical care as to watering, fertilizing, and all cultural treatment, with the exception that more lime or aluminum sulphate was added as the need arose to keep the plots at the desired reaction.

Tap water was used for the watering at first but this was found to be so alkaline that rainwater collected from the roof of the greenhouse was substituted whenever it was available.

Nitrate of soda was used at the rate of 300 pounds per acre per application whenever the plants showed a need of a nitrogenous fertilizer, and superphosphate was added to overcome any possible toxic effect that might arise from the application of aluminum sulfate. An 18 per cent superphosphate was applied at the rate of 500 pounds per acre once each year. Nitrate of soda was used for the nitrogen fertilizer, as it changed the reaction of the soils a very small amount.

Individual plant records were kept. The flowers were cut when they reached the proper state of maturity for market.

The same soil was carried over to the 1928-29 growing season, and crops were planted and treated in a similar manner to those of the 1927-28 season. Due to the low humus content of the soil and the reductions in yield resulting from carrying the soil over in raised benches for the second season, the yields and growth were far below the average for the 1927-28 season but the results were comparable. At the beginning of the 1929-30 season, new soil from the same field location was placed in the bench. To this was added a one-inch mulch of German peat (pH 3.5) in an endeavor to improve the humus content so that the crops could be grown more satisfactorily.

A variety of crops was planted in the bench, as had been done for the two previous seasons.

The soil was sampled and tested for reactions at approximately 2-week intervals. A cork borer was used to get a sample of soil through the entire depth of the bench. Four samples were taken per plot, or at the rate of 4148 samples per acre.

The soil samples were tested both electrometrically with a quinhydrone electrode and colorimetrically with the La Motte set. The colorimetric method was used most extensively as it was found to be much quicker and did not vary a great amount from the readings secured by the electrometric method.

To determine the divergence between the two methods, samples of the plots, and in some instances two samples, were taken and given a key number. The samples were then tested by the two methods. The results are given in Table 1.

TABLE 1.—Comparison of Electrometric and Colorimetric Methods of Testing Greenhouse Soils

Plot No.	Reading colorimetrically	Reading electrometrically	2nd sample colorimetrically	2nd sample electrometrically	Differences in pH	
1	5.4	5.35	....	....	.05	
2	6.0	6.05	6.0	5.90	.05	.10
3	6.6	7.00	....	....	.4	
4	7.2	7.35	....	....	.15	
5	7.8	7.60	....	....	.2	
6	8.0	8.25	....	....	.25	
7	8.2	8.00	8.2	8.15	.2	.05
8	8.2	8.20	....	....	.0	

As is seen from Table 1 the greatest variation between the two methods is .4 of a pH; whereas the two samples of the same plot when they were sampled at the rate of 4148 samples per acre gave .05 pH and .15 pH values, respectively. There was no great error shown between the two methods of determination, within the reaction ranges used in these tests. Slight errors are found to arise in sampling the plots and testing them regardless of the methods used when the methods known at the present time are used.

DIFFICULTIES ENCOUNTERED IN MAINTAINING DEFINITE SOIL REACTIONS

Investigators generally have encountered a great deal of difficulty in maintaining definite soil reactions in field plots. Variations have been found due to many environmental factors. The season of the year, amount of rainfall, variations in depth of borings, and the amount of organic matter present all have an effect on the pH values.

An attempt was made to overcome these difficulties in this work. With soil on a raised bench, artificially watered, and kept at a uniform temperature through most of the growing season, the above difficulties should be partially alleviated.

This was true to a certain extent; yet it was found very difficult to hold the readings at a constant value. It required quite a period of time for the lime and aluminum sulphate to change the soil reaction. Fluctuations were also noted from time to time, varying with the crop grown. There also appeared to be a seasonal trend in the pH values, regardless of the nearly constant environmental conditions.

In soil plots in the greenhouse, investigators will encounter apparently unavoidable fluctuations. Approximate values can be maintained, but the complexity of the soil prevents constant reactions such as are possible in the liquid media studies reported.

An attempt was made to grow pot plants to a definite size in soils of an approximate pH value and then hold them for their final stage of growth in soils with a definite reaction. Due to leaching that is unavoidable in watering pot plants, it was found impossible to maintain satisfactory reactions in pots for any length of time.

The pots were abandoned and the plants were set in the raised bench as previously described for the cut-flower crops.

TABLE 2.—pH values in Plots on Raised Greenhouse Benches for the Season, 1927-1928

