THE EFFECT OF CERTAIN COLLOIDAL
SUBSTANCES ON THE GROWTH
OF WHEAT SEEDLINGS

A THESIS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF CORNELL UNIVERSITY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

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DAVID STOUT JENNINGS

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THE EFFECT OF CERTAIN COLLOIDAL SUBSTANCES ON THE GROWTH OF WHEAT SEEDLINGS¹

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The power of a soil to retain water against the force of gravity, to counteract the bad odors of decaying organic matter, and to modify the concentration of a solution with which it is in contact, is due wholly or in part to the phenomenon of absorption. Since the chemical composition of the soil is so complex it is difficult to ascertain to what extent the process of absorption from solution by the soil in a given case is chemical and to what extent it is physical. The absorption by some of the relatively insoluble soil constituents such as silica, and iron and aluminum oxides is probably physical and is termed adsorption. Within the last few years considerable work has been done pertaining to the absorption of salts and ions from solution by soils and other finely divided materials. Little attention, however, has been given to the effect this might have upon plant growth.

As a rule, adsorption is positive, that is, the concentration of a salt in the bulk of a solution is usually reduced by introducing absorbing surfaces into the solution. Consequently, the concentration of the salt at the interface is greater than that of the bulk. The object of this work was to attempt to answer the following question: Is the change in concentration due to solid adsorbing surfaces sufficient to modify the production of dry matter in a plant?

REVIEW OF LITERATURE

Gregoire (5) grew barley to maturity in Detimer's nutrient solution to which was added three-tenths of a per cent of silica in one treatment, and the same per cent of aluminum oxide in another treatment. Solution cultures were used as checks. There was a decided increase in the yield of dry matter in the silica cultures, and an increase in the case of the aluminum oxide cultures, but less than for the silica. More than 43.5 per cent of the ash of the plants from the silica culture consisted of silica, while less than 5 per cent of silica was present in the ash of the check. This author believes that the increase was due largely to the absorption of silica by the plants and its consequent utilization in growth. The ash of the plant in the alumi-

¹ A thesis submitted to the faculty of the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

num oxide culture contained 6 per cent alumina, while there was less than 1 per cent alumina in the ash from the check.

By growing wheat plants in solutions of several different densities, Lyon and Bizzell (8) showed that for the nutrient solution used the dry matter produced per unit of transpiration increased with the density. An increase in this ratio is considered indicative of greater density of the nutrient solution. They found that plants grown in crushed quartz had a lower transpiration ratio than when grown in nutrient solution of the same concentration. It appeared, therefore, that the actual densities in the region of the absorbing surface of the roots may be greater in the case of quartz. Plants grown in crushed quartz develop an abundance of root hairs and the root hairs come in intimate contact with quartz grains. It is possible, therefore, that the root hairs are in the absorbed layer, and are, therefore, feeding from a denser solution.

McCall (9) grew wheat plants in Shive's 3-salt solution when a solid medium representing somewhat the condition of the soil, but without the biological complications was present. He used a granite-ware pot provided with a pipe at the bottom for drainage. The solution was renewed every third day. The dry weights of the plants grown in the quartz sand were compared with those obtained by Shive. Sand cultures gave a greater dry weight. It is suggested by the author that the thickness of the adsorbed layer is less than the outer cell wall covering the adsorbing protoplasm, and since the absorbing protoplasm does not come in direct contact with this concentrated layer, the salts here are unavailable except in so far as the slow process of diffusion takes place.

It is also suggested in this article that selective adsorption may be an important factor in modifying plant growth. Thus the author calls attention to the fact that a better growth was produced in the sand than in the water cultures as the ratio of calcium nitrate to magnesium sulfate increased. This is explained by assuming that the NO_3 radicle produces a beneficial effect, that the magnesium sulfate antagonizes this effect, and that the magnesium sulfate more than the NO_3 would be adsorbed by the sand, and, therefore, less magnesium sulfate would be present in a condition to antagonize the favorable influence of the nitrate radicle. The results giving rise to this suggestion are subject to criticism since there is no record of the treatment having been duplicated.

Gile and Carrero (3) grew rice plants in acid, neutral and alkaline nutrient solutions when supplied with 0.002 gm. and 0.008 gm. of iron per liter from the following sources of iron: ferrous sulfate, ferric chloride, dialyzed iron, ferric citrate, ferric tartrate. The dialyzed iron was prepared by the ordinary method. It was entirely inadequate for the plants, for they were strongly chlorotic at all times.

Negeli (10), Dandeno (2), True and Oglevee (12, 13), Breazeale (1), Livingston (7), Jensen (6), and others have shown that the introduction of

finely divided substances like carbon black into nutrient solutions causes increased growth. This effect has been attributed to the action of the solid on certain organic and inorganic toxins.

True and Oglevee (13) advanced the theory that the adsorbing substances increase the growth rate by reducing the concentration of the toxic material, acting in the same way as the addition of water would by leaving a fewer number of ions or molecules in the free solution.

According to this theory it would be possible to introduce a solid substance into a nutrient solution and reduce the actual concentration of the solution in the region of the absorbing surface. If the theory is correct, this application is true, it being only necessary to select the proper adsorbent.

Dandeno (2) suggests that the increase in growth may be due to a decrease in the diffusion rate, while Jensen (6) adds a third possibility: viz., chemical change induced by the presence of the finely divided material.

The literature fails to give conclusive evidence as to whether the introduction of a solid adsorbent into a nutrient solution increases or decreases the density of that solution at the absorbing surface of the roots. The present work was intended as a contribution to this subject.

PLAN OF THE INVESTIGATION

Baker's analyzed salts were used in making up the nutrient solution. The salts were weighed and dissolved in distilled water, giving a stock solution for each salt. The following table shows the concentration and composition of each stock solution:

Calcium nitrate.....	216 gm. in 2000 cc. of water
Potassium chloride.....	60 gm. in 2000 cc. of water
Magnesium sulfate.....	48 gm. in 2000 cc. of water
Ferric sulfate.....	4 gm. in 1000 cc. of water
Mono potassium phosphate.....	60 gm. in 1000 cc. of water

A complete nutrient solution containing about 4500 parts per million was made up by adding 25 cc. of each solution to distilled water, as follows: The calcium nitrate and potassium chloride solutions were added to 250 cc. of distilled water. The ferric sulfate, magnesium sulfate and potassium phosphate solutions were diluted each with 175 cc. of distilled water and put in 3 different containers. The diluted ferric sulfate and magnesium sulfate solutions were mixed and then added to the potassium chloride and calcium nitrate mixture. Finally, the potassium phosphate solution was added and the mixture shaken. At the latter addition there was always a slight precipitation. The solution was not filtered but was always shaken thoroughly before using.

Galgals wheat was used. The method of germinating and growing the wheat up to the point of placing it under treatment was the same in all cases and was as follows: A few hundred clean seeds were placed in a wide-mouth bottle provided with a cork with one hole through which a piece of glass

tubing was inserted, one end reaching to the bottom of the bottle. The other end was connected with the water tap. By providing a cork too large or slightly too small, the water would run over the top without allowing the seeds to pass out. The seeds were always kept in running water for 48 hours. They were then transferred to a large floating disc and here kept in running water until four or five centimeters in height. This required about four days. The floating disc was a piece of stiff wire netting covered with paraffin. Many small holes were made in the paraffin to furnish a contact between the seedlings and water. Many more plants were grown to this stage than were required for the experiment, which made more easy a selection of plants of uniform top and root growth. Strong healthy plants were always selected for the cultures. The endosperms were carefully removed and 6 plants threaded into holes in a cork that would fit the container to be used. The threading was most easily done by carefully pressing the tops together and passing them into the hole, and then working the seedling into the desired position. Each cork with the 6 plants was then placed in the container filled with tap water. It appeared early in the work that the placing of the plants under treatment as soon as the endosperm was removed was not satisfactory, for many of the plants died under these conditions, while if kept in tap water for a short time they developed very well. Four small sticks placed in holes bored near the circumference of the cork and tied together by twine furnished support for the tops of the growing plant.

Wherever possible the distilled water which was to be used in culture work was treated either with carbon black or with precipitated oxide of iron or aluminum. This treatment of the distilled water consisted in adding 15 gm. of the material to a liter of water, shaking and allowing to stand for a few hours and filtering.