Plot No.	8-25-27	9-2-27	9-16-27	9-30-27	10-7-27	10-10-27	10-18-27	10-26-27	11-10-27	11-28-27	12-12-27	12-28-27	1-6-28	1-26-28	2-13-28	2-24-28	3-5-28	4-25-28
1.	4.4	4.6	5.2	6.2	6.2	6.2	6.2	5.8	5.4	5.8	6.4	6.6	6.0	6.2	5.0	5.2	5.4	5.4
2.	6.8	5.6	6.2	6.4	7.0	7.0	6.4	6.0	6.0	6.6	6.6	6.8	6.2	6.2	5.6	5.4	6.6	6.2
3.	7.0	6.2	6.6	6.8	7.0	7.2	7.0	7.0	6.6	7.0	7.0	7.0	5.4	7.0	6.4	6.2	6.8	6.8
4.	7.4	6.2	7.0	7.4	7.2	6.8	7.6	7.0	7.0	7.4	7.4	7.0	6.6	7.2	6.8	6.4	7.0	7.2
5.	7.2	6.6	7.0	7.0	7.4	7.0	7.4	7.2	7.4	7.0	7.8	7.4	7.0	7.4	7.0	7.2	7.2	7.4
6.	7.0	7.0	7.2	7.4	7.6	7.4	7.4	7.2	7.6	7.4	7.4	7.8	7.0	7.2	7.4	7.6	7.4	7.6
7.	7.8	7.0	7.6	8.2+	8.0	7.6	7.6	7.8	8.0	7.8	8.0	7.4	7.6	8.0	7.6	8.0	7.6	7.6
8.	7.0	7.4	7.4	8.2+	8.2	8.0	7.8	8.2	8.2	8.2	7.8	8.0	7.6	7.8	8.2	8.0	8.0	7.8

Aluminum sulphate to plots 2 and 3 on 9/16/27.
Sheep manure to all plots on 9/29/27.
Aluminum sulphate to plots 1, 2, 3, 4, 5 and lime to plots 7 and 8 on 10/18/29.
Aluminum sulphate to plots 1, 2, 3, 4, 5 on 12/7/27.
Aluminum sulphate to plots 1, 2, 3, 4, 5, 6 on 12/28/27.
Aluminum sulphate to plots 2, 3, 4, 5 on 1/26/28.

TABLE 3.—pH Values in Plots on a Raised Greenhouse Bench for the Season, 1928-1929

Plot	Reaction	7-25-28	8-1-28	8-24-28	9-28-28	11-16-28	11-30-28	12-22-28	1-2-29	1-23-29	2-2-29	3-7-29	3-15-29	4-12-29	5-9-29
1.	5.0	6.2	6.2	6.2	6.4	6.4	5.6	5.4	4.4	5.0	5.2	4.8	5.2	5.0	4.8
2.	5.5	6.6	6.6	6.4	6.8	6.6	5.8	5.8	5.4	5.4	6.2	5.2	5.2	6.2	5.4
3.	6.0	6.8	6.8	7.0	7.2	7.4	6.0	6.6	6.8	6.2	6.4	6.2	6.2	6.6	6.2
4.	6.5	7.2	7.2	7.2	7.6	7.6	6.2	6.8	7.0	6.6	6.6	6.4	6.4	6.8	6.6
5.	7.0	7.6	7.6	7.8	8.2	7.6	6.6	7.2	7.4	6.8	7.0	6.6	6.8	7.4	7.2
6.	7.5	7.6	7.8	8.0	8.2	8.0	7.0	7.4	7.8	7.6	7.2	6.6	7.6	8.0	7.6
7.	8.0	7.8	8.0	8.2	8.2+	8.2+	7.4	7.8	8.0	8.0	7.2	7.4	7.8	8.2	8.0
8.	8.5	8.2+	8.2+	8.2+	8.2+	8.2+	8.2	8.2+	8.2+	8.2	8.2+	8.2+	8.2	8.2+	8.2+

40 lb. manure added 6/15/28.
Aluminum sulphate to plots 1, 2, 3, 4, and 5 on 8/1/28.
Aluminum sulphate to plots 1, 2, 3, 4, 5, 6, and 7 on 4/26/28.
Aluminum sulphate to plots 1, 2, 3, and 4 on 1/28/29.

Plots have been treated with lime and aluminum sulphate in the outdoor flower gardens at Wooster for the two seasons. The pH readings secured have been extremely variable. As a result, only an approximation of the soil requirement could be given for the plants growing in these plots and is omitted here.

Table 2 gives the desired reaction, the amounts of chemicals applied (with dates), and the readings for the 1927-28 growing season.

The greatest variation was shown after the application of sheep manure on Sept. 29, 1927. Sheep manure is very quick and very definite in imparting an alkaline reaction to the soil; in fact, it was the most active of the fertilizers used. This change is no doubt due to the production of ammonia and it gradually disappears. Sheep manure was used in this instance as it was evident that both humus and nitrogen were needed by the plants. During the remainder of the 1927-1928 and 1928-1929 seasons nitrate of soda only was used. After working with peat moss as a soil modifier, it was found that it could be used safely in small amounts without noticeably changing the soil reaction. It was, therefore, used during the 1929-1930 season as a source of organic matter.

It will be noted that the most alkaline plots were constantly too low in alkalinity, and applications of lime overcame this very slowly. Also the very acid plots tended to be insufficiently acid. Therefore, rainwater was substituted for the tap water on plots 1, 2, 3, 4, 5, and 6. Tap water was continued on plots 7 and 8. The pH value of the tap water was around pH 7.12, although fluctuations were found in it from time to time.

From Table 2 it can be seen that it is difficult to modify the very acid soil used sufficiently to make it very alkaline by the use of lime although considerable time is allowed to do this. The water with the slightly alkaline reaction used on some of the plots tended to make the soil more alkaline. It will be found very difficult to maintain plots under conditions as described in this experiment without variations of from 0.5 pH to 1.00 pH in the plots.