The hydroxides of iron and aluminum were prepared from the chlorides of these elements, by precipitation from solution by NH_4OH and then washing free of ammonium chloride. The iron hydroxide was used at the rate of 10 gm. of dry material calculated as Fe_2O_3 and the aluminum hydroxide at the rate of 8 gm. Al_2O_3 per liter of distilled water. They were kept moist and used in the same way as the carbon black. In the following discussion the term "treated" nutrient solution has reference to the distilled water used.

During the period that plants were growing under treatment, they were kept in the greenhouse at a temperature of about 55°F . during the night and 60°F . during the day.

At harvest the tops were removed and dried at a temperature of 90°C . In order to obviate lack of uniformity resulting from an unequal distribution of heat in the greenhouse, the relative positions of the cultures were changed at each weighing. The cultures were weighed or the solutions were renewed twice each week.

The following materials, all of which have been found by different investigators to adsorb from solution, were used in the present work: agar, silica, crushed quartz, and hydroxides of iron and aluminum.

Agar cultures

The agar solution was prepared by adding to the dry agar sufficient distilled water to make a 2 per cent solution and boiling the mixture in a double boiler for 2 hours. The resulting solution was then cooled to a temperature of 60°–75°C., and the proper amount of standard nutrient solution and distilled water added to give the desired dilution of nutrient salts. In the earlier part of the work a one per cent solution of agar was used, but difficulty was experienced in getting the tender roots of the wheat plants to penetrate this medium. It was found more satisfactory to use one-half per cent agar as the plant roots would easily penetrate this medium. After the agar medium had cooled to laboratory temperature the plants which had previously been selected and threaded into the corks were placed in the agar. Water cultures of the same concentration of nutrient salts were prepared as checks, the plants being placed in the water and agar cultures at approximately the same time. In certain of the cultures the solutions were not renewed but each culture was weighed twice each week and water added equivalent to the loss in weight.

In other cases the solutions were renewed by lifting the cork carrying the seedlings, discarding the old medium, rinsing the container, and adding 300 cc. fresh medium from stock solutions of the proper strength. The results of these experiments are given in tables 1, 2 and 3.

The results with agar were not entirely satisfactory, but the figures present some interesting indications. Referring to table 1, it will be seen that in concentrations of 500 p.p.m. of nutrient salts, agar was beneficial, while with a concentration of 2000 p.p.m. the agar was harmful. A similar effect may be noticed in table 2, where in the 500 p.p.m. solution, agar was beneficial while in the 1000 p.p.m. solution, agar was harmful. With the exception of the 85 p.p.m. concentration, more dilute solutions were benefited by agar, while the higher concentrations were injured. It is conceivable that with the more concentrated solutions the agar rendered the effective concentration at the surface of the particles so great as to become toxic to plants.

TABLE 1

Dry weights of wheat plants grown in solution and in agar cultures. Solution not renewed; volume of solution 930 cc.; each result the average of 4 cultures

TREATMENT	CONCENTRATION	PERIOD OF GROWTH	DRY WEIGHT			DIFFERENCE	
			Tops	Roots	Whole plant		
	p.p.m.	days	gm.	gm.	gm.	gm.	per cent
Nutrient solution + 1 per cent of agar.....	500	30	0.3240	0.1262	0.4502	+0.1740	62.9
Nutrient solution.....	500	30	0.1799	0.0963	0.2762		
Nutrient solution + 1 per cent of agar.....	2000	37	0.3011	0.1133	0.4144	-0.1098	-24.0
Nutrient solution.....	2000	37	0.3568	0.1674	0.5242		

TABLE 2

Dry weights of wheat plants grown in a nutrient solution and in a nutrient solution with 1 per cent of agar. Volume of solution 500 cc.; solution not renewed; each result the average of 4 cultures