Table 3 gives the results secured on the same soil during the 1928-29 season. Forty pounds of cow manure and five-tenths of a pound of superphosphate were added to each plot on June 6, 1928, previous to planting the chrysanthemums and pompons. Tap water was used on plots 7 and 8, with rainwater on the other plots when available. The results were very similar to those of the previous season. The more alkaline plots were nearer the desired reaction, with a tendency for all of the plots to be more uniform from one reading to another. It was also found necessary to apply aluminum sulphate to the more acid plots. These plots had a tendency to decrease in acidity from time to time.

The range between the desired reaction and that obtained was within the pH 1.0 limit as suggested, in the majority of readings.

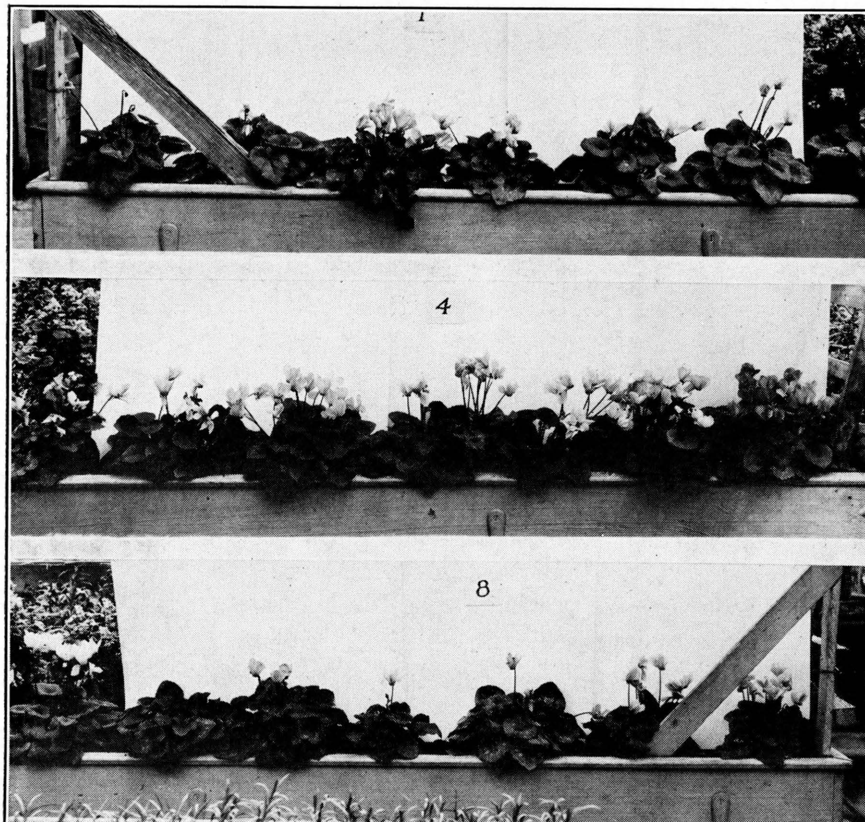

Fig. 2.—Cyclamen growing in a greenhouse bench in soil with pHs of 5.0, 6.5, and 8.5, respectively

EFFECT OF SOIL REACTION ON FLOWER CROPS

The following material deals with the effect of the different soil reactions on certain flower crops. As has already been shown from the review of the literature, definite soil reactions are required for some crops. The profitable commercial production of the crops has been taken as a basis for determining the crop response to the different reactions. If a crop can be grown in a range of reactions with sufficient success so that the crop could make a good commercial venture, that range of reactions should be considered satisfactory for the crop.

The soil reaction and the optimum and minimum growth of crops resulting from it are valuable and have been sought in this investigation. Due to the extreme complexity of soils, however, optima are difficult to ascertain definitely.

EFFECT OF SOIL REACTION ON CHRYSANTHEMUMS

Chrysanthemums were planted in the series of plots. Seven varieties of chrysanthemums were used during the tests. The tests were conducted for a 3-year period. During 1927 and 1928, the diameter of blossoms and the stem lengths were recorded. In 1929 diameters were not recorded; there was too much error in recording them to make the results significant, because the diameters of the blossoms change as they become mature. All plots were treated the same, with the exception of the applications of lime or aluminum sulphate as indicated. The plants were benched from the 10th to the 20th of June each year, out of 3-inch pots and grown there until mature. Six or twelve plants of each variety were grown.

Table 4 gives the reactions in the plots and the responses from the different varieties under the treatments given.

As seen from Table 4, neither the diameter of blossoms nor stem length was consistently affected. Stem length on an average of all varieties was the greatest on Plot 4 which had a pH of 6.5, or was only slightly acid. A good commercial yield was secured on all the plots, diameters of blossoms, stem lengths, and general growth being adequate for commercial purposes. Root development was poorer in the more acid plots. Color of flowers and keeping quality were not affected materially except in one instance—the white flowers in Plot 8 in 1928 turned brown on the outside tips of the petals and were unsalable very soon after expanding.

Chrysanthemum growers should avoid extremely alkaline soils for best results. Soil reactions between pH 5.0 and 8.2 have little effect apparently on the proper growth of this crop. Foliage color was somewhat darker on many varieties in the acid plots. Chlorosis was apparently more apt to occur under alkaline than under acid conditions with this crop.

TABLE 4.—Effect of Soil Reaction on Chrysanthemums

Plot No.	pH value desired	1927—Chrysolory			1928—Chatanooga			1929						
									Av. stem length of flowers					
		Av. pH value obtained	Diam. of flower	Stem length	Av. pH value obtained	Diam. of flower	Stem length	Av. pH value obtained	Detroit News	Gladys Pearson	Golden Glory	Glorious	Indian-ola	All vari-eties
			Inches	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1	5.0	5.62	5.1	37	5.70	5.2	45	5.0	35.3	38.7	30.3	26.5	27.5	31.66
2	5.5	6.31	5.1	36	6.16	5.2	43	5.4	38.3	42.8	32.9	28.8	30.8	34.72
3	6.0	6.72	5.5	35	6.72	5.2	42	6.2	36.3	43.9	28.0	28.0	33.3	33.90
4	6.5	7.03	4.8	34	7.00	5.0	42	6.6	39.3	43.9	36.1	32.1	32.1	36.70
5	7.0	7.20	5.2	37	7.38	5.1	44	7.0	34.1	41.6	31.1	30.1	32.3	33.84
6	7.5	7.37	5.2	34	7.66	5.7	45	7.4	33.9	35.3	30.3	32.3	30.0	32.36
7	8.0	7.73	4.6	36	7.86	5.7	46	7.8	35.3	40.3	32.8	29.8	29.8	33.60
8	8.5	7.88	4.8	36	8.20	5.4	44	8.2	38.5	38.5	32.6	27.9	31.5	33.80

TABLE 5.—Effect of Soil Reaction on Pompon Chrysanthemums

Plot	pH value	1927						1928							All varieties	
		Sunshine			Blanche			Mariana		Izola			Varsity			
		Av. pH value per plot	Av. shoots per plant	Av. stem length	Av. pH value per plot	Av. shoots per plant	Av. stem length	Av. shoots per plant	Av. stem length	Av. pH value per plot	Av. shoots per plant	Av. stem length	Av. shoots per plant	Av. stem length	Av. number shoots	Av. stem length
			Number	*Inches*		*Number*	*Inches*	*Number*	*Inches*		*Number*	*Inches*	*Number*	*Inches*		*Inches*
1	5.0	5.62	4.6	10	5.70	8.3	25	4.0	18.9	5.0	7.5	23	8.0	25	6.4	20.3
2	5.5	6.31	4.6	11	6.16	9.6	25	4.3	16.7	5.4	9.0	23	8.1	25	7.1	20.1
3	6.0	6.72	5.3	10	6.72	7.8	25	2.7	15.7	6.2	10.5	22	11.0	25	7.4	19.5
4	6.5	7.03	5.1	13	7.00	8.1	28	2.7	17.3	6.6	9.0	24	7.0	24	6.4	21.0
5	7.0	7.20	4.3	10	7.38	8.7	25	3.8	17.8	7.0	9.4	25	10.0	23	5.4	20.1
6	7.5	7.37	4.5	10	7.66	9.8	26	3.8	20.8	7.4	10.3	27	10.0	24	7.7	21.5
7	8.0	7.73	5.1	11	7.86	8.0	25	4.8	16.7	7.8	10.3	27	6.6	23	6.9	20.5
8	8.5	7.88	5.0	13	8.20	9.1	26	5.1	17.0	8.2	9.5	21	4.6	21	6.7	20.0

EFFECT OF SOIL REACTION ON POMPON CHRYSANTHEMUMS

Table 5 gives the results where pompon varieties of chrysanthemums were grown in the same soil reactions as the large-flowered type. Five varieties were used, extending over a period of 3 years. Twelve plants of each variety were grown to a plot. Both the largest average number of shoots per plant and the largest average stem lengths were secured on Plot 6, (pH 7.5) or slightly alkaline. They differed from the large-flowered type of chrysanthemum in that the maximum yield was secured at a different soil reaction but were similar in that a good commercial growth was secured on all of the plots. This, as with the large-flowered type, indicates little soil preference when extremes are avoided.

Root development was not as great in the more acid plots. Keeping quality of flowers and color were not materially affected by any of the treatments with the pompons.

EFFECT OF SOIL REACTION ON CARNATIONS

Table 6 gives the results of growth of three varieties of carnations planted on soils with different reactions. The test was carried on for two seasons. There were 12 plants of the Akehurst variety in 1927-28 and 6 each of Red and White Matchless in 1928-29. The yields per plant were very low when considered from a commercial standpoint. The soil, however, was a silt loam low in organic matter. As a carnation needs a lighter soil high in organic matter, the soil was not suitable.

There were no marked preferences in respect to soil reaction when judged by either yield of blossoms or stem length. There were good yields in acid, as well as alkaline, conditions; and length of stem growth showed no definite trends in soil preference. Slightly stiffer stems were secured on plots where lime had been applied. The keeping quality and color of the flowers were not affected significantly by the treatments.

It is evident that the carnation is not sensitive to the reaction of the soil unless extremes are encountered.