TREATMENT	CONCENTRATION	PERIOD OF GROWTH	WEIGHT OF			DIFFERENCE	
			Tops	Roots	Whole plant		
	<i>p.p.m.</i>	<i>days</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>per cent</i>
Distilled water.....		18	0.0918	0.0311	0.1229		
Distilled water + agar.....		18	0.1239	0.0524	0.1763	+0.0534	+42.6
Nutrient solution.....	85	20	0.1643	0.0488	0.2252		
Nutrient solution + agar...	85	20	0.1494	0.0478	0.1972	-0.0280	-12.4
Nutrient solution.....	250	29	0.2367	0.0604	0.2971		
Nutrient solution + agar...	250	29	0.2790	0.0667	0.3457	+0.0486	+16.3
Nutrient solution.....	500	36	0.2721	0.0569	0.3290		
Nutrient solution + agar...	500	36	0.3217	0.0681	0.3898	+0.0608	+18.1
Nutrient solution.....	1000	36	0.4420	0.1076	0.5496		
Nutrient solution + agar...	1000	36	0.3075	0.0636	0.3711	-0.1786	-32.4

+ Indicates increase in agar culture compared with check.

- Indicates decrease in agar culture compared with check.

TABLE 3

Dry weights of wheat plants when grown for 5 weeks in a nutrient solution and in a nutrient solution to which was added 0.5 per cent agar. Solution renewed twice per week; volume of solution 300 cc.; concentration 750 p.p.m.

TREATMENT	LAB. NO.	WEIGHT OF		
		Tops	Roots	Whole plant
		<i>gm.</i>	<i>gm.</i>	<i>gm.</i>
Nutrient solution.....	80	0.4042	0.0905	0.4947
	81	0.5175	0.1133	0.6308
	82	0.4355	0.0858	0.5213
	83	0.6204	0.1401	0.7605
	84	0.5456	0.1198	0.6654
	85	0.5479	0.1479	0.6958
	86	0.4456	0.0839	0.5295
	87	0.5531	0.1179	0.6710
	88	0.5372	0.1239	0.6611
	89	0.4485	0.0923	0.5408
Average.....		0.5056	0.1114	0.6171
Nutrient solution + 0.5 per cent of agar.....	90	0.3951	0.0884	0.4845
	91	0.3786	0.0677	0.4363
	92	0.5104	0.0921	0.6025
	93	0.3970	0.0896	0.4866
	94	0.4119	0.0945	0.5064
	95	0.3629	0.0882	0.4511
	96	0.4551	0.0816	0.5373
	97	0.7340	0.1569	0.8909
	98	0.6323	0.1440	0.7763
	99	0.5562	0.0927	0.6489
Average.....		0.4829	0.0995	0.5824

Difference between the solution and agar cultures, -0.0347 gm. or - 5.62 per cent.

Silica cultures

Colloidal silica was prepared by dialysis following in general the method used by Graham (4). A preliminary test was made as follows:

With a pipette approximately 10 cc. of a 10 per cent solution of hydrochloric acid were measured into an Erlenmeyer flask. Sodium silicate (a 10 per cent solution) was slowly added from a burette while the mixture was shaken vigorously. As the sodium silicate increased, the mixture gradually became more viscous and finally set to a gel. The amount of silicate solutions required to form the gel was then noted. In preparing a quantity of the mixture for dialysis, only one-half to two-thirds of the total required sodium silicate solution was used. In a mixture of these proportions the silica will not set until the chlorides are reduced to a very small percentage.

Two kinds of dialyzers were used. A very efficient dialyzer was made by taking 5 feet of a heavy quality of parchment paper tubing, tying one end carefully and then telescoping it into a piece of glass tubing of a little less length but of somewhat greater diameter. The end of the glass tube containing the closed end of the parchment paper tubing was provided with a one-hole stopper and a short piece of glass tubing sealed into the hole in this stopper. One end of a rubber tube was then attached to the small glass tubing, the other end leading to a container of distilled water which furnished a head of three or more feet. The parchment paper was always soaked for two or three days in distilled water, and carefully tested for leaks. The solution to be dialyzed was run into the parchment paper tubing from the open end which was then tied and crowded into the glass tube. This end of the dialyzer, which was supported about two feet above the opposite end, was provided with a one-hole stopper and glass tubing for drainage to the sink. A constant stream of distilled water was then forced from the lower to the upper end, flowing outside of the parchment tubing and carrying the chlorides which diffused through the paper into the drainage. Such an arrangement exposes a large surface to a steady stream of water and therefore makes a very efficient dialyzer. As we were unable to obtain a sufficient amount of the parchment paper tubing for all the work with silica, a modified Stern dialyzer was also used. This consists of two pans each of about five liters capacity arranged so that a stream of distilled water comes in at the bottom of one, fills the pan and overflows evenly at the top. The other pan has parchment paper drawn tightly over the top and tied, and a hole made in the bottom large enough to insert a funnel. This pan is placed upon the first pan bottom up so that the parchment paper comes in contact with the water in the first pan. Dialysis begins at once when the mixture of sodium silicate and hydrochloric acid is put in the top pan. A few short pieces of filter paper laid between the two pans help to establish a uniform distribution of the water as it flows from the pan. About five liters could be dialyzed at one time with this apparatus which requires a period of nearly three weeks.