EFFECT OF SOIL REACTION ON SNAPDRAGONS

Table 7 gives the results of varying soil reactions on snapdragons. One variety was grown in 1927-28 and two varieties in 1928-29. Twelve plants of each variety were grown to a plot.

TABLE 6.—Effect of Soil Reaction on Carnations

Plot	pH value desired	1927–1928							1928–1929		All varieties	
		Akehurst				Red Matchless			White Matchless			
		Av. pH value per plot	Total flowers per plot	Av. diam. flowers	Av. stem length	Av. pH value per plot	Total flowers per plot	Av. stem length	Total flowers per plot	Av. stem length	Total flowers	Av. stem length
			Number	*Inches*	*Inches*		*Number*	*Inches*	*Number*	*Inches*	*Number*	*Inches*
1	5.0	5.62	95	2.4	21	5.70	57	17.2	39	16.3	191	18.2
2	5.5	6.31	107	2.6	22	6.16	66	17.9	57	16.6	230	18.8
3	6.0	6.72	95	2.6	21	6.72	51	17.5	51	15.9	197	18.1
4	6.5	7.03	113	2.5	22	7.00	57	17.6	36	16.7	206	18.8
5	7.0	7.20	105	2.5	22	7.38	33	18.6	39	15.5	177	18.7
6	7.5	7.37	88	2.5	22	7.66	84	17.1	57	16.5	229	18.5
7	8.0	7.73	90	2.4	20	7.86	57	17.1	54	16.4	201	18.8
8	8.5	7.88	117	2.4	21	8.20	33	17.3	30	16.3	180	18.2

TABLE 7.—Effect of Soil Reaction on Snapdragons

Plot No.	Desired reaction	1927–1928								All varieties	
		Orlando			White Rock			Orlando			
		Av. pH value per plot	Av. shoots per plant	Av. stem length	Av. pH value per plot	Av. shoots per plant	Av. stem length	Av. shoots per plant	Av. stem length	Av. shoots per plant	Av. stem length
			Number	*Inches*		*Number*	*Inches*	*Number*	*Inches*	*Number*	*Inches*
1	5.0	5.62	8.9	22	5.70	3.9	34	11.0	22.2	7.9	26.1
2	5.5	6.31	9.2	24	6.16	3.4	36	7.0	22.7	6.5	27.7
3	6.0	6.72	9.5	26	6.72	3.9	36	14.0	24.3	9.1	28.7
4	6.5	7.03	10.2	25	7.00	3.0	40	25.0	27.0	12.7	30.6
5	7.0	7.20	9.2	27	7.38	3.2	39	32.0	25.0	14.8	30.3
6	7.5	7.37	8.6	26	7.66	2.7	44	22.0	26.5	11.1	32.1
7	8.0	7.73	7.3	24	7.86	3.2	38	20.0	23.9	10.2	28.6
8	8.5	7.88	6.9	23	8.20	2.4	39	20.0	22.9	9.8	28.3

The Orlando variety was left in much longer in 1928-29 than in 1927-28 which accounts for the much larger yield of flowering shoots per plant. No appreciable differences were noted in root development or keeping quality or color of the flowers in the different plots. It will be noted that they respond in a manner very similar to the crops already discussed; that is, they prefer a reaction near the neutral point. The best growth of shoots and maximum yield, however, occurred on the slightly alkaline plots. On very acid soils at least, applications of lime would be beneficial.

EFFECT OF SOIL REACTION ON CALENDULAS

Table 8 gives the effect of the different soil reactions on calendulas. Two varieties were grown during the experiment, and 12 plants of a variety were grown for each of the two growing seasons. Root development was much retarded in plots 1 and 2, which were below 6.5 pH. The keeping quality of the flowers and the color were not materially affected by the different treatments.

As will be noted from the table, calendulas made the maximum growth and yield near the neutral points. They show a noticeable decline in the acid plots, but in general do not show a great deal of preference for any particular soil condition. Very alkaline conditions did not retard proper development in the calendulas as with many crops. Growing conditions appear to be satisfactory for the calendulas with a wide range of soil reaction.

GROWTH OF POT PLANTS AS AFFECTED BY SOIL REACTION

In the case of some pot plants, the results were more definite than with the foregoing crops, the most striking example being with the hydrangea. Greenhouse hydrangeas are of the order, Saxifragaceae. French and German hybrids are types popular at the present time.

The common difficulties encountered with this type of hydrangea is poor growth and a yellowing of the foliage. An effort was made to overcome these troubles by applications of nitrogen fertilizers and iron compounds, but to no avail, except for slight growth increases with the nitrogen. When hydrangeas were placed in the soil plats having different soil reactions, the results were soon apparent and marked.

TABLE 8.—Effect of Soil Reaction on Calendulas

Plot No.	Desired reaction	1927-1928						1928-1929			All varieties	
		Ball's Orange			Lemon Queen			Ball's Orange				
		Av. pH value per plot	Av. flowers per plant	Av. stem length	Av. flowers per plant	Av. diam. flowers	Av. stem length	Av. pH value per plot	Av. flowers per plant	Av. stem length of flowers	Av. flowers	Av. stem length
			Number	*Inches*	*Number*	*Inches*	*Inches*		*Number*	*Inches*	*Number*	*Inches*
1	5.0	5.62	5.7	19	5.6	3.13	12	5.70	9.4	17.0	6.8	16.0
2	5.5	6.31	5.4	18	7.2	3.29	12	6.16	8.5	17.8	7.0	15.8
3	6.0	6.72	6.3	21	6.5	3.27	12	6.72	12.0	19.8	8.2	17.6
4	6.5	7.03	7.1	20	6.6	3.19	12	7.00	11.0	15.2	8.2	15.7
5	7.0	7.20	6.3	18	6.6	3.25	12	7.38	14.0	19.8	8.9	16.6
6	7.5	7.37	5.8	19	7.4	3.46	13	7.66	13.0	17.4	8.7	16.3
7	8.0	7.73	6.7	18	7.4	3.61	14	7.86	13.1	20.1	7.8	17.3
8	8.5	7.88	6.3	18	7.5	3.25	13	8.20	12.1	18.5	8.6	16.5

Table 9 gives the results secured for the spring of 1928 when hydrangeas were grown in pots with soils of different reactions. These results were likewise secured in the field during the summer, but the plot reactions were not so carefully controlled as the greenhouse plots. Different soils in different parts of the State have since been used with comparable results. Thirty plants were grown under each treatment, with three replications. Caprice and E. J. Hill were the varieties used. Previous experience with the formation of blue hydrangeas had led to the conclusions that only white or light pink varieties should be planted in very acid conditions. Deep pink and red varieties, when grown on very acid soils, bear blossoms of a very unsightly color.

TABLE 9.—Effect of Soil Reaction on Hydrangeas

Soil reaction	Av. height of plant	Color of foliage	Color of blossoms
	Inches		
4.0 to 5.0	12.7	Very dark green	All blue.
5.0 to 6.0	12.1	Very dark green	Occasional blue.
6.0 to 7.0	10.3	Dark green	All true to color of the variety (pink).
7.0 to 8.0	7.6	Light green	All true to color of the variety (pink).
Above 8.0	4.5	Yellowish green	All true to color of the variety (pink).

From the data on height of plants in Table 9, it is seen that the hydrangea prefers an acid soil reaction, the color of foliage and the best growth being made on the more acid plots, and these desirable qualities diminishing as the soil becomes more alkaline. As shown, all of the flowers on the most acid plot were blue in color. An occasional blue flower was encountered at the range pH 5.0 to 6.0. The pH 6.0 to 7.0 plot gave flowers all true to color. Above the neutral point growth was very poor and not sufficient for commercial production. A grower with a little experience should determine the amount of aluminum sulphate or lime needed to produce the desired reaction in his soil under his soil and growing conditions. A good growth of foliage of dark green color is desired but only a small number of blue flowers are usually desirable.

The above results are in close accord with the results secured by Connors (10, 11).

Cyclamen showed a preference for acid conditions. Ten plants were grown to a plot with three replications for a 2-year period. Table 10 gives the average number of blossoms per plant for the two seasons and the length of blossom stems for the 1929-1930 season.

Fig. 3.—Cyclamen growing in soil of different reactions and treated at the same time with different fertilizing materials

TABLE 10.—Effect of Soil Reaction on Cyclamen

Soil reaction	Av. blossoms per plant 1928-1929	Av. blossoms per plant 1929-1930	Av. height of plants
	Number	*Number*	*Inches*
pH 4	31	22	10
pH 5	42	27	12
pH 6	25	26	11
pH 7	28	22	10
pH 8	10	17	9

A better growth of flowering stems and foliage accompanied the increased flower production on the pH 5 pots. Cyclamen showed a more decided preference for the acid conditions than the majority of plants tested.

Begonias, both *melior* and *gracilis* types, were tested over a 2-year period. No record was kept of the number of blossoms; the height of the plants was taken as the most reliable record. Table 11 gives these heights.

TABLE 11.—Effect of Soil Reaction on Begonias

Soil reaction	1928-1929		1929-1930	
	Melior, height	Gracilis, height	Melior, height	Gracilis, height
	Inches	*Inches*	*Inches*	*Inches*
pH 4	10	9	13	11
pH 5	12	12	15	13
pH 6	11	10	14	10
pH 7	10	9	11	9
pH 8	10	9	10	7

Although an increased growth was secured on the acid plots, all of the plots made a good commercial growth. Only extreme reactions were found detrimental to the begonias.

Calla lilies have been tested for two seasons. Three plants in 7-inch pots were used per treatment in 1928-1929; while six plants were used per plot in the 1929-1930 treatments. Three replications were made of each treatment. Table 12 indicates the results secured.

TABLE 12.—Effect of Soil Reaction on Calla Lilies

Soil reaction	1928-1929		1929-1930	
	Av. flowers per plant	Av. length flower stems	Av. flowers per plant	Av. length flower stems
	Number	*Inches*	*Number*	*Inches*
pH 4	4.2	19	3.3	23
pH 5	5.0	16	3.2	21
pH 6	4.4	14	2.7	18
pH 7	4.2	14	3.1	17
pH 8	4.0	14	3.0	18

Fig. 4.—Above. Chrysanthemums and Pompon Chrysanthemums growing in a slightly acid soil (pH 6.5)

Below. Chrysanthemums and Pompon Chrysanthemums growing in an alkaline soil (pH 8.0)

A slight preference is shown for the acid reactions, but a good commercial growth was secured in all cases, however, which would indicate a wide possible range in soil reaction.