with the water running continuously. As dialysis continues, the viscosity of the sol gradually increases, finally setting to a gel. The extent to which the silica can be purified before setting depends, of course, upon the concentration of the silica. Thus in one case with 2.8 per cent of silica, gelation began when nearly 5000 p.p.m. of chlorides were present, while in another case with 1.5 per cent of silica, gelation did not begin until the chloride content was reduced to 700 p.p.m. The silica was never allowed to set firmly in the dialyzer, but was siphoned into a large container and then enough measured into the culture jars to give 1 per cent of silica when diluted to 500 cc. The dilutions were made from the standard nutrient solution or from this solution and distilled water. Before measuring the colloidal silica solution into the jars for the cultures, total solids and chlorides were determined and the latter calculated as sodium chloride. As it was not practicable to remove all chlorides from the silica, sodium chloride was added to the cultures containing no silica so that all culture media contained the same amount of

TABLE 4

Dry weights of wheat seedlings grown for 27 days in pure nutrient solutions and in nutrient solutions containing 1 per cent silica

TREATMENT	DRY WEIGHT OF TOPS	INCREASE DUE TO SILICA	
	gm.	gm.	per cent
Nutrient solution 85 p.p.m.	0.3627		
Nutrient solution 85 p.p.m. + silica 1 per cent..	0.4276	0.0649	17.8
Nutrient solution 250 p.p.m.	0.4594		
Nutrient solution 250 p.p.m. + silica 1 per cent.	0.5936	0.1342	29.2

sodium chloride. Wheat plants were selected, threaded into corks and transferred from tap water to the culture solutions in the manner described for agar cultures. Within two to three days the plants growing in nutrient solutions containing 1 per cent of silica were larger and had better color than those growing in pure nutrient solutions. This difference was maintained until harvest. The results of this experiment are given in table 4.

The weights of roots are not given in the above table since it was not always possible to make an accurate separation from the adhering gel.

The figures in table 4 show that the silica was decidedly beneficial to the wheat seedlings. It occurred to the author that the effect might be due to increased absorption of silica by the plant. Determinations of silica in the seedlings showed that the suspicion was well founded. The data may be seen by reference to table 5. An attempt was made to obviate this disturbing factor by introducing into one set of cultures 50 p.p.m. of colloidal silica, on the assumption that this amount would supply the requirements of the plant for silicon. Accordingly, three sets of cultures were set up in the manner already described. Four concentrations of nutrient salts were used. The data are given in table 5.

TABLE 5

Dry weights and silica content of wheat seedlings grown in nutrient solutions and in nutrient solutions containing silica

TREATMENT	DRY WEIGHT OF TOPS	SILICA IN DRY MATTER
	<i>gm.</i>	<i>per cent</i>
Nutrient solution 85 p.p.m.....	0.2628	5.3
Nutrient solution 85 p.p.m. + colloidal silica 50 p.p.m.....	0.2875	8.3
Nutrient solution 85 p.p.m. + silica gel 1 per cent.....	0.4669	16.0
Nutrient 250 p.p.m.....	0.5635	3.1
Nutrient solution 250 p.p.m. + colloidal silica 50 p.p.m.....	0.5846	5.1
Nutrient solution 250 p.p.m. + silica gel 1 per cent.....	1.0540	20.2
Nutrient solution 500 p.p.m.....	0.5743	2.8
Nutrient solution 500 p.p.m. + colloidal silica 50 p.p.m.....	0.6389	3.9
Nutrient solution 500 p.p.m. + silica gel 1 per cent.....	1.1404	22.8
Nutrient solution 1000 p.p.m.....	0.9688	2.0
Nutrient solution 1000 p.p.m. + colloidal silica 50 p.p.m.....	0.7961	3.6
Nutrient solution 1000 p.p.m. + silica gel 1 per cent.....	1.4235	31.3

The results show a striking correlation between silica in the culture medium, growth of plant, and silica in plant. The medium does not, therefore, fulfill the requirement of an inert colloidal substance and is, therefore, not suitable for the problem undertaken in this study. The data are given merely for the benefit of those who may wish to undertake similar work.

Sand cultures

The amount of salt adsorbed from a solution by an adsorbent depends upon the surface exposed by the adsorbent. If a change in the concentration of the nutrient salts due to adsorption is sufficient to modify the production of dry matter in plants, the difference ought to be increased when the fineness of the adsorbent is increased. Quartz sand was selected as the adsorbent on the assumption that being very insoluble it would not supply nutrients to the plant. Three different grades of sand were secured from the New England Quartz Company of New York City. These are known commercially as no. 000, 1 and 2. A mechanical analysis is given in table 6.

The sands were purified by heating with hydrochloric acid (1:3) for about ten hours, washing with distilled water until free from chlorides, thoroughly drying and storing for future use.

In growing plants either in soil or in water cultures it is necessary to replace the water lost by transpiration and evaporation. With water cultures this renewal is accomplished either by adding at frequent intervals sufficient distilled water to maintain the original volume or by discarding the old medium entirely and adding fresh nutrient solution equivalent to the original amount of the old. The second procedure is preferable since it eliminates the possible accumulation of toxic excreta. With quartz sand cultures renewal of solutions has not been practiced. The method used by McCall

in which solutions were renewed but old sand retained did not take into account the possible saturated condition of the quartz after continual use. The writer has devised a method for renewing not only the nutrient solutions but also the quartz.

For this purpose glass fruit jars of 1 pint capacity were used. A hole $\frac{1}{2}$ inch in diameter was drilled in the bottom of each jar. The holes were stoppered and plants which had been selected and threaded into the corks were transferred to the jars which were to be used in the experiment. A volume of 250 or 300 cc. of nutrient solution of the desired concentration was transferred to the jar by means of a funnel, a large hole having previously been made in the cork for this purpose. Seven hundred grams of quartz sand was then weighed, a large funnel inserted in the hole of the stopper, and the sand allowed to fall gently into the solution. By using a small scoop and

TABLE 6
Mechanical analysis of quartz sands

	NUMBER 2	NUMBER 1	NUMBER 000
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Fine gravel (2-1 mm.).....	0.08	0	1.53
Coarse sand (1.0-0.5 mm.).....	21.09	0	2.63
Medium sand (0.5-0.25 mm.).....	68.93	2.25	8.93
Fine sand (0.25-0.1 mm.).....	8.45	92.51	69.62
Very fine sand (0.1-0.05 mm.).....	0.16	1.91	12.27
Silt and clay (less than 0.05 mm.).....	0.86	3.29	4.78
	99.57	99.96	99.76

sprinkling the sand into the funnel the stream of sand falling into the solution could easily be regulated. The roots of the plants were completely buried in the sand. At renewal periods the old sand and solution were removed by first taking out the small stopper at the bottom of the container, and then allowing a gentle stream of distilled water to run in at the top, the cork holding the plants remaining in place. Being under a low head this water never ran swiftly. A large glass siphon was used, and to give flexibility to that end which was inserted through the hole in the stopper containing the plants, a piece of rubber tubing was attached. The fresh solution and sand were added in the same manner as the first addition.

All solutions were renewed twice per week. The checks were solution cultures and were grown in the same amount and same concentration of nutrient solution as the sand cultures. The distilled water used in all cultures was treated with carbon black. The process of renewal just described appears not to be detrimental to the seedlings, as the comparison in table 7 will show.