Similar tests were made with ferns (Dwarf, Boston, and Teddy Jr.), Primula (*Malacoides* and *obconica*), cinerarias, geraniums, amaryllis, coleus, and fuchsias. Geraniums preferred alkaline conditions, as did the Primulas. The latter were very sensitive to extreme acidity, a marginal drying out of the foliage and a stunted growth resulting from too high acidity. The amount of trouble increased in proportion to the acidity. Cinerarias, ferns, fuchsias, amaryllis, and coleus preferred acid conditions. Cinerarias was the crop that desired the most acid conditions, then ferns, fuchsias, amaryllis, and coleus.

Fig. 5.—Above. Hydrangeas. The effect of soil reaction on growth of hydrangeas grown in pots in the greenhouse. Below. Geraniums. Growth was greatly retarded in the very acid soils

As indicated in the literature citations, investigators have found decided soil reaction preferences for certain crops. A check on the methods used was thought advisable. Thus, two crops, alfalfa and spinach, that are recognized as having a decided preference for alkaline conditions were grown in the plots in the fall of

1930. The results secured were very marked. The crops germinated very poorly in the most acid plot and the growth of both the alfalfa and spinach increased with decreasing acidity and increasing alkalinity as shown in Table 13.

TABLE 13.—Growth of Spinach and Alfalfa in Soils of Different Reactions

Plot No.	Av. pH value for plots	Spinach Weight in grams	Alfalfa Weight in grams
1	4.03	None; Seed failed to germinate	15
2	4.52	12	60
3	4.92	363	110
4	5.78	500	130
5	6.53	480	215
6	7.22	655	375
7	7.28	730	440
8	8.03	760	445

The results were convincing that the indifference and slight preferences shown by the majority of crops tested were not due to faulty procedure. Flower crops were not as sensitive to soil reaction as was the alfalfa and spinach, and other crops, as reported, show strong preferences for either acid or alkaline conditions. It is common knowledge, for example, that members of the plant family composing Rhododendrons, Azaleas, Vaccinium (blue berry), and others will not tolerate alkaline conditions.

DISCUSSION

The above report indicates that there is no specific soil reaction necessary for the successful growth of most of the commonly grown greenhouse flower crops. Extreme acidity or extreme alkalinity are both detrimental for the best growth, in most cases. In the majority of crops, there seems to be a slight depression in growth near the neutral point; the best growth was secured on either side of the neutral point. The majority of crops grown preferred somewhat acid conditions rather than alkaline. The use of lime promiscuously as a plant food material and soil modifier is a questionable practice.

Occasionally, extreme conditions are encountered. Where the soil or water used is very alkaline, the growth of such crops as hydrangeas, cyclamen, ferns, cinerarias, and the other crops showing an acid preference is accomplished with difficulty. By using rainwater from the greenhouse roofs (where no whitewash is applied on the outside) the difficulty arising from alkaline water is overcome. Applications of aluminum sulphate to the soil, in amounts depending on the original soil reaction, amount of organic matter present, and crop to be grown, will overcome the difficulties encountered by a too alkaline soil. The aluminum sulfate can either be mixed with the soil or put in solution after the crops are established. Where it is desirable to grow a crop that prefers an alkaline condition on acid soils, the difficulty can be alleviated by applications of lime in one of its several forms.

Fig. 6.—The effect of soil reaction on hydrangeas in the field. First plot very acid (pH 4.0); each plot thereafter diminishing in acidity, or increasing in alkalinity, by approximately one pH. The second plot (pH 5.0) produced the best foliage and general growth.

Growers, encountering difficulty with their crops, have been prone to blame the trouble on improper soil reaction. Occasionally this is true, but in the majority of such cases the soil reaction is not the limiting factor, and the reasons why this is so are apparent in the tolerance shown by the crops tested.

THE EFFECTS OF FERTILIZERS, SEASON, AND CROP GROWTH ON SOIL REACTION

Applications of some fertilizers to soil affects the soil reaction, due to residues. Some fertilizers increase the acidity, some increase the alkalinity, and others tend to have little effect. The reaction changes resulting from application of different fertilizers are very prompt in some instances; in others, very slow.

The following work was undertaken to determine these reactions, and the time required for the reaction to occur:

The fertilizers, in all cases, were scattered evenly over the soil surface, scratched into the soil, and the soil was then watered. Borings were taken through the depth of soil in the benches or beds. Readings were made by the colorimetric method.

Sheep manure, cow manure, sulphate of ammonia, nitrate of soda, air-slaked lime, superphosphate, bone meal, a 3-12-4 complete fertilizer, Vigoro (a commercial complete fertilizer), peat moss, standard slag, and combinations of several of the above materials were used in the tests.

The reaction of the plots was taken before the crops were planted, several times during the growth of the crop, and when the crop was removed. Readings were taken on plots containing carnations, chrysanthemums, pompon chrysanthemums, calendulas, and sweet peas, during two seasons of growth.