TABLE 7

Dry weights of wheat seedlings grown in quartz to which nutrient solutions were added

	WEIGHTS OF SEEDLINGS GROWN IN	
	Quartz sand number 2	Quartz sand number 000
	gm.	gm.
Nutrient solution and sand renewed twice each week.....	0.6551	0.8033
Nutrient solution and sand not renewed, but distilled water added.....	0.5089	0.5888

* These figures indicate a better development where solutions were renewed.

In tables 8 and 9 are given the results of experiments showing the effect of quartz sands of different degrees of fineness on the growth of wheat.

TABLE 8

*Dry weights of wheat plants grown 35 days in nutrient solutions with and without quartz sand of different degrees of fineness.**(Concentration of nutrient solution 750 p.p.m.; sand and nutrient solution changed twice per week.)*

TREATMENT	DRY WEIGHT OF WHEAT SEEDLINGS. TOPS ONLY						AVERAGE
	1	2	3	4	5	6	
	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Nutrient solution.....	0.2624	0.2717	0.2011	0.2816	0.2449	0.2339	0.2492
Nutrient solution + sand no. 2.....	0.2158	0.2440	0.2362	0.2448	0.1920	0.2663	0.2332
Nutrient solution + sand no. 1.....	0.2382	0.2245	0.2279	0.2280	0.2368	0.2312	0.2311
Nutrient solution + sand no. 000.....	0.1911	0.2298	0.2179	0.2356	0.1984	0.1842	0.2073

TABLE 9

*Dry weights of wheat plants grown for 28 days in nutrient solutions with and without quartz sand of different degrees of fineness.**(Concentration of nutrient solution 370 p.p.m.; sand and nutrient solution renewed twice each week.)*

TREATMENT	DRY WEIGHT OF WHEAT SEEDLINGS. TOPS ONLY					AVERAGE
	1	2	3	4	5	
	gm.	gm.	gm.	gm.	gm.	gm.
Nutrient solution.....	1.0442	1.1595	1.0149	1.2198	1.1670	1.1211
Nutrient solution + sand no. 2..	0.6827	0.6175	0.6871	0.6696	0.6038	0.6551
Nutrient solution + sand no. 000.	0.8749	0.8826	0.8930	0.6370	0.8743	0.8033

It will be seen that the amount of dry matter produced is greater for a nutrient solution of a given concentration than for the same concentration in sand cultures. Although the differences are small, it seems sufficient to indicate that the decrease in concentration of the nutrient solution by the sand may be a factor causing a smaller production of dry matter.

Ferric hydroxide cultures

It occurred to the author that hydroxides of iron and aluminum might be suitable for a study of adsorption. These substances are relatively insoluble, are colloidal in character, and supposedly would not furnish nutrients to increase plant growth. The ferric hydroxide was prepared as follows: A 10 per cent solution of chemically pure ferric chloride was prepared and placed in a large bottle. Ammonium hydroxide was then added carefully until the mixture was faintly alkaline to litmus. The bottle was then filled with distilled water, stoppered, shaken thoroughly, and allowed to stand until the precipitate had settled. The supernatant liquid, was siphoned off and the washings repeated until free from chlorides. After the last washing the suspension was allowed to settle for several weeks and the supernatant liquid drawn off. A sample of the remaining suspension was used for determination of the ferric hydroxide and the remainder used in the cultures to be described. The cultures were made up so that all solutions contained the same concentration when calculated on a basis of total volume of water and total nutrient salts. Sufficient ferric hydroxide suspension was used to give 1.5 per cent ferric hydroxide calculated on volume of culture solution. The plants were grown in glass tumblers of 300 cc. capacity, the plants being previously selected and threaded into corks and placed in the different cultures. In all cases the entire medium was renewed twice each week. The results of the experiment are given in table 10.

No difference could be seen in the general appearance of the ferric hydroxide cultures and the checks during the early part of the growing period, except that the latter in most cases developed a heavier growth. Towards the end of the growing period, however, the plants in the ferric hydroxide cultures had a somewhat darker green color. The duration of the growing period was in every case determined by the plants in the iron, there being a more marked yellowing of the ends of the leaves in these cultures. These effects may result from an excessive use of iron in the metabolism of the plant, although, in view of the work of Gile and Carrero and from the insolubility of the colloidal iron, this would not seem to be the case.

In every case the dry weight of the tops is less for the plants grown in ferric hydroxide cultures.

The colloidal ferric hydroxide adheres to the roots forming a very tenacious covering. The roots were always washed carefully in distilled water before drying, but it was impossible to remove all of the iron oxide from them.

TABLE 10

Dry weights of wheat plants grown in nutrient solution and in nutrient solution containing ferric hydroxide calculated as Fe_2O_3

TREATMENT	WEIGHT OF TOPS . ONLY	AVERAGE
Length of growing period—5 weeks		
	gm.	gm.
Nutrient solution, 750 p.p.m.....	0.4042	
	0.5175	
	0.4355	
	0.6204	
	0.5456	
	0.5479	
	0.4456	
	0.5531	
	0.5372	
	0.4485	0.5056
Nutrient solution 750 p.p.m. + ferric hydroxide 1.5 per cent.....	0.3706	
	0.3283	
	0.4044	
	0.5868	
	0.4408	
	0.3499	
	0.3507	
	0.3457	
	0.4374	
	0.3876	0.4002
Length of growing period—30 days		
Nutrient solution 750 p.p.m.....	1.2430	
	1.7361	
	1.9641	
	1.6378	
	1.6540	1.6490
Nutrient solution 750 p.p.m. + ferric hydroxide 1.5 per cent.....	0.8435	
	1.1832	
	0.7775	
	0.7405	
	0.9629	0.9015
Length of growing period—31 days		
Nutrient solution 370 p.p.m.....	1.1147	
	1.3210	
	1.6747	
	1.5611	
	1.5614	
	1.4955	1.4894
Nutrient solution 370 p.p.m. + ferric hydroxide 1.5 per cent.....	0.9688	
	0.9892	
	1.1689	
	1.0984	
	1.0029	
	1.0927	1.0535

Aluminum hydroxide cultures

The procedure already described for the preparation of ferric hydroxide was followed in preparing the aluminum hydroxide, the chloride of aluminum being used in the place of ferric chloride. The suspension was made of such strength that the cultures contained 2 per cent of aluminum hydroxide calculated as Al_2O_3 . The experiment was performed at the same time and under the same conditions as were the ferric hydroxide cultures. The results are given in table 11.

TABLE 11

Dry weights of wheat plants grown in nutrient solution and in a nutrient solution containing 2 per cent of aluminum hydroxide calculated as Al_2O_3

TREATMENT	WEIGHT OF TOPS ONLY	AVERAGE
Length of growing period—31 days		
	gm.	gm.
Nutrient solution 370 p.p.m.....	1.1147	
	1.3210	
	1.6747	
	1.5611	
	1.5614	
	1.4955	1.4894
Nutrient solution 370 p.p.m. + aluminum hydroxide 2 per cent.....	1.1188	
	1.4504	
	1.2624	
	1.1612	1.2481
Nutrient solution 750 p.p.m.....	1.6490	1.6490
Nutrient solution 750 p.p.m. treatment with Al_2O_3 ..	1.3607	
	1.4984	
	1.3131	
	1.5164	1.4222
Nutrient solution 750 p.p.m. + aluminum hydroxide 2 per cent.....	1.4411	
	1.6344	
	1.1921	
	1.7367	
	1.5414	1.5091

Difference between nutrient solution (treated) and nutrient solution with Al_2O_3 gm. — 0.0530, per cent — 2.8.

The results in table 11 show that aluminum hydroxide is similar to ferric hydroxide in that its addition to nutrient solutions caused a decrease in the growth of the wheat plants.

SUMMARY

The effect of adding agar to nutrient solutions was to increase the growth of wheat seedlings in low concentrations and to decrease the growth in higher concentrations of nutrient salts. The introduction of colloidal silica into nutrient solutions resulted in increased weight of wheat seedlings. The increase was apparently due to direct absorption of silica by the plant and not to a change in the effective concentration of the nutrient solution. Silica gel is, therefore, considered unsuited for studies of the character described in this paper. The introduction of quartz and, ferric hydroxide, and aluminum hydroxide into nutrient solutions resulted in decreased growth of wheat seedlings. It appears that these substances by their absorptive properties reduce the effective concentration of the nutrient solution.

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