The data will be omitted as they are rather voluminous and only slight changes were encountered with most of the materials used. Some of the more pronounced changes will be mentioned.

Organic ammoniates, such as the sheep manure, increased the alkalinity of the soils to a considerable extent. The action was apparent soon after the material was added (24 hours in the case of the sheep manure), and the action continued for a considerable period of time, usually gradually diminishing with time due to nitrification. At the end of 5 months, plots to which sheep manure had been applied were still considerably more alkaline than the checks to which nothing had been added.

Growers should avoid heavy applications of these organic ammoniates on very alkaline soils, at least on crops that do not tolerate high alkalinity; or the materials should be applied a sufficient time in advance of the crops to allow for the nitrification of the ammonia.

Standard slag gave a markedly alkaline reaction, and the reaction remained high for the remainder of the tests wherever it had been used. Standard slag has been recommended as a soil modifier to lighten heavy soils and as a medium for rooting cuttings. As a means of reducing acidity, it apparently could be used with favorable results. When growing crops or rooting those that do not tolerate extreme alkalinity, the alkalinity of the slag should not be overlooked. Slag is sometimes used in the bottom of flower pots for drainage. This practice would be questionable in crops that do not tolerate extreme alkalinity, such as cyclamen.

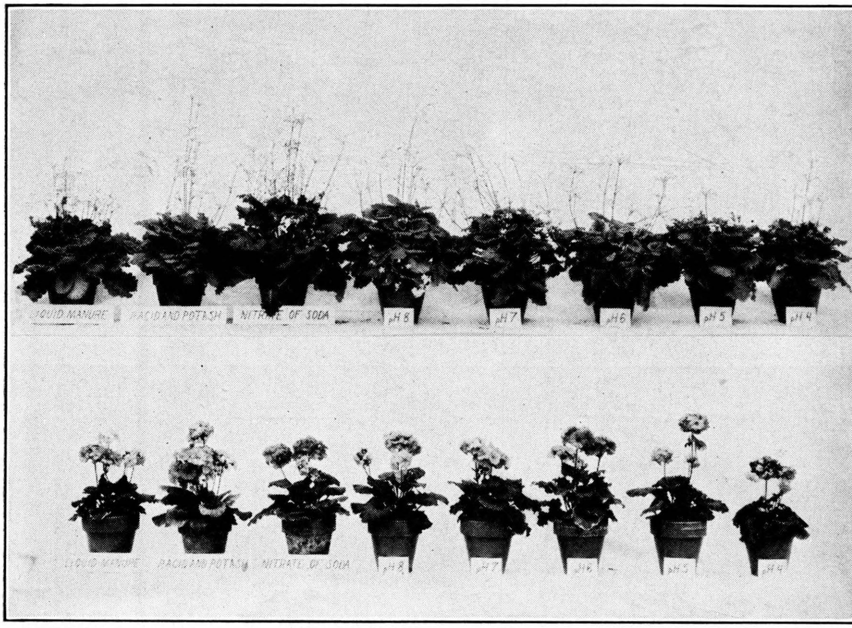

Fig. 7.—Primula malacoides and P. obconica, two crops that developed poorly in the very acid soils

Peat moss, particularly the imported brands, has a decidedly acid reaction, testing around pH 4.0 or less in many cases. Many authors of popular articles have advised the use of this acid peat moss as a means of acidifying the soil where an acid reaction is desired. Moistened, imported peat moss was added to the soil in some of the plots at the rate of one-fifth peat moss, testing pH 3.8, to four-fifths compost, that tested pH 7.4. A decrease in pH of only a fraction of a degree was noticeable as a result. The effect might be due to the great absorptive properties of the peat moss or to its buffer action. Peat moss has been used as a soil modifier on hydrangeas, which prefer an acid medium, with favorable results at Wooster. Domestic peats vary considerably in their reaction as they are generally surface or near-surface products.

Air-slaked lime caused the plots to become much more alkaline, as would be expected.

There were no significant changes in reaction that could be attributed to the remainder of the fertilizer treatments tested. Sulphate of ammonia, Vigoro, and straw mulches showed a slightly acidifying tendency. The trend of the plots containing nitrate of soda was toward increased alkalinity. These were only fractions of a pH unit and were in close proximity to the neutral point which would indicate little excess of anions or cations remaining in the soil.

Flower growers often have the opinion that certain fertilizers can be added to the soil to change its reaction for certain crops. Sulphate of ammonia would apparently be a better source of nitrogen than nitrate of soda for the acid-preferring hydrangeas, if the fertilizer were to be used in relatively heavy quantities or over a long period of time. Fertilizers cannot be used to modify soil reactions to any considerable degree, with the exceptions stated above.

There was a tendency for all of the plots to become more acid during the summer months, doubtless due to nitrification. However, from early fall, there was a tendency for the alkalinity to increase until the following summer, due to ammonification. These changes at different seasons add to the difficulty of maintaining definite reactions in plots.

The plots on which calendulas were grown increased in alkalinity above the average for the check plots in general; whereas the snapdragon plots became more acid. The other crops showed tendencies to change the reaction but they were not as striking as the crops mentioned. This is further proof that some crops are able to absorb more cations or anions than other crops.

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